Modeling Surface Water/Groundwater Interactions of the Waimakariri River, New Zealand

Sarah B. Hardy[1,2], Joshua M. Blackstock[1]
[1]University of Canterbury, Christchurch, New Zealand
[2]Lafayette College, Easton, PA, United States

Abstract: Understanding how changes in stage affect groundwater levels is important in quantifying water resources in the Canterbury region. This study sought to determine how groundwater wells in the Canterbury region respond to changes in Waimakariri River stage levels and how responses have changed over time. 50 years of stage and groundwater levels in the lower Waimakariri catchment were used to determine how quickly and how high groundwater levels peak in response to various storm events. Most well data was collected at weekly or monthly intervals, but the one instance of daily sampling of a well was analyzed in further detail using a linear equation to determine the flux. Results suggest that each groundwater wells peak somewhat consistently in terms of water rise and time lag; however, this conclusion is uncertain, as groundwater levels were measured at time intervals too large (monthly or weekly) for accurate analysis. Peak stages during the dry season were lower in the last 30 years.

Introduction: There remains a pressing need to understand surface water/groundwater interactions to better manage water resources worldwide. The Waimakariri River is the largest river in the northern Canterbury Plains (see Figure #1) and is therefore a significant water resource; however interactions between the river and groundwater are not sufficiently understood.

The Waimakariri is primarily snow fed from the Southern Alps and flows generally southeast towards the Pacific Ocean. Over 90% of the river flow comes from precipitation in the upper catchment. Several main tributaries contribute to the Waimakariri including the Bealey, Poulter, Esk, and Eyre. Lying on primarily postglacial fluvial deposits and exhibiting braided patterns, the Waimakariri exhibits dynamic behavior. Flood events occur but on other occasions parts of the river run dry (Gair 1966, Taylor 1989, and Environment Canterbury 2011).

This study seeks to better understand the interactions between the surface water and groundwater of the Waimakariri River. In particular, it will be focusing on how water flows from staging locations on the river to nearby groundwater wells. Results assume that water flows in one direction (river to well); however bank storage is likely influencing the system.

In addition to the naturally complicated system, human interaction and extreme events have also significantly altered the system. In the case of the Waimakariri, water is being extracted at an increasingly fast rate due to a changing local economy. Several large seismic events are also likely to have changed the flow of water through the system. Determining specifically how these changes have affected the hydrologic system is beyond the scope of this study; however this study did seek to characterize changes in groundwater level responses to peaks in stage data were observed over time.

Methods: This study used groundwater well and stage data to depict how wells respond to peaks in stage. Two staging locations (Gorge and Old Highway Bridge) and four wells (0163, 0931, 0948, and 1451) were analyzed in Microsoft Excel using data obtained from Environment Canterbury.

At least one peak in the Gorge stage was selected from each decade in the last 50 years and graphed with each groundwater wells' data from the same time frame. If groundwater levels peaked after the stage data peaked, the time to groundwater response and increase in groundwater levels from before the stage peak was recorded. In instances where there was no noticeable increase in groundwater levels after an event groundwater trends were qualified rather than quantified ('steady decline' or 'constant'). Well data was labeled 'insufficient' if sampled on a weekly or monthly basis with no points near storm event and 'limited' if data was taken on a weekly or monthly basis with at least one point close to storm event. See Table #1.

The one period of daily well data collection (well 1451, October 1981 to mid-April of 1982) was applied to a linear equation (1) as well as a flux diagram to qualify changes in recharge (Sophocleous 2002; Scanlon, Healy, and Cook 2002). See Figures #3 and #4.

$$q = k\Delta h \tag{1}$$

where:

- q is the flux of water (positive indicating river recharging groundwater and negative meaning groundwater adding to river flow)

- k is a constant representing streambed leakage (hydraulic conductivity of the semi-impervious streambed divided by its thickness)

- $\Delta h = h_r - h_a$ with h_r for the river stage and h_a for the aquifer head

As stage influences groundwater levels and Gorge stage data was available at daily intervals over a long period of time (50 years), a wavelet analysis was conducted on Gorge stage data using the statistics program PAST to see if periodic cycles in the data are shifting (becoming more or less frequent or changing in period). The analysis was performed on two sets of data: one from 1962 to 1970 and the second from 2002 to 2011 data (see Figures #5 and #6).

Results: There were no significant trends (increasing, decreasing, remaining constant) in groundwater time to peak or water level increase in response to stage peaks over the last 50 years. In relation to other wells, groundwater well levels peak in succession with the most upstream well (0163) peaking first, with larger increases in groundwater levels occur further upstream. Increases in Gorge stage data from storm events during dry months (March, April, and May) were less in the last 30 years than in the first 20 years of data collection. See Table #1.

Analysis of daily groundwater levels from well 1451 showed that the flux of the river was positive, and water was flowing from the river to the well, and the maximum difference in head over that time span was 244.99m. This occurred 4 months after the primarily stage peak on October 5th 1981 when a secondary stage peak occurred (see Figures #2, #3, and #4).

Wavelet analysis determined that the most frequent cyclical patterns in Gorge stage data occurred in yearly and biyearly cycles. The frequency of these patterns changed over time in the ’02-’11 data, with the frequency being less in the first five years. Several other cycles occurred frequently, though none as strongly as the yearly and biyearly cycles. See Figures #5 and #6.

Discussion: There were no observed trends in groundwater response to peaks in stage because groundwater levels were not sampled at a scale fine enough for meaningful analysis. Wells can vary greatly in the week or month after a storm event, so the data obtained was not enough to accurately depict the system.

It is also difficult to draw accurate conclusions from the results, as they do not account for storm events that were preceded or followed by secondary events during a well response peak. Exterior forces further affected well responses including climatic influences such as unusually dry periods as well as inaccurate stage data resulting from a dynamic stream bed and infrequent recalibration of stage recorders.

Analysis of water flowing from the Gorge staging location to well 1451 does not depict solely groundwater flow as well 1451 is considerably downstream from the Gorge (see Figure #1). The stage of the river at a location closest to well 1451 is likely much less than the stage at the Gorge, as water has left the river (this is evident from groundwater rises in wells 0163, 0931, and 0948). Therefore the head difference, Δh, and the flux are likely less than indicated in Figure #4. There are no staging locations downstream of the Gorge but upstream of well 1451, so results are a best estimate.

All of these influences make it difficult to draw conclusions from the results or extend them further to water resources applications such as how increased well pumping for irrigation in recent years have affected the system. Although historical daily groundwater levels cannot be collected, if wells were sampled daily starting as soon as possible, water losses along the Waimakariri and similar systems worldwide could be much better understood. Without this knowledge, it would be difficult or even impossible for decision makers to accurately quantify and manage a precious resource.

Conclusions: Groundwater well data sampled at a weekly or monthly scale is insufficient to depict responses to peaks in river stage or display trends in those responses over long time periods. With more daily sampling the surface water/groundwater system can be analyzed in various ways including more accurate graphs of response peaks, wavelet analyses of groundwater levels instead of stage data, and cross-correlations between well and stage data to accurately quantify and qualify responses to stage peaks.

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Figure #1: Map of groundwater well and staging locations with Christchurch indicated for reference.

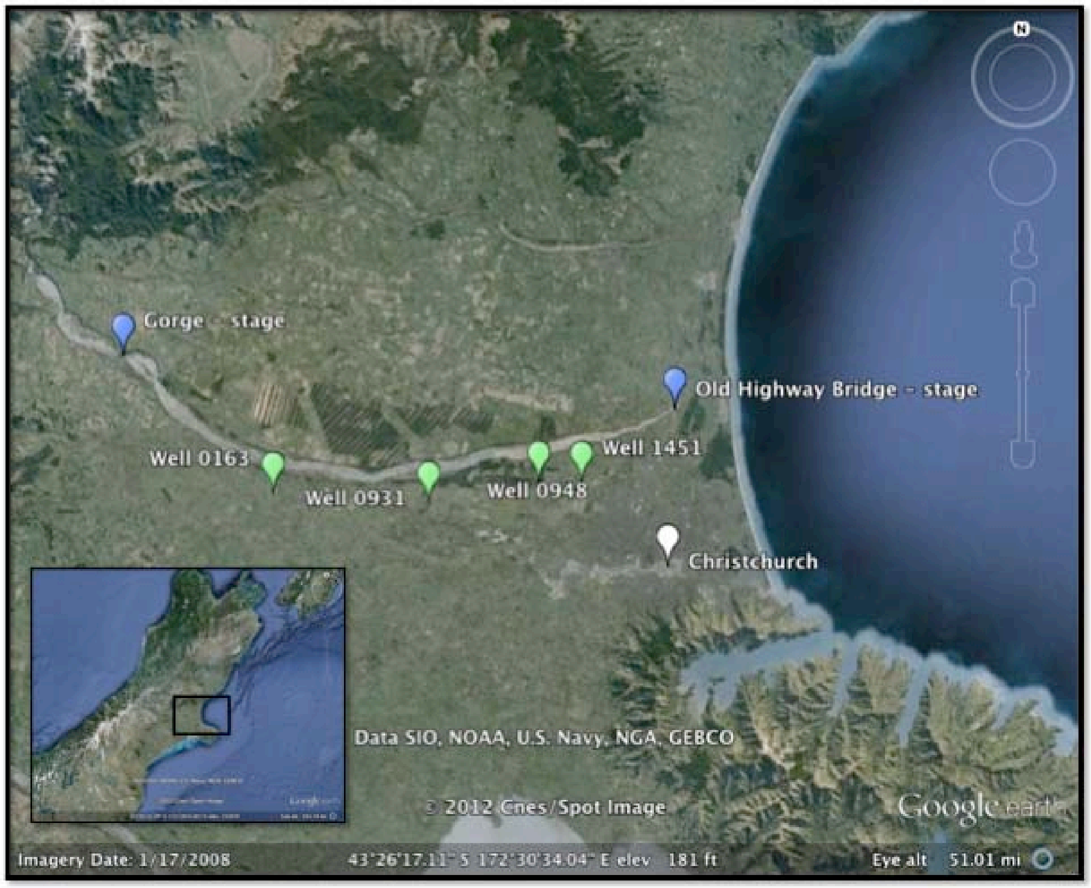

Table #1: Well responses to a variety of peaks in stage at Gorge staging location. Data includes: time to peak after Gorge stage peak (days); water level increase (m); and data quality of samples taken at intervals greater than one day.

	May ‘64	**March ‘67**	**May ‘79**	**Oct ‘81**	**May ‘88**	**Sept ‘88**	**April ‘96**	**Dec ‘97**	**Dec ‘10**
Gorge	1.437	1.476	1.660	1.520	0.835	1.979	0.678	1.481	1.568
Well 0163	Steady decline; limited	Constant; limited	3; 0.74; limited	Initial: 11; 2.17; Long term: 53; 3.40; limited	Steady decline; insufficient	Steady decline; limited	Steady decline; insufficient	Steady decline; limited	Steady decline; limited
Well 0931	No data	No data	23; 0.69; limited	16; 0.06; limited	11; 0.11; limited	Steady decline; insufficient	9; 0.027; limited	1; 0.03; limited	21; 0.298; limited
Well 948	No data	No data	Steady increase (>2 months after;) insufficient	29; 0.290; limited	11; 0.03; limited	18; 0.11; limited	18; 0.10; limited	21; 0.05; limited	36; 0.23; limited
Well 1451	No data	No data	No data	Initial: 15; 0.02	No data	No data	18; 0.13; limited	21; 0.03; insufficient	Constant; limited data
Old High-way Bridge	No data	1; 1.479	<1; 1.136	<1; 1.136	<1; 1.695	<1; 2.288	1; 0.929	<1; 1.692	<1; 1.379

Figure #2: Graph of water elevation (m) versus time (days) with Gorge staging location in blue and groundwater well 1451 in red. Note the label indicating peak stage on October 5th, 1981 and how groundwater levels do not rise until long after the storm event.

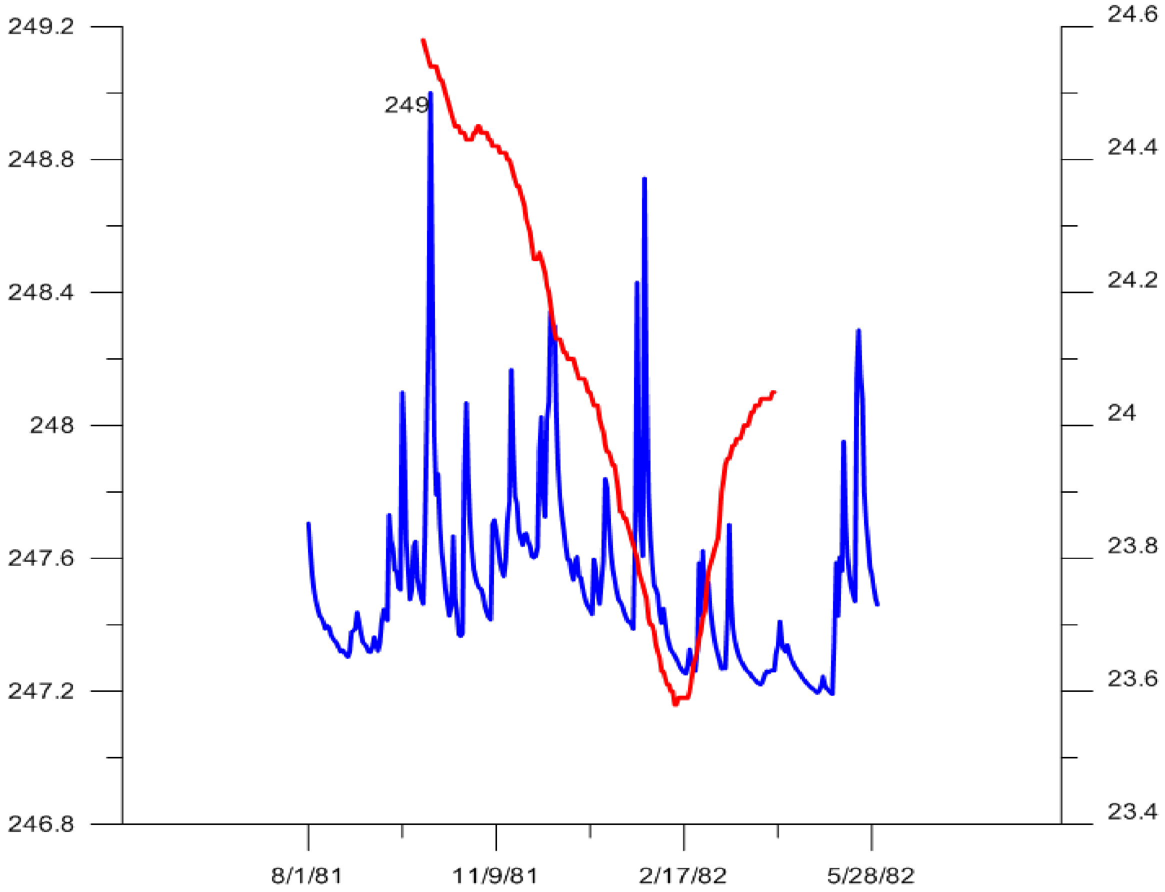

Figure #3: Cross-sectional diagram of water distribution in Waimakariri River and nearby groundwater wells. Variables labeled on diagram correspond to equation (1). In this diagram Δh and q are positive meaning there is a positive flux in the direction of groundwater recharge (Sophocleous 2002). This diagram and equation (1) are useful for understanding Figure #2.

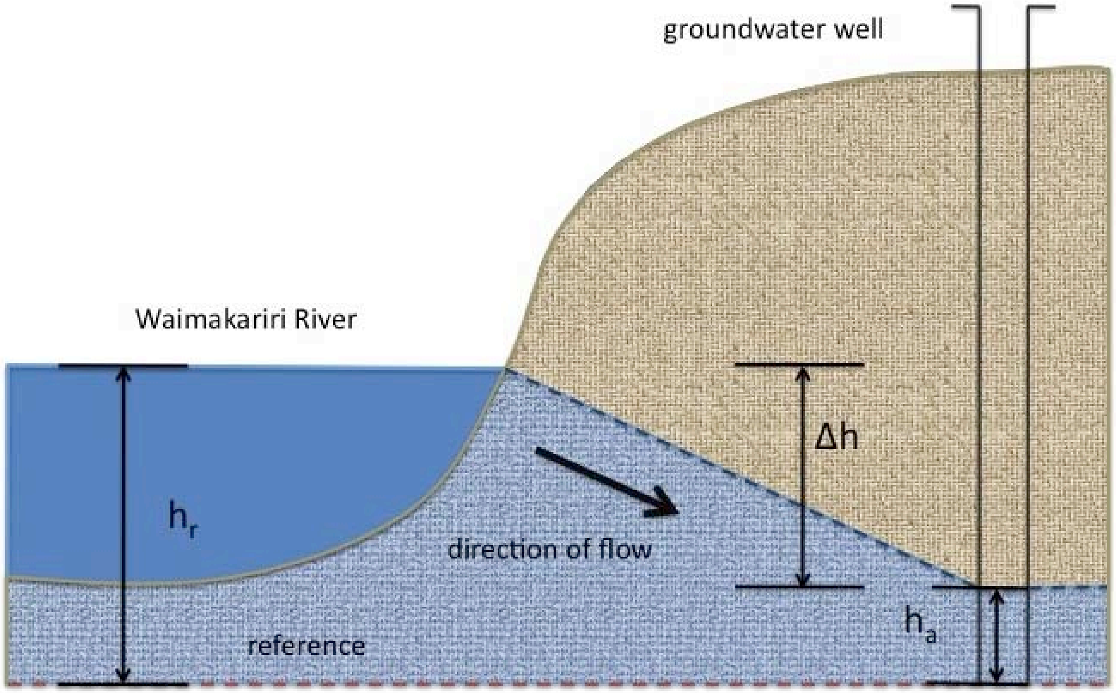

Figure #4: Graph of river water level at Gorge staging location and well 1451 groundwater level on January 27th, 1982 when maximum positive flux occurred in the year following the October 5th, 1981 flood event. In this diagram, Δh = 244.99m which is proportional to the flux (see equation 1). The red dot indicates a positive flux, which means water is flowing from the river to groundwater. If Δh and the flux were negative, water would be flowing from ground to stream, and the red dot would be in the top left-hand corner.

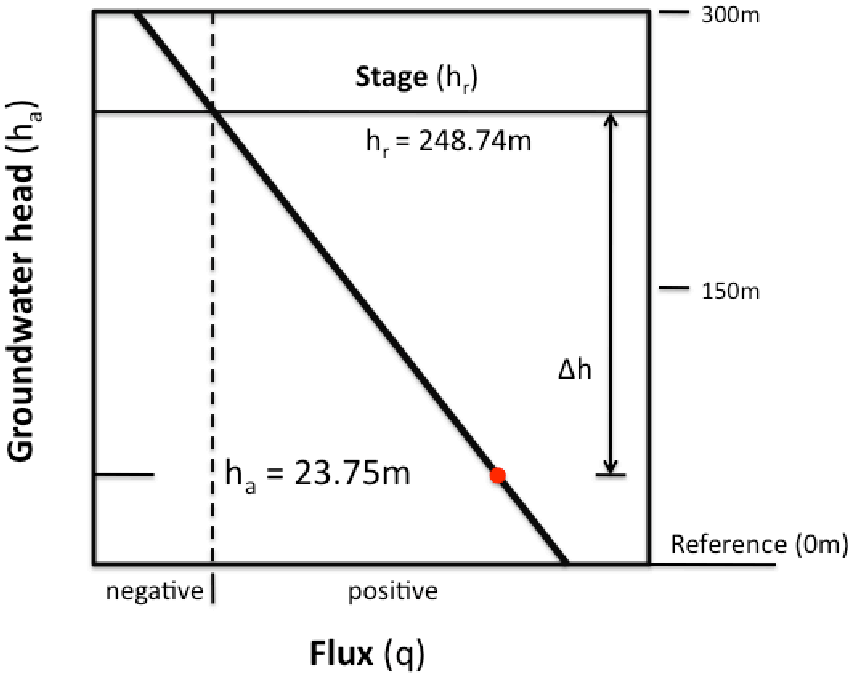

Figure #5: Graph of wavelet analysis of Waimakariri water level data (m) at Gorge staging location from 1962 to 1970. The top horizontal bar of orange (at about $\log_2$ of 8.5) indicates a strong correlation between the data and cycles with a 365-day period. The lower bar (at about $\log_2$ of 9.25) corresponds to two-year cycles.

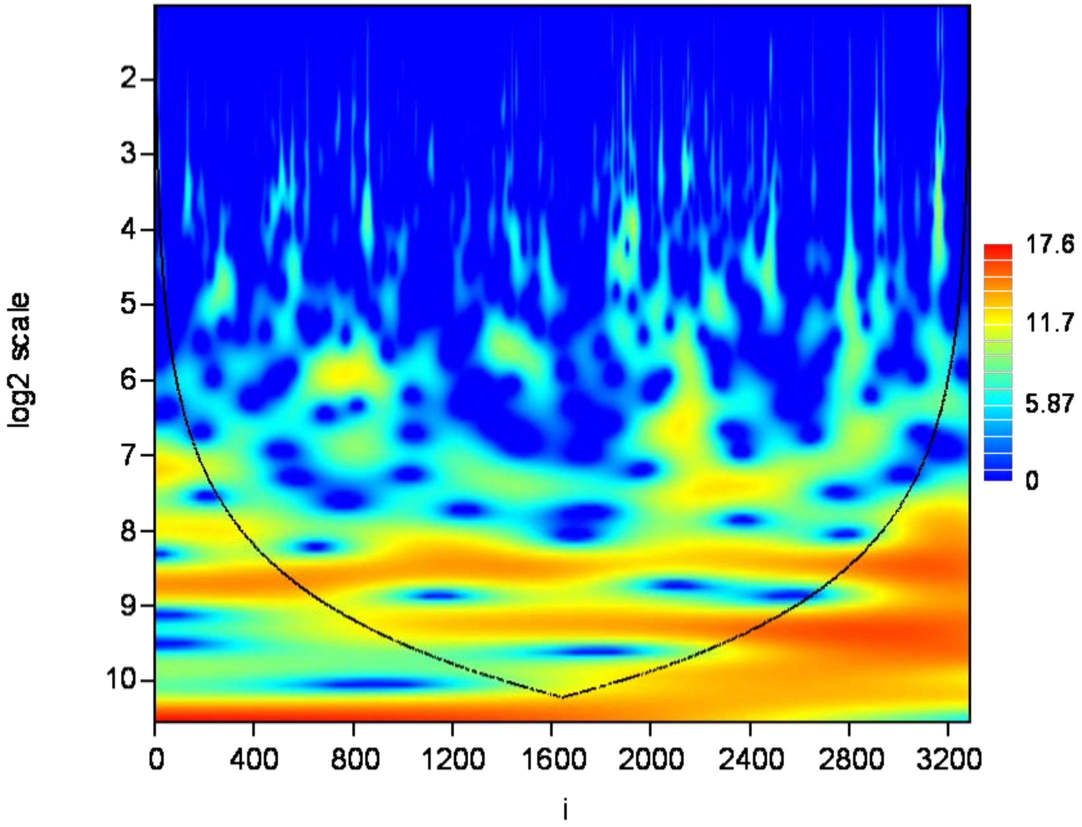

Figure #6: Graph of wavelet analysis of Waimakariri water level data (m) at Gorge staging location from 2002 to 2011. As with Figure #5, the top horizontal bar of orange/red (at about $\log_2$ of 8.5) indicates a strong correlation between the data and cycles with a 365-day period. The lower bar (at about $\log_2$ of 9.5) corresponds to two-year cycles. Note the change in scale between this and Figure #5.

The yearly cycle (period of 365 days) was less frequent in the first half of the year, indicating stage values that deviated from yearly norms. There are also several other cycles with $\log_2$ less than 8.5 in this figure that do not appear in Figure #5 such as $\log_2$ of about 7.25 and 7.1 that alternate in high and low frequencies over time. These would correspond to cycles with periods of about 150 and 135 days, though their relation to real-world processes is beyond the scope of this study.