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Field drainage lysimeter research in New Zealand: a review

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Summary

Field drainage lysimeters are widely used throughout New Zealand (NZ) primarily to measure rainfall and/or irrigation recharge to groundwater. The NZ lysimeter network currently consists of 25 sites distributed across the country, which have been in place from approximately 3 months to 14 years. The continued operation of these sites is dependent on financial contributions from local regional councils and input from research and industry organisations. As the number of lysimeter sites have increased over the last few years, there have been questions raised about their role in influencing large-scale water management, and policy discussions and decisions. The authors undertook a survey of organisations in NZ that are actively involved in lysimeter research and operation, including regional councils, research organisations, universities and consultancies. The primary aims of the survey were to: 1) document the use of lysimeter data for management and policy decisions by scientists and regulators at the regional councils; 2) assess the future uses and continuation of the current lysimeter sites; and 3) identify and record the current and future science and research needs associated with lysimeter data. Based on the survey, it is evident that a lack of national context to lysimeter research may lead to varying levels of lysimeter data use across NZ. Regional councils are well aware of the local context, however, a national context would allow to develop standards for lysimeter data collection and use. While the regional councils see lysimeter data as a useful communication tool with end-users and stakeholders, there are still science questions and gaps around the scaling of lysimeter data to catchment and regional scales and the ability of lysimeter sites to include water quality (leaching) measurements. To sustain lysimeter research in NZ, these two critical science gaps must be addressed immediately, in addition to the development of a national context for lysimeter research.

Introduction and background

In New Zealand (NZ), field-based, passive, soil monolith lysimeters (hereafter referred to as lysimeters) have been in use since 1950's to quantify rainfall and irrigation recharge. Until the end of last century, the majority of recharge data collected at these sites were used as input to groundwater models (e.g., White et al. 2003, Graham et al. 2018). Meanwhile, there has been an increasing pressure mounting on groundwater resources in NZ. This pressure is predominantly due to the continued increase of irrigated area in NZ, which has been doubling approximately every 12 years since 1970 (Irrigation NZ, 2017), combined with full allocation of easily-accessible surface water resources (Tait 1999).

With the introduction of resource management act (New Zealand Legislation, 1991), the regional governments (referred to as regional councils) are empowered and expected to manage their surface and ground water resources sustainably as one linked resource. Post-2000, regional councils had started engaging with lysimeter research groups in developing a real-time knowledge of rainfall and irrigation recharge to enable sustainable allocation of groundwater. This has led to several regional councils installing lysimeters in real operational farms. Currently, there are 25 active lysimeter sites across NZ (*Figure 1*), where research groups and regional councils are collaborating from installation, data collection, and data analysis.

A recharge monitoring site typically includes two or three lysimeters individually connected to tipping buckets gauges to measure drainage, a ground-level rain gauge to measure rainfall-irrigation, a climate station to measure rainfall, wind speed and direction, humidity, barometric pressure and solar radiation, and a series of soil moisture sensors buried at multiple depth from surface to 70 cm (*Figure 2*). Sites include both irrigated and non-irrigated (dryland) land use, and, barring two, all are under pastoral land cover. Despite that several researchers have analysed data from many of these lysimeter sites (Thorpe & Scott 1999, White et al. 2003, Duncan et al. 2016, Graham et al. 2018), the usability of lysimeter data for making water allocation management decisions and policy setting is yet to be fully examined. We undertook a survey of all organisations that are currently operating lysimeter sites in NZ to assess 1) the current state of their lysimeter data use; 2) their future plans and needs for lysimeter sites and data; and 3) the science gaps and limitations that they have identified while using lysimeter data for water allocation decisions.

Data collection survey

For all known lysimeter sites in NZ, information such as location, length of datasets, and site purpose were compiled. All regional councils and other organisations known to operate these sites were contacted to confirm the accuracy of the compiled information. In addition, the following questions were presented to each organisation:

- What are the primary aims and objectives of the recharge monitoring sites?
- To what extent does recharge data inform science, policy, and management decisions?

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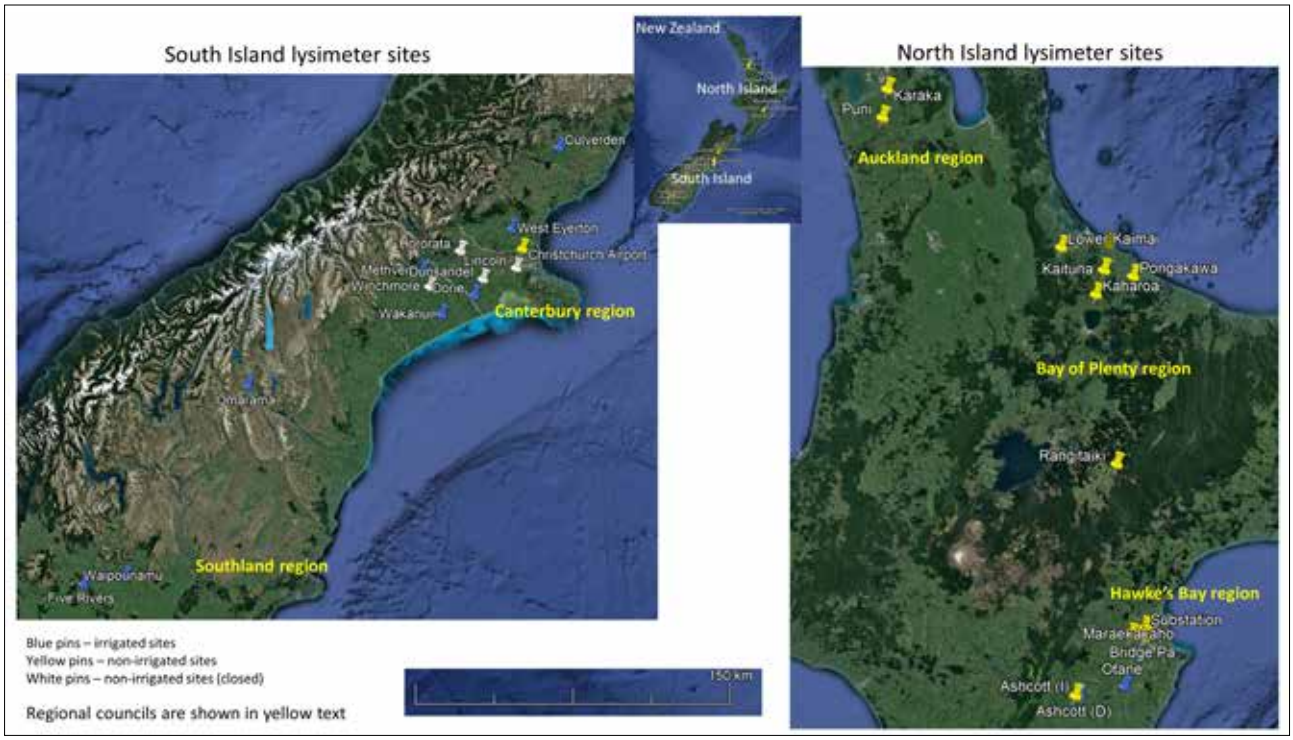

Figure 1. **Distribution of recharge monitoring lysimeter sites in New Zealand as of January 2019.**

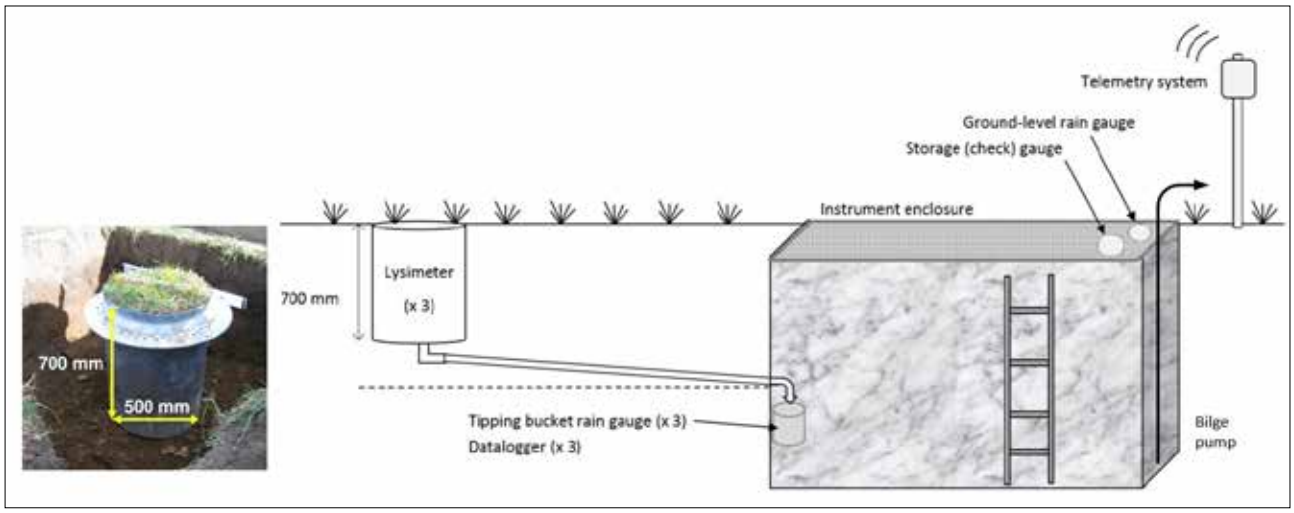

Figure 2. **Arrangement of instrumentation in a typical lysimeter site. Bilge pump to pump out ponded excess water.**

- How widely are datasets and information from recharge monitoring sites distributed among stakeholders including public?
- What is the current role of research agencies in developing the usefulness and application of the recharge monitoring?
- Are there any emerging issues that you would like addressed using recharge monitoring sites?

In this paper the information compiled from these regional councils which is likely to guide the science and management challenges posed at the researchers is presented. Based on the response, gaps in scientific understanding and use of lysimeters in answering wider water resources management issues across NZ have been identified.

Survey results

1. What are the primary aims and objectives of the recharge monitoring sites?

The regional council objectives fell into three broad categories –

a. Quantification of groundwater recharge for water resource management: Councils foresee using the recharge data in water allocation, policy setting and water budgeting. Research providers are actively involved with regional councils in developing procedures to quality control recharge data (e.g., Male 2015, White et al. 2014, 2017).

When regional councils installed sites, they selected locations that were representative of soils and climate in the region. In regions where irrigation has been expanding rapidly (e.g., Canterbury and Southland), the regional councils also focused on irrigation recharge. However, the up-scaling of point scale data to inform and guide regional scale recharge estimation has not fully occurred.

b. Quantification of water use efficiency: While this was not a primary objective, since the majority of recharge sites in Canterbury and Southland regions are located on irrigated farms, they also offer an opportunity to monitor irrigation efficiency. Studies by Srinivasan et al. (2018) demonstrated the use of drainage data from lysimeter sites in informing farmers of their irrigation practices and influencing their water use behaviour. Although regional councils see an opportunity for improved water resources management, they have largely not engaged themselves fully with using the lysimeter data to this effect.

c. A tool to engage with farmers: At those sites where research providers and regional councils are collaborating (Southland, Hawke's Bay and Canterbury), the host farmers are provided with daily updates of their irrigation and drainage output. This has proven to be a useful way of engaging with farmers. The Bay of Plenty and Hawke's Bay Regional Councils publish lysimeter drainage datasets on their websites. However, it is not known as how well these data are used by the farmers in these regions to manage on-farm water use.

In addition to the above, research providers have been using data from recharge sites in parameterising hydrological models (e.g., White et al. 2003, Graham et al. 2018).

2. Current availability of recharge data from lysimeter sites

The availability of data from lysimeter sites vary between regions. The regional councils such as Bay of Plenty and Hawke's Bay provide data access via their websites, while Canterbury and Southland make the data available to the host farmers via daily email. These latter mentioned regional councils work with one of the research providers (NIWA) in making this possible.

Current limitations in the datasets are that publicly available data are not typically quality checked. Also, the site-specific nature of the data has not appeared to have attracted many in using the data. Since all sites are placed within operational farms, there is also a need for collecting on-farm management data (e.g., grazing, plant type), and this is not currently happening at any of the sites. A national standard may provide guidance for those additional data collection.

3. Application of recharge data

The use of recharge data from lysimeter sites varies between councils. Both Canterbury and Hawke's Bay Regional Councils use lysimeter recharge data in verifying groundwater models (e.g., White et al. 2014). It appears as though the data usage and uptake has been more effective at sites that are led by research providers. Furthermore, sites where lysimeters are under controlled conditions, nutrient leaching data from lysimeters are used in calibrating validating nutrient budget and crop growth models (e.g., Di & Cameron 2007).

Emerging challenges and future research needs

Lysimeter research in NZ has grown considerably over the last 15 years following a quiet period from 1970 to 2000. The last two decades have seen the development a science and management business cases for the installation of lysimeters. As many as 23 out of 25 active sites today (January 2019) were installed within the last 10 years, indicating a renewed interest for lysimeter research. This interest mainly emerges from the need to understand, manage and allocate water resources sustainably.

Based on the survey results, it is evident that to sustain an interest in lysimeter research, there is a need to develop a national context around the collection, processing and application of recharge data from lysimeters for groundwater management and monitoring of nutrient leaching. This context may include development of procedures and protocols for the installation of lysimeter sites, quality control of data collected, application of models and methods to scale the lysimeter data spatially and temporally, and finally, methods to combine lysimeter drainage to nutrient leaching.

Lysimeter recharge data offer an approximation of groundwater recharge. Currently, many regional councils use an annual allocation volume when allocating groundwater for irrigation and other uses. Since lysimeters offer time-series recharge information, the annual allocations could be dynamically altered (monthly to seasonal scales as opposed to annual).

The biggest challenge with drainage lysimeters and similar tools have been their representative sizes. These tools provide point scale measurements while water allocation and nutrient management, measurements and target-setting happen at field, farm- or catchment- scales. Owing to other factors such as variability in nutrient transport pathways from land to receiving waters and associated time lags and attenuations further challenge the translation of point scale measurements into usable catchment scale information. Models developed based on laboratory-scale lysimeters may provide a pathway to bridge this spatial gap.

Challenges of using field lysimeters installed in operational farms for water quality monitoring have been discussed in detail in Lilburne et al. (2012). At all but one lysimeter site shown in *Figure 1*, only climate, soil moisture, and recharge data are collected. The site (Methven, Canterbury, South Island) where there is a limited sampling of leachate for water quality is conducted, the lysimeters are fenced off from cattle access. This is to prevent direct deposition of animal excretion on lysimeters.

There has been a sustained interest from the stakeholders (e.g., end-users, farmers and regional councils) to finding ways of integrating water quantity and quality monitoring at the lysimeter sites. The first reported lysimeter study in NZ (Annett 1953) was originally designed to examine the leaching of nutrients through soil profile and the rainfall recharge was not the main focus. Even after more than six decades of lysimeter research in NZ, the leaching question has not yet been fully answered, for a number of reasons (see Lilburne et al. 2012). Apart from the issues such as soil heterogeneity, variable rainfall distribution and amounts, variabilities in plant water uses and differences in land

management activities such as irrigation, the biggest impediment to advancing lysimeters to study nutrient leaching has been the absence of appropriate tools and methods to accurately define and measure the surface nutrient input from animal excretions. In NZ, grazing is widely practised year round and animal excretions have been shown to be an important and significant nutrient input (Lilburne et al. 2012). Several laboratory based studies are attempting to describe nutrient transport through soil profile (e.g., Di & Cameron 2007). These controlled lysimeter experiments provide a comprehensive understanding of soil physical (texture, structure, infiltration), chemical (conversion of nutrients into plant available forms within the root zone) and biological (the process of plant absorbing soil nutrients) controls on nutrient availability, dynamics and leaching within and immediately below the root zone. Since these experiments are controlled, they assist in developing a tight relationship between nutrients inputs to outputs (leaching). However, these studies generally do not represent realistic on-farm controls (e.g., climate, soil drying and wetting, evapotranspiration) and management practices (grazing, irrigation), making the translation of knowledge between laboratory- and field- scales challenging.

Conclusions

In New Zealand, there has been a renewed interest in lysimeter research and the need to have field measured recharge data to better inform water allocation models. This has resulted in the development of 25 recharge lysimeters in operational farms across five regions.

The survey and contacts with various regional councils, research providers and stakeholders such as farmers highlighted two key issues that are directly linked to lysimeter research. The first one is the ability of scaling up lysimeter data from point to larger scale, which questions the place of lysimeter research in a catchment or regional scale context, and the second is around the use of lysimeters sites in monitoring nutrient leaching.

Data from many of these sites have been successfully used in verifying groundwater models and communicating with end-users on issues such as water use efficiency. In order to sustain and advance the current level of interest in lysimeter research, science providers, resource managers and farmers need to work together in enabling the integration of on-farm water quantity and quality management. The current lysimeter design owing to the limitation of size may not offer a pathway for this integration. Indirectly this could be advanced by developing models that can link on-farm in-situ and in-lab, controlled lysimeters.

Finally, the lysimeter research in NZ would greatly be benefitted if placed within a national context. While the local context allows the lysimeters to represent region specific soil, climate and land management variables, a national context would provide for the development of standards for lysimeter data collection and use across the country.

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