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Fabrication and installation of an arable lysimeter for measuring groundwater recharge in New Zealand

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Summary

In New Zealand, regional councils maintain statutory responsibility for the management of land and water resources. An important component of groundwater management is to understand the rate, source, and timing of groundwater recharge to aquifers from rainfall and irrigation. Recharge can be estimated using models, or measured at recharge monitoring sites, where the quantity and timing of recharge is recorded directly from lysimeters. Since recharge varies spatially (e.g., as a function of climate, soil type, land use, land form, aquifer conditions, and application rate of irrigation), multiple recharge monitoring sites should be established within a region on the most representative soil and land-use types of a recharge zone. Hawke's Bay Regional Council (HBRC) installed five recharge monitoring sites on recharge zones of the two important aquifers (Figure 1), which included three 500 mm diameter by 700 mm deep soil monolith lysimeters. These sites were all installed on pastoral land-use, due to the negative effects of construction materials on farm machinery. Results from subsequent projects to design, fabricate and install non-weighing soil monolith lysimeters for measuring recharge to groundwater under arable land-use in New Zealand are presented in this paper.

Keywords: soil monolith lysimeter, Hawke's Bay

Introduction/Background

At least 22 monitoring sites are currently operating in five regions throughout New Zealand for the purposes of measuring rainfall and irrigation recharge to groundwater (*Figure 1*). Each site consists of: three 500 mm diameter by 700 mm deep, cylindrical, non-weighing, soil monolith lysimeters; a underground instrument enclosure with tipping bucket rain gauges to measure drainage, a ground level rain gauge and a storage (check) gauge; soil moisture sensors and/or soil neutron probe access tubes. Sites have been installed nearby to existing long-term climate stations, or alternatively a compact weather station is installed at the site. Of the New Zealand monitoring sites, all have been installed on pastoral land-use, including 20 dryland sites and 5 irrigated sites (Lovett et al. 2014). An understanding of recharge occurring under arable land-use is also an important consideration for water resources management. However, lysimeters are typically composed of steel drums that are buried flush to the ground surface or just above the soil surface, and are incompatible with the mechanical cultivation processes and land management on arable farms. The need for a lysimeter design suitable for application on arable land-use in New Zealand was highlighted at the National Lysimeter Workshop (2014). Subsequently, a literature review of national and international designs for arable lysimeters was completed by Lovett (2015), including three options for the design of an arable lysimeter. Subsequent projects were established to: 1) convene a working group to discuss and design a prototype arable lysimeter; 2) manufacture the arable lysimeter (Lovett and Cook 2017); and 3) install an arable lysimeter site for testing (Lovett 2017). Informatio obtained during these three projects are presented in this paper.

Literature review and workshop

A review of national and international literature on arable lysimeters was completed to identify potential designs suitable for the New Zealand arable setting (Lovett 2015). The main outcome of this review was the selection of three arable lysimeter designs that were suitable to consider for further development. These designs included: a modified standard lysimeter to have a manually-replaceable mobile upper ring; a dual-chamber lysimeter where an outer steel ring could be lowered below the ground surface; and a lysimeter with steel rods that are raised to accept an upper mobile ring. These designs were primarily selected based on their practicality, cost effectiveness, practicality, maintenance of soil structure, and the perceived ability of the lysimeter to accurately measure recharge under arable land-use. A subsequent workshop was convened to discuss arable lysimeter designs, and select a single design for progression to the fabrication stage. An additional three designs were introduced at the workshop, including: a lysimeter with an upper rim that sits 200 mm below the ground level; a standard steel lysimeter with an upper ring made of plastic (e.g., HDPE, polyethylene); and a design that allowed the entire lysimeter to be removed from the ground for cultivation to proceed. At the workshop, it was agreed by consensus that the design with highest potential to succeed consisted of a standard steel lysimeter (700 mm deep x 500 mm wide), that would be modified to include an upper ring made of a plastic material (e.g., HDPE, polyethylene). Potential limitations of the design were that: it could be difficult to obtain a suitable plastic material; the plastic may be damaged during tillage; and that an effective seal was maintained between the plastic and the steel casing. These limitations were considered during the subsequent fabrication of the lysimeter.

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Method: Lysimeter fabrication

The steel base for each arable lysimeter was fabricated from 3 mm thick steel that was rolled and welded to produce a cylinder 700 mm high and 500 mm in diameter. A 95 mm wide circular plate was welded 100 mm below the top of the lysimeter to prevent soil consolidation around the outside of the lysimeter once installed. The ring was drilled with tapered holes to facilitate drainage. A sheet of 2 mm polyethylene plastic was cut and plastic welded to produce a 400 mm deep x 500 mm wide riser. A steel clamp was fabricated from the 3 mm thick steel plate, and welded onto the lysimeter bases, and there was approximately 100 mm overlap of steel and polyethylene. The lysimeter base plate was manufactured to be slightly concave (c. 10 mm) to promote drainage from the lysimeter. A 32 mm diameter female pipe fitting was welded to the centre of the base plate for attachment of alkathene pipe fittings. An 8 mm thick by 50 mm wide bevelled steel ring was attached to the inside base of the casing to provide an internal cutting ring. Four steel rods (700 mm long with a 100 mm long threaded end) were provided to secure the base plate to the lysimeter casing following preparation of the lysimeter. In addition, a steel clamp was fabricated to protect the polyethylene plastic during the installation on the lysimeter. This clamp was removed once the soil column had been isolated and prepared. Following fabrication, all lysimeter components were hot galvanised.

Method: Lysimeter Installation

Site selection

The arable lysimeter site was installed at Otane, Central Hawke's Bay between 17 – 20 October, 2016. At the time of installation, the paddock was in a fallow period of the cropping rotation. A typical crop rotation is likely to consist of mixed cropping and pasture (e.g., carrots, peas, maize, beans, and ryegrass pasture) with differing periods of fallow between each crop. Mechanical practices that are undertaken on the property include minimal tillage and direct drilling of crops. A site plan was designed to ensure workable placement of the enclosure, lysimeters and telemetry system alongside the centre pivot irrigator. Lysimeters were established approximately 10 m from the edge of the paddock to limit 'edge effects' on the crop and recharge measurements. A 1 m deep test pit was dug to ascertain suitability of the soil conditions at the site. Soil conditions appeared to be free draining with absence of impermeable layers or pans, therefore the installation proceeded. A soil profile was completed.

Lysimeter extraction

A protective steel clamp was placed over the upper polyethylene rim to protect it during driving, and lysimeter casing was driven into the ground using a combination of weight from the hydraulic arm of the 12 tonne excavator and sledge hammers. Magnetic levels were placed on the side of the casing to ensure the lysimeter was driven down vertically. Once the lysimeter had been driven approximately 50 mm into the ground soil was gradually removed from around the lysimeter base to facilitate driving of the casing and to decrease the risk of damage to the internal soil column. Each lysimeter was driven into the ground until the upper lip was approximately level or 5 mm above ground level. Petroleum Jelly was heated until liquefied and pumped inside the gap between the soil column and the lysimeter casing to seal any gaps and prevent preferential drainage. A 10 tonne pump was used to drive a cutting plate under each lysimeter and isolate the soil column. Threaded rods, a wooden cover, headworks and a swivel clamp were attached t the lysimeter. The lysimeters were lifted, inverted 180°, and lowered onto the head clamp to allow for preparation of their bases. The cutting plate was removed and the base of the lysimeter was levelled, and shade cloth was used to cover the base. The base plate was inserted and the lysimeters were inverted 180°, back to their original orientation. Each lysimeter column was cleaned and three tubes of sealant were applied sparingly to the lower 150 mm of the lysimeters, and left to set overnight.

Lysimeter installation

During excavation of the enclosure pit, an approximately 100 mm fall gradient away from the instrument end of the concrete tank was created in order to remove water from within the enclosure. A truck-mounted crane was used to lift the tank into the prepared pit. Three holes were drilled through the installed concrete enclosure wall using a 20 mm drill bit. Three soil moisture probes were installed into the soil face of the excavated trench at approximately 400 mm, 700 mm, and 1100 mm below ground level. Cable from the sensors was cable-tied and run along the edge of the trench to a control box at the enclosure. String lines were set at ground level and three sets of 125 mm x 125 mm x 1,250 mm house piles were installed in the base of the excavated trench. Three sets of alkathene pipe fittings (including a 32 mm diameter female right-angle fitting, a coupler, and a 15 mm reducer) were wrapped with thread tape and tightened. The pipes were attached to the base of each lysimeter. The lysimeters were lowered into the pit using the excavator, and installed to ground level. Three lengths of 15 mm diameter alkathene pipe (c. 10 m) were cut, one end was heated in hot water, and then attached to the reducer at the base of each lysimeter. The 15 mm alkathene pipes were inserted through the enclosure holes and were taped together in parallel within the trench to ensure they were kept in a constant fall during infilling. A fall of at least 250 mm over 8 m was created from the base of the lysimeter fittings to the concrete enclosure to ensure that once operational, all drainage would be transferred to the tipping-bucket rain gauges inside the enclosure, without delay. Infilling of the excavated area around the lysimeters and platforms was undertaken using the excavator and manual compaction of the soil. Particular care was taken to ensure that the lysimeters were packed into the surrounding sediment to minimise any subsidence following installation. Care was also taken during infilling around the soil moisture sensors. Soil was filled back to ground level which completed the site remediation. A wooden extension (approximately 300 mm high) and protective grating were installed on the top of the concrete tank. Following completion of the enclosure, three tipping bucket rain gauges, a ground level rain gauge, data loggers, telemetry system, and an automatic bilge pump to complete the site. The monitoring site resumed collection of recharge data in January 2017, and at the time of writing, no results were available.

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Figure 1: **Location of the 22 active recharge monitoring sites throughout five regions in New Zealand.**

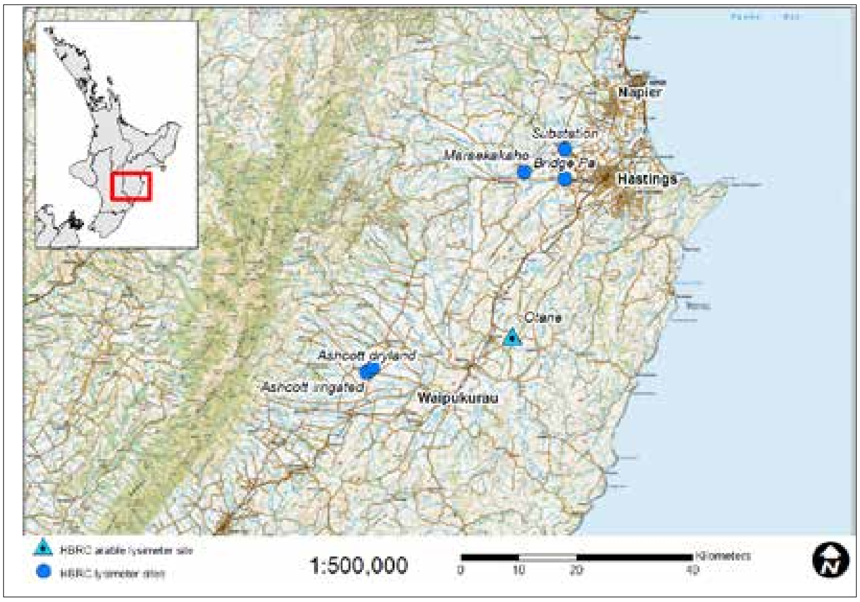

Figure 2: **Location of HBRC recharge sites, Hawke´s Bay.**

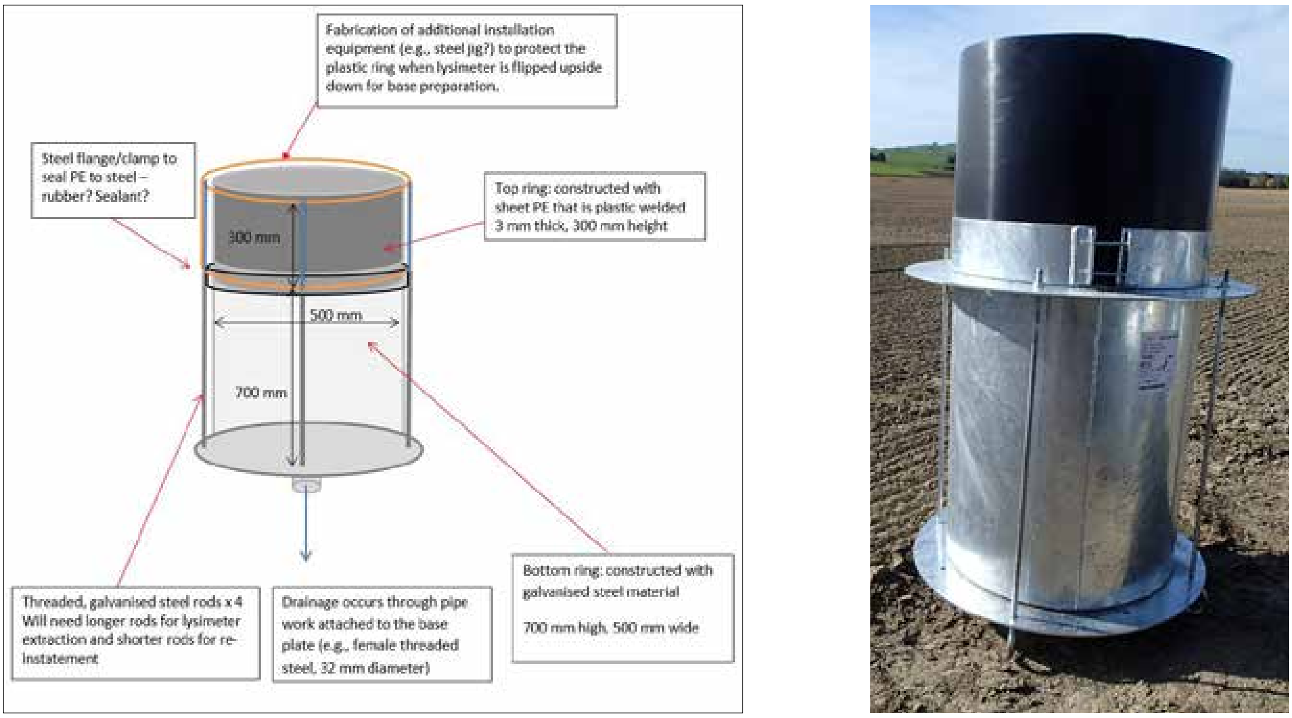

Figure 3: **Arable lysimeter during design and after fabrication. The standard soil monolith lysimeter (500 mm diameter, 700 mm deep) was modified by the addition of a 400 mm polyethylene upper rim and clamp.**