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Field measurement of groundwater recharge under irrigation in Canterbury, New Zealand, using drainage lysimeters

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ABSTRACT

Irrigation using groundwater in Canterbury, New Zealand, is reaching sustainable limits and to assist with water allocation a better understanding of groundwater recharge from irrigated agriculture is required. To help characterise groundwater recharge from irrigated pasture, three sets of three drainage lysimeters were installed in three irrigated dairy farms in Canterbury, New Zealand. Two farms have free draining, shallow, stony soils over gravel and the third site has a deep silt loam. The sites are spread across three landscape positions within the Canterbury Plains–foot-hill, mid plains and coastal plains. Average annual rainfall during the study period (2010–13) at the sites varied between 633 mm (coastal plain) and 891 mm (foothill). Irrigation management varied among the farms. Irrigation applications increased as actual evaporation increased and ranged from 144 to 445 mm/season (September–April). Drainage tended to increase with annual rainfall and most (70%) occurred in the winter (May–August). Drainage from the shallow stony soils and deep silt loams averaged 33 and 18% respectively of total precipitation (irrigation plus rainfall), a similar percentage to those reported from dryland lysimeters studies in this region. However, as the total precipitation on the irrigated sites is greater than rainfall in the dryland studies, irrigated agriculture had more drainage. This implies that irrigation of dryland will result in more recharge, but in much of Canterbury efficient centre pivot irrigators have replaced border dyke flood irrigation that has very high recharge rates, so there may be an overall reduction in recharge.

1. Introduction

Groundwater reserves are important for many reasons: they provide vital municipal water supply, enable irrigation, sustain river base-flows and support aquatic habitats. However, in many parts of the world, an increasing use of groundwater threatens to reduce the stored water volume and, with it, the services this water provides (Zhang et al., 2003; Rodell et al., 2009). It is necessary to actively manage water use in order to sustain groundwater stores. To make accurate estimates of the consumptive use that an aquifer can sustain, the rate of recharge is a key variable that must be quantified (de Vries and Simmers, 2002; Scanlon et al., 2002, 2006).

Groundwater recharge typically derives partly from the land surface and partly from rivers. Land surface recharge is controlled by precipitation depths and patterns, soil structure and antecedent conditions, which themselves depend on climate and vegetation (Bethune et al., 2008). Where land is used for agriculture, irrigation can dramatically change total precipitation depth (rainfall + irrigation) and soil wetness conditions, and therefore can potentially alter recharge. It is therefore important to quantify the effects of irrigation on recharge, to ensure that recharge estimates are valid in irrigated landscapes, and establish whether recharge observations from dryland (non-irrigated) landscapes are applicable.

A better understanding of groundwater recharge under irrigation can also be used to inform farm management practice. In New Zealand, intensive dairy farming leads to recharge associated nutrient leaching and subsequent contamination of groundwater and eutrophication of waterways (Di and Cameron, 2002; Monaghan et al., 2014). Where recharge is well understood, irrigation management can be optimized to ameliorate water stress on crops or pasture without causing recharge and leaching (Bryla et al., 2010; Martin et al., 1994).

Use of groundwater for irrigation in Canterbury, New Zealand is approaching sustainable limits due to a relatively dry climate combined with recent expansion of irrigated dairy farms. This expansion drove the irrigated area in the region up to 6800 km^2 or an increase of 65% in the period between 1990 and 2010, with 42% of allocated water sourced from groundwater (Rajanayaka et al.,

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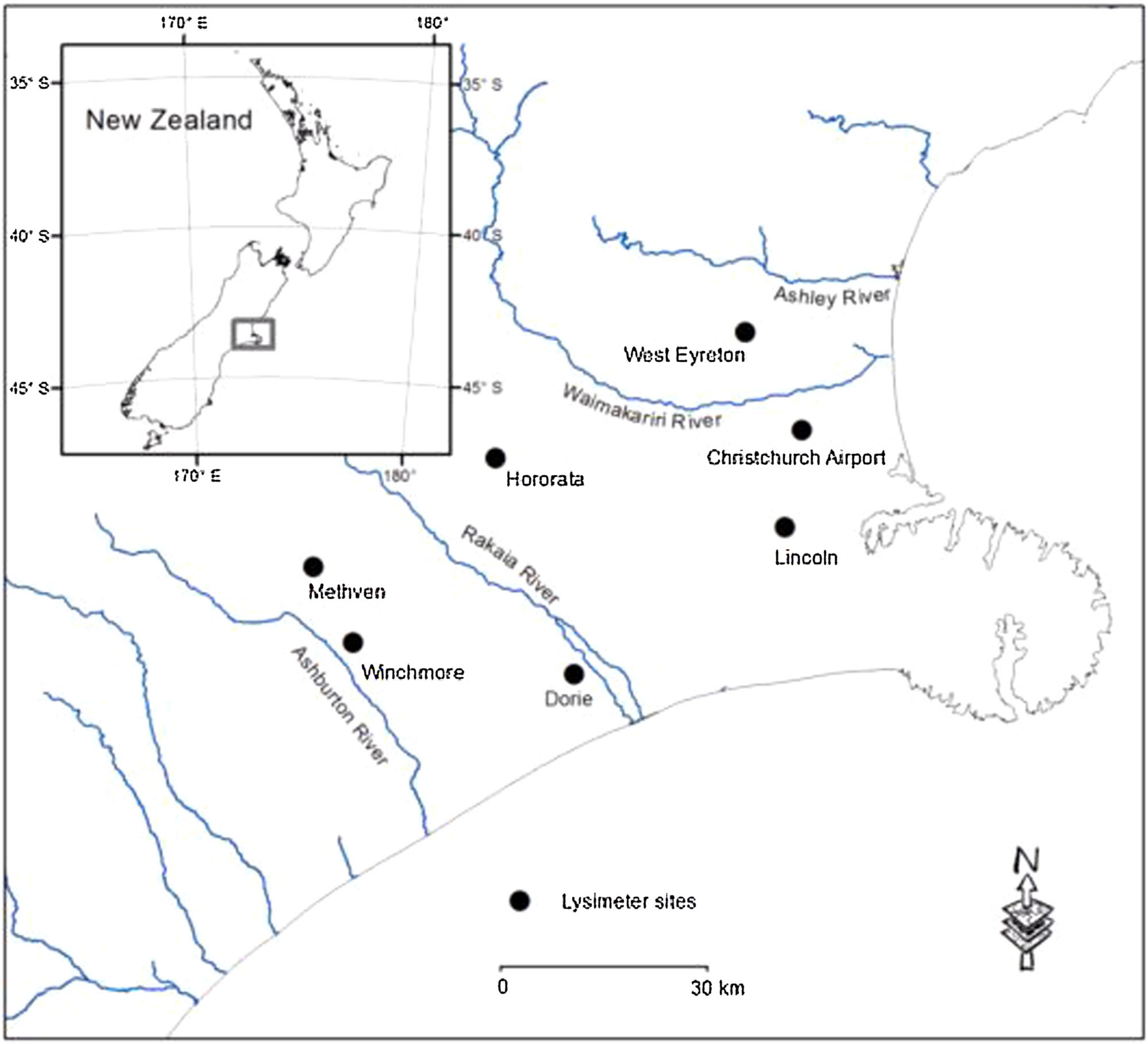

Fig. 1. Study locations.

2010). There is currently high uncertainty in recharge estimates for the region due to a bias in studies toward unirrigated land uses. There is a need for more measurements under irrigation to determine the effects on recharge given local climate and soil characteristics. The shallow, stony soils of the region (described in more detail below) are typically fast draining, implying that recharge from the land surface could be an important source for the underlying groundwater. Improved knowledge could potentially allow more efficient allocation of water, reducing water use and enhancing the economic benefits of irrigation.

This study presents initial results of recharge from irrigated dairy farms on the Canterbury plains, in eastern South Island New Zealand (Fig. 1). The “Canterbury Lysimeter Network” currently includes lysimeter installations at four sites, each of which includes three drainage lysimeters and a climate station. Three sites are located on irrigated dairy pasture. A further site is located on a cropping farm and is not included here. The aims of the network are to provide measurements of recharge under irrigation in Canterbury, and to allow comparison with previous dryland recharge measurements in the region made using lysimeters similar to those in this study. In this paper we investigate sources of variability in the rate of groundwater recharge, including between-site variability due to soil type, climate, and irrigation management practices, and within-site variability due to small-scale soil and vegetation heterogeneity. Our long-term aim is to improve region-wide estimates of recharge, and inform irrigation management practice.

1.1. Lysimeter design

Measurement of recharge through soils must account for the dual pathways of matrix flow and macropore flow (Greve et al., 2010; Schoen et al., 1999). Instruments should therefore be designed to cover sufficient area to include a representative sample of macropores resulting from plant roots, earthworm or other animal activity, or by soil cracking. The most common method is through the use of a lysimeter; a controlled volume of soil through which water movement can be measured (Goss and Ehlers, 2009).

Two types of lysimeter are commonly used: “weighing lysimeters” (e.g., Campbell, 1989; Evett et al., 2009; Marek et al., 2006; Yang et al., 2000; Young et al., 1996) which continuously weigh