Arable lysimeter review and design – Part 1

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GNS Science Consultancy Report 2015/146
July 2015

BIBLIOGRAPHIC REFERENCE

Lovett, A. 2015. Arable lysimeter review and design – Part 1, *GNS Science Consultancy Report* 2015/146. 24 p.

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EXECUTIVE SUMMARY

Lysimeter monitoring sites have been installed throughout New Zealand to determine the timing and quantity of rainfall and irrigation recharge to groundwater, predominantly on pasture land use. Lysimeters are typically composed of steel drums that are buried flush to the ground surface or just above the soil surface. However, this installation method is incompatible with the mechanical cultivation processes and land management on arable farms. Hawke’s Bay Regional Council requires a lysimeter design suitable for arable land use, and in addition the need for a design was supported by scientists and technical specialists at the National Lysimeter Workshop, August 2014. Recharge from arable land use is required to support development of science research models and inform water management policy throughout New Zealand. The aim of this project is to explore options for an arable lysimeter design suitable for New Zealand conditions. To achieve this, the following three objectives were set for this project: complete a literature review of international designs that are suitable, or can be adapted, to New Zealand conditions; identify a number of suitable designs to be reviewed by an expert panel; and facilitate a remote expert panel discussion involving research and consulting agencies to review the proposed design and provide expert comment.

Following the literature review, three designs were selected for expert panel consideration including: a modified standard lysimeter to have a manually-replaceable mobile upper ring; a dual-chamber lysimeter where an outer steel ring can be lowered below the ground surface; and a design that has a spindle drive which is raised to accept an upper mobile ring. It is intended that this report will be used by an expert panel to evaluate each potential design, and therefore includes a design evaluation template to be used by the panel.

1.0 INTRODUCTION

An understanding of the volume and timing of recharge to aquifers is important for groundwater management. Quantifying rainfall and irrigation recharge can be either estimated using models (e.g., Scott, 2004), or measured at a drainage lysimeter monitoring site, where direct evidence of the quantity and timing of recharge is provided (White *et al.*, 2007). New Zealand lysimeter monitoring sites typically consist of a minimum of three soil monolith lysimeters connected by pipework to a nearby instrument enclosure, tipping bucket rain gauges for measuring recharge, and a ground-level rain gauge for measuring rainfall. A number of lysimeter sites are required to characterise regional scale recharge due to spatial variation in recharge as a function of soil type, land use, land form, aquifer conditions, irrigation, and climatic conditions. Recharge monitoring sites In New Zealand are currently operating in Canterbury, Bay of Plenty, Hawke's Bay, and Southland regions, and the majority of these sites are located on pasture.

Lysimeters are typically installed so that the steel casing is buried flush or 10-15 mm above the soil surface. Therefore these lysimeters are unsuitable for cultivated land use as the steel casing is incompatible with mechanical cultivation. The need for an arable lysimeter design was identified by scientists and technical specialists at the National Lysimeter Workshop (2014). Hawke's Bay Regional Council requires a lysimeter to be designed for the measurement of recharge from arable land use as this information is essential to support the development of science research models and to inform water management policy.

The aim of this report is to explore options for a lysimeter design that can be implemented for arable land use to measure land surface recharge in Hawke's Bay, that is also suitable for application elsewhere in New Zealand. In order to achieve this aim, the following objectives were identified:

- complete a literature review of international designs that are suitable for, or can be adapted to, New Zealand conditions;
- identify a number of suitable designs to be reviewed by an expert panel; and
- facilitate an expert panel discussion involving research and consulting agencies to review the proposed designs and provide expert comment.

Information from the literature review, design concepts, and a template for the expert panel review are presented in this report, which is the key deliverable of this project. In addition, a final recommendation for an arable lysimeter design will be provided once the expert panel comments are compiled.

2.0 ARABLE SITE SETTING

The intended field site for installation of the first arable lysimeter design is located on a mixed arable farm in Otane, Hawke's Bay. Paddocks on the property have recently been deeply cultivated, levelled and contoured to allow for the installation of a centre-pivot irrigator in 2014 (Mathers, 2015). Future farm management practices will involve minimal cultivation and include strip tillage and direct drilling. Crop rotation is likely to consist of annual ryegrass grazed by sheep, and crops of carrots, maize, peas, or beans (Mathers, 2015). As deep cultivation has recently been completed, tillage depth is likely to be shallow, and no deeper than 200 mm below ground level (BGL).

3.0 LITERATURE REVIEW

3.1 LYSIMETER DEFINITION

The original aim of a lysimeter was to measure soil leaching, and the term originates from a combination of Greek words "lusis" (solution) and "metron" (measure). A lysimeter can be defined as an instrument containing a soil column that is installed plane to the land surface and is used to collect seepage water, or "*a device that isolates a volume of soil or earth between the soil surface and a given depth and includes a percolating water sampling system at its base*" (Lanthaler, 2004). The following key factors are associated with lysimeter design and construction (Lanthaler, 2004; Payero and Irmak, 2008):

- Size: generally 0.5 m^2 to > 1 m^2 in area.
- Material: brick, concrete, galvanised steel, PVC.
- Soil filling method: disturbed (artificially filled) or undisturbed (monolithic).
- Vegetation: bare soil, pasture, arable, viticulture, forestry.
- Soil type/fractions: sand, silt, clay, gravel.
- Measurement method: weighable (quantity: change in water storage through measurement of weight); or seepage (quality and quantity: measurement of water that seeps from the lysimeter base).
- Location: field (integrated into land use), experimental (controlled environment).
- Sampling: gravimetric seepage or suction sampling.

3.2 NEW ZEALAND LYSIMETER INSTALLATIONS

More than 20 lysimeter sites have been installed throughout New Zealand for monitoring recharge to groundwater. Current sites are operating in Canterbury (White *et al.*, 2003; Srinivasan and Duncan, 2011), Bay of Plenty (White *et al.*, 2007; Lovett *et al.*, 2012; Lovett and Harvey, 2013), Hawke's Bay (Lovett and Cameron, 2013; Lovett, 2013; Lovett, 2014); and Southland regions (Lovett and Payne, 2014; Lovett, 2015). The majority of lysimeters installed in New Zealand are cylindrical, non-weighing, monolithic lysimeters containing an undisturbed soil column. These lysimeters typically measure 500 mm in diameter by 700 mm deep, with a volume of approximately 0.14 m^3. The lysimeters are either installed to ground surface level or 10-15 mm above the ground surface. Lysimeters are composed of galvanised steel casing and fittings and are connected to polyethelene pipework and fittings. Discharge is generally measured by tipping-bucket rain gauges and dataloggers located in a nearby instrument enclosure. All functioning sites are currently located on pasture i.e., land use that does not involve mechanical cultivation, or in a location where the lysimeters can be excluded from cultivation.

Alternative lysimeter monitoring sites have been installed in New Zealand such as the Landcare Research site in the Western Bays, Lake Taupo (Landcare Research, 2015). Twelve cylindrical lysimeters measuring 1 m diameter by 1.5 m height were installed primarily for the purposes of monitoring nutrient leaching from different combinations of pasture (lucerne and ryegrass/clover) and nutrient treatments (fertilizers and biochar). Alternative designs include channel lysimeters which have been installed in Otago (Landcare Research, 2015), and fluxmeters which are installed throughout New Zealand, predominantly for measurement of nutrient and chemical leaching (e.g., Green *et al.*, 2014).

3.2.1 Lysimeter installation under arable land use

A lysimeter site consisting of three modified barrel lysimeters was installed on cropping land use at Wakanui, Canterbury in 2011 (Flintoft, 2015). Modifications to the standard steel cylinder included construction of removable plates (300-400 mm) and lowering of the external ring to below the connection of the plates and the main lysimeter vessel (Figure 3.1A) (Flintoft, 2015; Cook, 2015). Prior to cultivation soil around each lysimeter was dug up to remove the upper plates, and the paddock was cultivated as normal (Flintoft, 2015). The lysimeters were located and the soil around the lysimeters was hand dug to locate the steel casing following cultivation (Figure 3.1B). The upper plates were reconnected to the lysimeter, the soil was in-filled, and the gap between the steel and soil column was sealed with petroleum jelly (Flintoft, 2015).

A) B)

Figure 3.1: Modified lysimeters at Wakanui during A) installation, and B) relocation (Flintoft, 2015).

The site was abandoned in 2013, primarily due to an unexpectedly high water table which flooded the instrument enclosure (Flintoft, 2015). In addition:

- a time lag (3-4 weeks) between cultivation and sowing created uncertainty in recharge over this period, as plates were not fixed to ground level (Flintoft, 2015);
- removal and replacement of the upper plates was time consuming and created considerable disturbance to the surrounding soil (Flintoft, 2015);
- lysimeters were difficult to locate after cultivation (Duncan, 2015); and
- soil height varied due to mechanical cultivation and crop type, therefore lysimeters were not flush with ground level, which was likely to affect the water balance (Srinivasan, 2015).

3.3 INTERNATIONAL LYSIMETER INSTALLATIONS

The oldest known lysimeter monitoring was installed in 1880 at Rothamsted Research, United Kingdom and is still operational (European Lysimeter Platform, 2015a). This non-weighable monolithic lysimeter was constructed from concrete and brick, predominantly for monitoring nitrogen, agrochemical, anion and cation leaching (Lanthaler, 2004). Monolith lysimeters were first installed in the USA in the late 1800s, including a site in Missouri where the lysimeters had a surface area of 40.5 m^2, and were installed using a tile drain system (Goss and Ehlers, 2009). Recently there has been considerable development in the design, instrumentation, and installation of lysimeters, predominantly in Europe. The lysimeter has been significantly developed from a relatively simple device which only measures discharge into a precise tool for water flux, soil water calculation and water balance studies (Umwelt-Gerate-Technik GmbH (UGT), 2015; Goss and Ehlers, 2009; von Unold and Fank, 2008).

A considerable network of lysimeters now exists in Europe, with over 2,500 individual lysimeters being operated in at least 15 countries and additional lysimeter sites being installed every year (Lanthaler, 2004; UGT, 2015). The majority (65% in 2004) of European lysimeters have been installed on arable land or fields (Lanthaler, 2004). Further review of the European lysimeter study sites indicated that the majority of ground above the lysimeters is cultivated using traditional, manual or hand methods rather than mechanical cultivation (Table 3.1). This supports the view of Goss and Ehlers (2009) who identified that a key limitation of lysimeter methods is that agronomic activities associated with cultivation (e.g., ploughing, sowing, harvesting) interrupt the accuracy of water flux measurements. Contact was made with researchers at several sites that appeared to have mechanical cultivation to obtain more information on the lysimeter design. Arable lysimeter design for New Zealand conditions needs to allow for mechanical cultivation. Therefore, this review focussed on international sites that used cylindrical, non-weighing, monolithic field lysimeters.

Several European organisations are leading the product development, design and installation of lysimeters worldwide, including UGT, and umwelt-monitoring-systeme (UMS) (Cepuder, 2015). UGT holds several patents on the excavation and instrumentation of lysimeters and have designed installation equipment that eliminates the need for large excavators to be used (Reth, 2015). UGT have installed over 400 lysimeters in locations including Germany, Russia, China, Iran, France, Slovakia, and Switzerland (UGT, 2015).

Table 3.1: Summary of the location, type, and purpose of selected lysimeters installed on arable land/fields in Europe, including an indication of the cultivation method.

Country	Location	Type	Investigations	Cultivation
UK	Rothamsted Research	Gravitational, monolithic	Leaching of nitrogen, anions and cations, and agrochemicals	Hand tools
France	Fagnieres	Gravitational, monolithic	Transfer and balance of elements in the soil	Unknown
	Avingnon	Gravitational, monolithic	Mass and particle transport in agricultural, heterogeneous soils	Unknown
Germany	Dedelow	Gravitational, monolithic	Effects of fertilization and cultivation on: yield, water and nutrient balance	Integrated
	Grass Lusewitz	Combination	Water balance, nitrogen leaching	Unknown
	Julich	Combination	Water balance and relationship with anthropogenic substance input	Unknown
Switzerland	Bern-Liebefeld	Gravitational, backfilled	Nutrient leaching, mainly nitrogen. Closed in 2009	Conventional (direct drilling)
	Zurich-Reckenholz	Gravitational, backfilled	Nutrient leaching	Conventional (direct drilling)
	Lausanne	Gravitational, backfilled	Bare soil, salinization, pesticide transport	No (bare soil)
Austria	Grass-Enzersdort	Combination	Determine seepage water volume	Manual
	Hirschstetten/Wien	Gravitational, backfilled	Agriculture: nutrient and pesticide fluxes, groundwater	Conventional
	Siebersdorf	Combination	Pesticides, soil contaminants	Manual
	Wagna	Combination	Water movement, nutrient transport, hydrochemistry, natural cultivation	Manual/ mechanical
Hungary	Karcag	Combination	Soil cultivation and reclamation research	Conventional, reduced till
	Szarvas	Gravitational, non-weighable	Water and nutrient balances	Traditional
Spain	Mollerussa EEL fields	Gravitation, backfilled	Orchard water requirements, irrigation and evapotranspiration study	N/A
Italy	Udine	Weighable, backfilled	Leaching of nitrogen and water regimes	N/A

3.3.1 Lobau, Austria

In 1996, three non-weighing monolithic field lysimeters were installed at Lobau for the purposes of evaluating soil water balances and nutrient dynamics under arable land (European Lysimeter Platform, 2015b). The lysimeters had a 1 m^2 surface area, were 1.5 m deep, and were composed of a concrete cylinder and mobile steel ring for removal during cultivation (Figure 3.2) (European Lysimeter Platform, 2015b). Issues have been identified with the sites including the rise of the water table which flooded the measurement instruments (European Lysimeter Platform, 2015b). Contact was made with Wilfried Hartl to obtain more information about the mobile ring design. Wilfried indicated that he would send further details of the lysimeter site at the end of July, however no further information was obtained prior to publication of this report (Hartl, 2015).

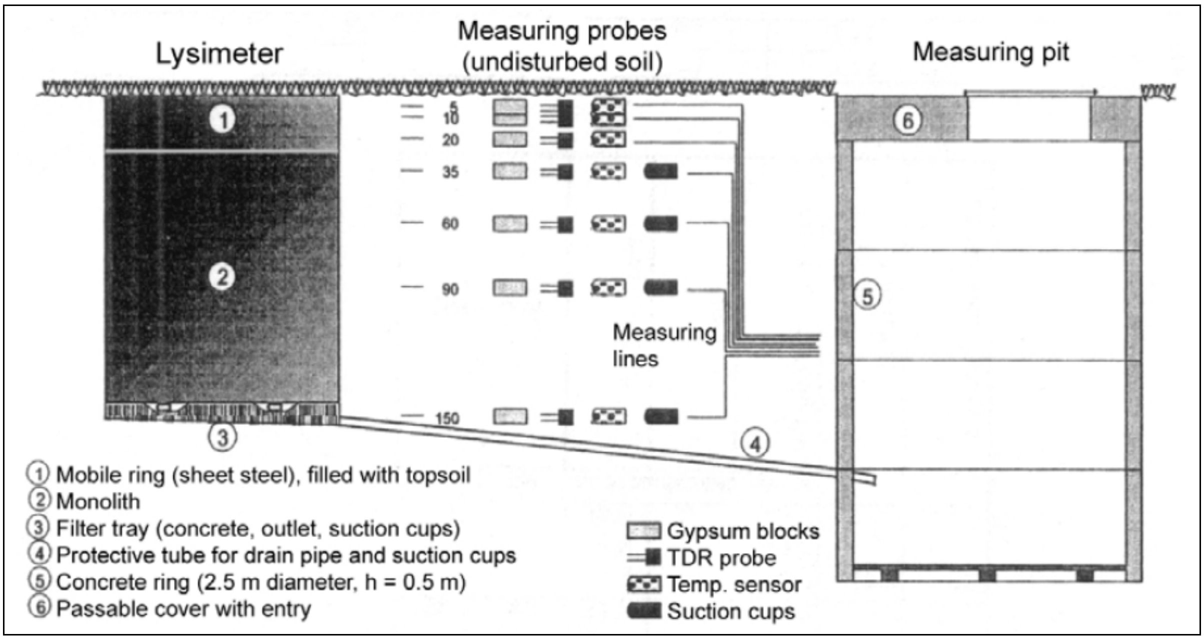

Figure 3.2: Diagram of a non-weighing, monolithic field lysimeter with soil hydrology probes (European Lysimeter Platform, 2015b).

3.3.2 Wagna, Austria

In 2004, two newly-developed, weighable, monolithic field lysimeters were installed in Wagna, Austria (Fank, 2008; von Unold and Fank, 2008). These lysimeters were designed to have a mobile ring which can be removed to allow for mechanical cultivation. The purpose of the “Agro-Lysimeter” was to measure root water stress, water drainage, and solute flux under field conditions for a cultivated field (von Unold and Fank, 2008). The monolithic lysimeter was composed of a stainless steel cylinder with a surface area of 1 m^2 and a monolithic depth of 2 m BGL. An upper ring 35 cm in height was constructed to enable removal for mechanical cultivation and tillage and subsequent replacement. Unlike many of the modern lysimeters being installed in Europe, the Agro-Lysimeter is non-weighable and discharge volume is measured using tipping bucket rain gauges. The Agro-Lysimeter design is ideal for recurrent monitoring of groundwater recharge and solute leaching from arable land, and is considerably cheaper than weighing designs. The lysimeter was developed by UMS, Munich, the Institut fur Kulturtechnik (Institute for Culture/Technology) in Petzenkirchen, and Joanneum Research. Full installation details of the installation are available from the European Lysimeter Platform website (European Lysimeter Platform, 2015b).

Selected components of the installation method that relate specifically to the installation of the removable ring have been provided in further detail (Figure 3.3; Lanthaler, 2004). The installation pit is backfilled with soil around the installed lysimeter (Figure 3.3A), and the mobile steel ring of the inner cylinder is removed from the lysimeter monolith (Figure 3.3B). The remainder of soil is backfilled (Figure 3.3C and 3.3D). Following this, the field is cultivated down to 25 cm ensuring that the tractor does not drive over the lysimeter, although the lysimeter is designed to support the weight from mechanical equipment. To install the ring, the lysimeter is firstly located using accurate GPS and the mobile ring is gradually inserted onto the inner cylinder (Figure 3.3E and 3.3F). Surrounding soil is removed to expose the wooden ring that is located between the main cylinder and the removable ring (Figure 3.3G). A mobile ring is also put on top of the outer lysimeter and the soil is backfilled (Figure 3.3H and 3.3I). During the fieldwork, this process is split into two components: removal of the mobile ring and insertion of the wooden ring, then following cultivation, removal of the soil around the lysimeter to locate the wooden ring, then repositioning of the mobile ring and infilling the surrounding soil (von Unold, 2015). The effort required to complete the removal and replacement of the mobile ring is approximately 2 days for each lysimeter (von Unold, 2015).

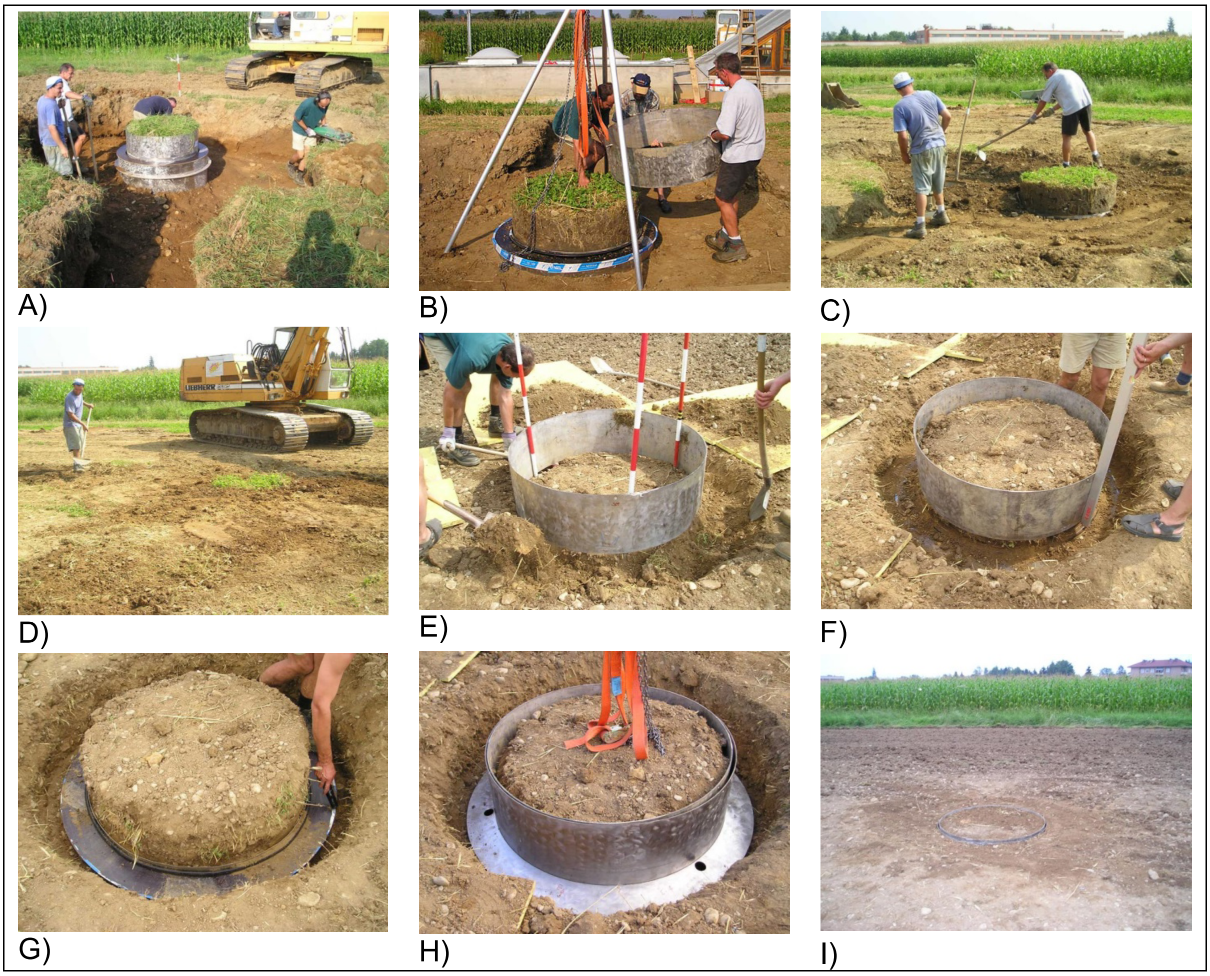

Figure 3.3: A – D) installation of the lysimeter; and E – I) relocation of the lysimeter following cultivation and replacement of the mobile upper ring. Images were obtained from the European Lysimeter Platform (2015b): http://www.lysimeter.com/photos_wagna/index.htm.

3.3.3 Tanikon, Switzerland

Prashun (2015) provided a summary of the process used to install mobile rings onto integrated lysimeters at the Tanikon station, Switzerland (Appendix 1). This method is very similar to that used at Wagna, Austria. Although successful at integrating the lysimeter into the arable land (Figure 3.4A), the Tanikon arable trial was discontinued in 2013. The primary reason for abandonment of this trial was due to the excessive amount of time taken for the mobile rings to be installed, and the level of disturbance to the surrounding soil (Figure 3.4B) (Prashun, 2015).

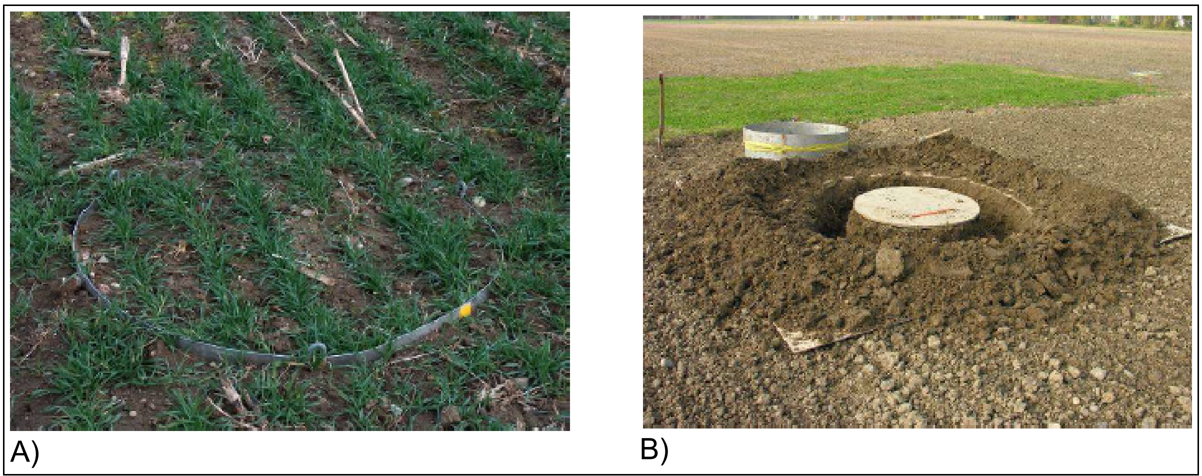

Figure 3.4: Photographs of the integrated lysimeter at the Tanikon station showing (Prashun *et al.*, 2011).

3.3.4 Borovce, Slovakia

UGT has recently developed a monolithic weighing lysimeter that can be fully maintained underground (Reth, 2015). In this design, the upper surface of the lysimeter is located 400 mm BGL to allow for cultivation (Figure 3.5A). Following cultivation, three spindle drives are raised to the surface, and the steel ring is attached. The spindle drives are then retracted which lowers the steel ring to the top of the lysimeter vessel (Figure 3.5B). The interface between the mobile ring and the vessel can then be sealed. Although the lysimeter requires additional equipment, the time taken to attach the mobile ring is minimised considerably, as is the disturbance to the surrounding soil.

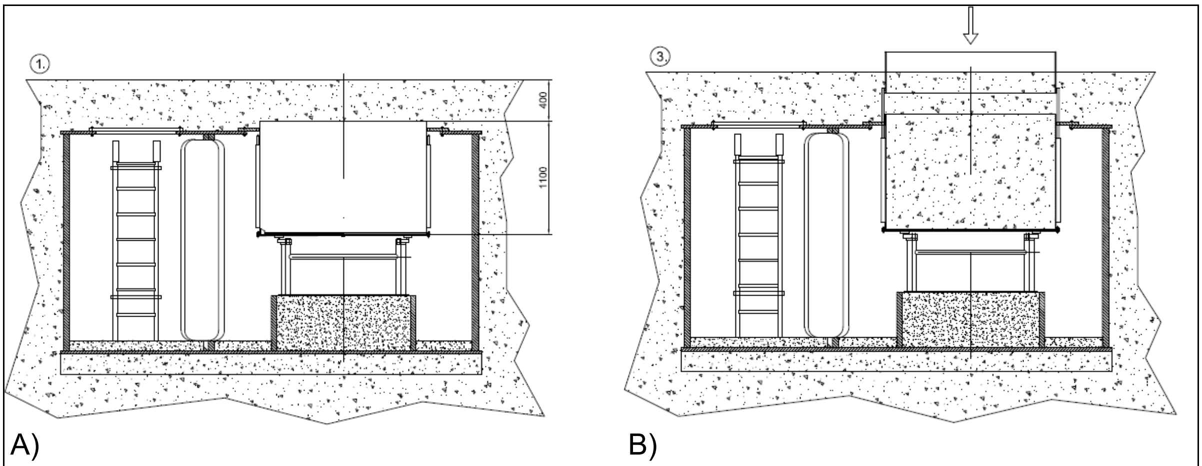

Figure 3.5: Schematic diagrams showing the UGT arable lysimeter A) for cultivation/tillage, B) following extension of three spindle drives from the lysimeter to the surface, the mobile ring is retracted cutting of the tilled topsoil, and then sealed.

A lysimeter station recently installed on arable land at Borovce, Slovakia, was intended to be the pilot study for the UGT arable lysimeter, however, a funding cut for the installation resulted in a modified design (Reth, 2015). The installed station consists of four lysimeters and a weather station (Hrckova, 2015). A single weighing lysimeter was installed under pasture, and three non-weighing lysimeters were installed under arable land use. The cylindrical, monolithic arable lysimeters measure 2 m^2 in surface area by 1 m deep, and are constructed of steel (Hrckova, 2015). Installation was completed by removing the upper 500 mm of soil, and then installing the soil lysimeter as a monolith (Hrckova, 2015). The soil was then replaced on the surface of the monolith and cultivation was then possible (Figure 3.6). Although the design is cost effective and allows cultivation to occur without removing the mobile ring, the lysimeter casing does not extend to ground level, which may cause uncertainty in calculation of water balances.

Figure 3.6: A non-weighing lysimeter during installation at Borovce, Slovakia (Katarina Hrckova).

3.3.5 Reckenholz, Switzerland

The Agroscope Reckenholz-Tanikon Research Station (ART) in Switzerland contains 72 monolithic lysimeters which represent the three typical arable soils (Agroscope, 2015). The lysimeters are designed so that they can be lowered from the surface into the subsurface (Figure 3.7). Although many of the trials run on these lysimeters involve investigation of tillage techniques, all of the lysimeters are hand cultivated for efficiency. The concept of lowering the lysimeter could be adapted to lowering an upper ring around the outside of the lysimeter monolith to allow for cultivation.

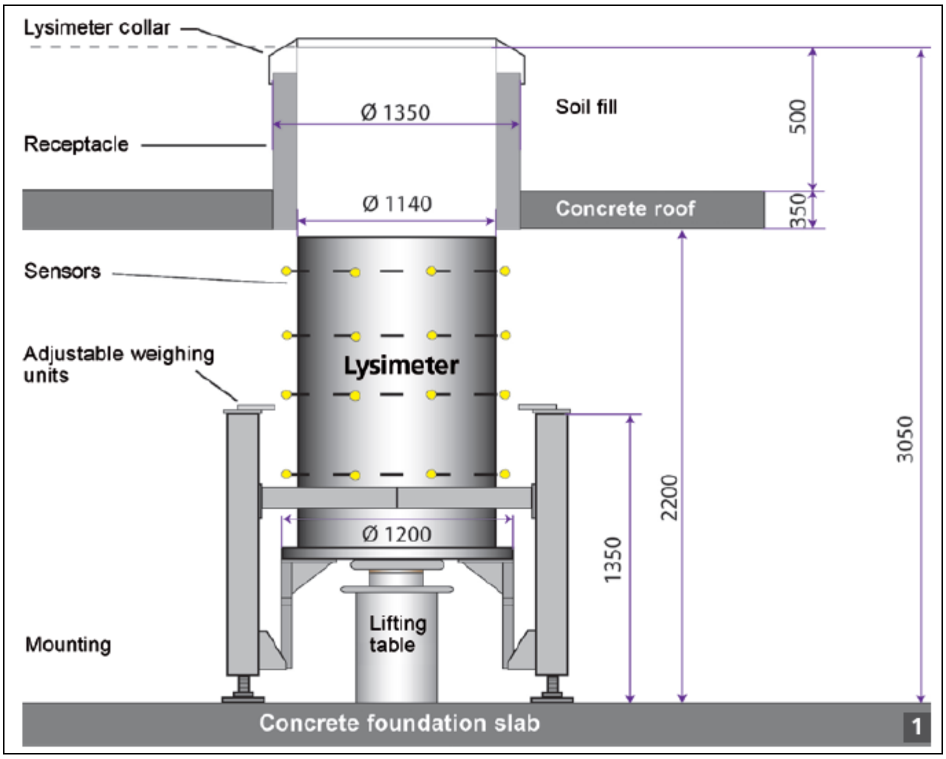

Figure 3.7: Schematic of the ART lysimeter design, Switzerland (Agroscope, 2015).

3.3.6 United Kingdom

In response to the need for a lysimeter under cultivated land use, a large-scale field lysimeter site was established in Oxfordshire, UK (Goss and Ehlers, 2009). The site consisted of 20 lysimeters, each 0.25 ha in surface area, separated by a series of polythene films, permeable fill, interflow drains and v-notch weirs. This type of installation was not investigated further, as the scale of the installation was far too extensive for intended use at integrated sites in New Zealand.

3.4 LITERATURE REVIEW SUMMARY

Based on consideration of the current design and installation methods used in New Zealand, the intended arable site in Hawke's Bay and findings from international literature, the following conclusions can be made:

- weighing or non-weighing, monolithic, cylindrical, drainage lysimeters, similar to those installed in New Zealand, have been installed in a number of localities throughout the world;
- several designs exist for integrating lysimeters into farm fields to allow for mechanical cultivation, tillage and seeding;
- a common design involves a mobile upper ring which is removed for cultivation, and replaced afterwards, however this approach has been deemed to be time consuming and creates disturbance to the surrounding soil; and
- a simplified design (e.g., Borovce (Section 3.3.4)) allows for the lysimeter to be set 500 mm BGL without a mobile upper ring; and
- a more complex design allows for lowering the mobile upper ring onto spindles to re-connect it to the main lysimeter vessel.

4.0 POTENTIAL ARABLE LYSIMETER DESIGNS

Based on consideration of the New Zealand context and international lysimeter designs, three potential designs are presented in this section for evaluation by an expert panel.

4.1 MODIFIED STANDARD LYSIMETER

The current lysimeter design, composed of a steel, cylindrical barrel lysimeter (500 mm diameter, 700 mm deep), can be modified to allow for the removal of an upper ring (*c.* 250 mm) (Figure 4.1). The method of fixing the ring to the main cylinder, relocating the ring, and re-attaching the ring requires refinement from the initial design used at Wakanui in 2011. Options include attachment of a wooden ring between the cylinder and mobile ring to assist in placement (e.g., Wagna (Section 3.3.2)). Considerable labour effort is required to replace the mobile ring following cultivation, and soil is disturbed.

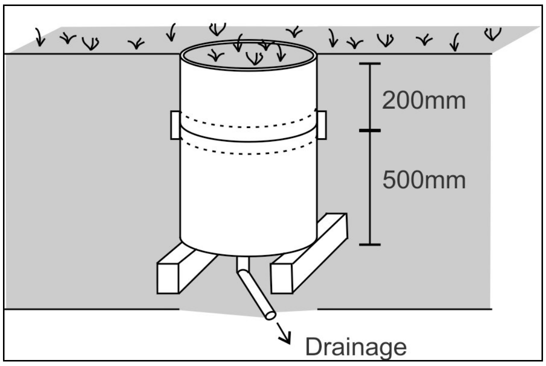

Figure 4.1: Schematic of a standard cylindrical barrel lysimeter (500 mm diameter, 700 mm deep) with modifications including addition of a mobile upper ring and wooden plate.

4.2 DUAL CHAMBER LYSIMETER

This is a novel design composed of the inner lysimeter body (500 mm deep), and an outer steel casing (Figure 4.2). The inner lysimeter remains static, but the outer casing can be lowered and raised for cultivation. This method relies on a suitable seal being created between the inner lysimeter and the outer casing (not identified on the schematic). The outer casing can be raised/lowered by hydraulics (e.g., a porta pump), or manually (e.g., axle mechanism), but in both cases has little weight resting on it. Proposed dimensions are 500 mm diameter by 500 mm deep (inner lysimeter), and 510 mm by 200-400 mm deep (outer casing). Although design and installation costs will be higher, labour and disturbance to the soil prior to and following cultivation will be considerably minimised.

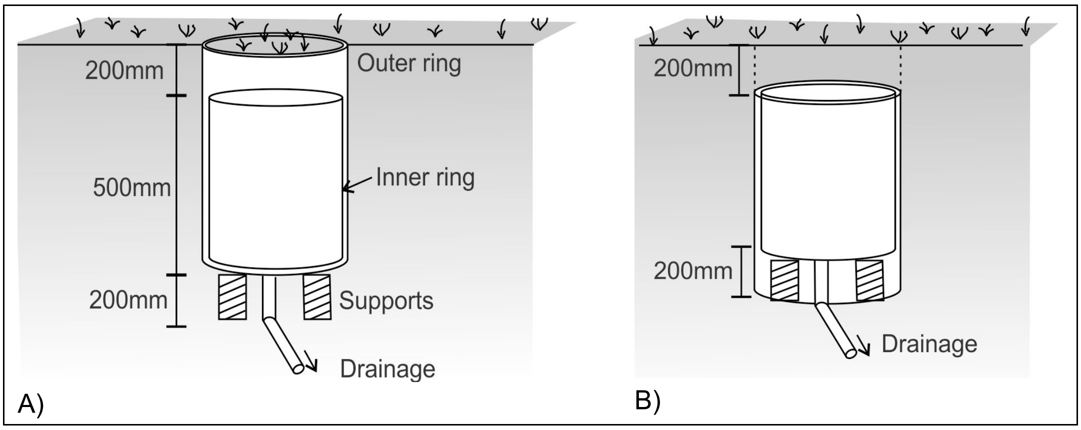

Figure 4.2: Schematic of a simple two chamber lysimeter showing: A) the lysimeter in the raised position, and B) the lysimeter in the lowered position ready for cultivation.

4.3 LYSIMETER WITH SPINDLES AND REMOVABLE UPPER RING

A modified design based on the design developed by UGT (Reth, 2015) (Figure 3.5) could be used to easily attach and seal the mobile ring to the lysimeter. Drawings provided by UGT (Figures 4.3 and 4.4) indicate a weighing lysimeter design (Reth, 2015), however this could easily be modified to represent a non-weighing lysimeter. Benefits of this design are that the soil disturbance around the lysimeter is minimised, and that the time taken to install and remove the mobile ring is considerably reduced. Although design costs and installation of the additional spindle drive will be greater than a standard barrel lysimeter, the ease of ring placement will save considerable time during ring removal and replacement, and disturbance of soil and sowed seed around the lysimeters will be significantly minimised.

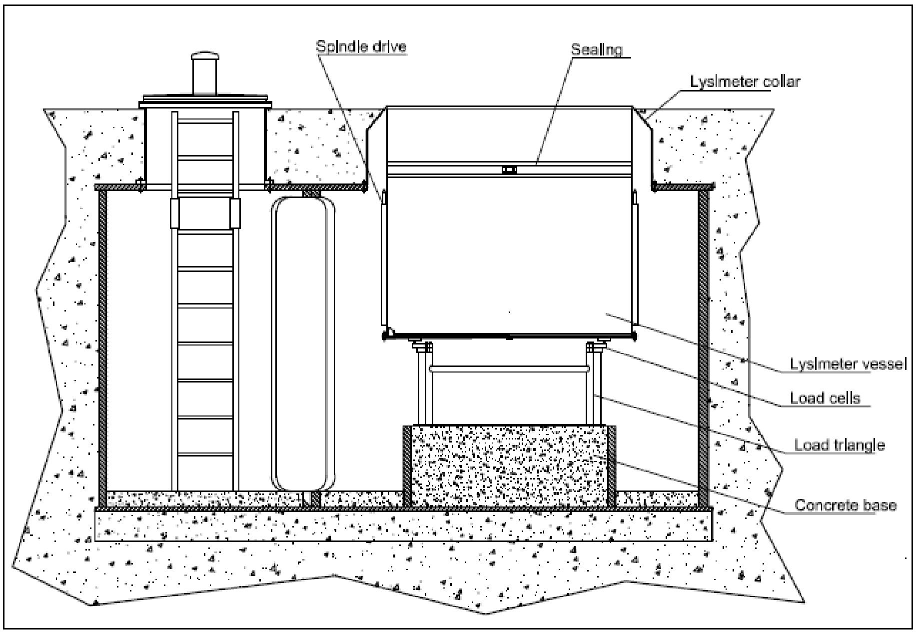

Figure 4.3: Design of a UGT weighing monolithic lysimeter for arable land use showing key components of the spindles and removable ring system (Reth, 2015).

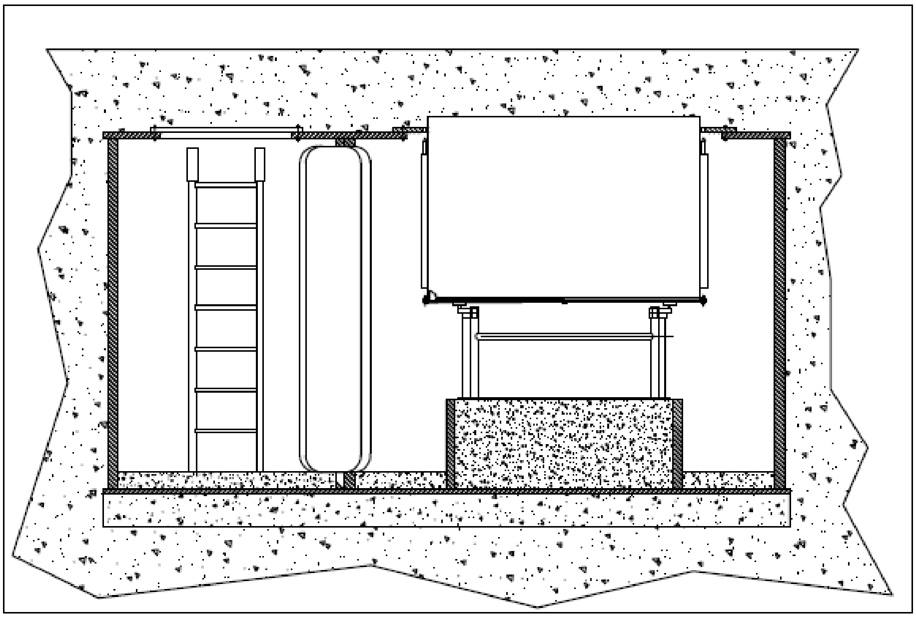

Figure 4.4: Design of a UGT weighing monolithic lysimeter for arable land use ready for mechanical cultivation (Reth, 2015).

5.0 SUMMARY AND CONCLUSIONS

A review of lysimeter monitoring sites in New Zealand and internationally has revealed that there is a demand for integrated arable lysimeters for research and land management projects. Limitations surrounding the methods that currently exist include: time taken to remove and replace a mobile ring, disturbance to the surrounding soil, manual or hand cultivation of soil, and or installation of the lysimeter well below ground level. The three lysimeter designs proposed here were selected to minimise these limitations and include: a modified standard lysimeter to have a manually replaceable mobile upper ring; a dual chamber lysimeter where an outer steel ring can be lowered below the ground surface; and a spindle drive that can be raised to accept the upper mobile ring. The evaluation template (Appendix 2) can be used by the expert panel to evaluate each design, and to determine the most appropriate design for New Zealand conditions.

Results of the peer review will be collated and into a GNS Science Letter Report (Part 2 – peer review of proposed designs). Following the review, is it anticipated that a final design will be completed and then tested with a trial installation.

6.0 ACKNOWLEDGEMENTS

Acknowledgement goes to the following people for providing their time, professional expertise and opinions during the brief duration of this project:

- Marc Reidi (GNS Science)
- Dougall Gordon (Hawke's Bay Regional Council)
- Diana Mathers (Foundation for Arable Research, Hawke's Bay)
- Mark Flintoft (Aqualinc Research)
- Katarina Hrckova (Department of Agrosystems, Slovakia)
- Sascha Reth (Managing Director, Umwelt-Gerate-Technik GmbH, Germany)
- Volker Prasuhn (Senior Scientist, Agroscope, Zurich)
- Jens Rekker (Lincoln Agritech)
- Roger Cook (Lincoln Agritech)
- MS Srinivasan (National Institute of Water & Atmospheric Research)
- Maurice Duncan (National Institute of Water & Atmospheric Research)
- Gernot Krammler (Joanneum Research Resources, Graz, Austria)
- Georg von Unold (Umwelt-monitoring-systeme, Munich, Germany)
- Peter Cepuder (University of Natural Resources and Life Sciences, Austria)
- Jozef Gubis (Department of Agrosystems, Slovakia)
- Paul White (GNS Science)
- Wilfried Hartl (Bioresearch, Austria)
- Greg Barkle (Aqualinc)

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APPENDICES

APPENDIX 1: LYSIMETER RING INSTALLATION

Procedure to install lysimeter rings, Tanikon, (Prashun, 2015).

This text was translated from German to English by GNS Science.

The top ring is removed before the mechanised cultivation starts.

After cultivation/seeding takes place the exact location of the top of the lysimeter, which is 30 cm below ground level, is located using a GPS device.

In order not to disturb too much ground nearby, sheets of timber are placed on the floor around the location of the lysimeter. Using a shovel a narrow trench is excavated with the aim of exposing/finding the edge of the lysimeter.

After excavation, the top of the lysimeter is visible. Now we can start to build-up the ring back onto the lysimeter.

The ring is now accurately fixed onto the top of the lysimeter. In order to avoid water entering or leaving the lysimeter (which would falsify measurements) the gap between the lysimeter and top ring is sealed with tape.

Now the soil is re-filled back into the previously excavated trench.

The installation of the ring is completed. Seeding/cultivation of the outside ring (where the trench was refilled) is now necessary in order to ensure a smooth transition from the cultivated inside ring and the rest of the field.

APPENDIX 2: EXPERT PANEL TEMPLATE

Three potential designs have been selected for peer review by experts. To guide the review, three risks need to be considered in a critique of design options.

1. Disturbance of soil and preferential flow
2. Costs and resourcing (labour)
3. Practicalities of measurements and compatibility with farm tillage operations.

Table A 2.1: Template of the information request table that was facilitated to the expert panel for consideration and comment on the proposed lysimeter designs.

Name	
Organisation	
Position	
Contact phone no.	
Design 1)	**Modified standard lysimeter (mobile ring)**
Positives	
Negatives	
Other comments	
Support (%)	
Design 2)	**Dual chamber lysimeter (lowered ring)**
Positives	
Negatives	
Other comments	
Support (%)	
Design 3)	**Spindles and removable ring**
Positives	
Negatives	
Other comments	
Support (%)	

Name	
Organisation	
Position	
Contact phone no.	
Other comments	
Please provide a design, sketch and evaluation (positives, negatives)	

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