CONTROLLED DRAINAGE
– ASSESSING RELEVANCE TO NZ PASTORAL SITUATIONS

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Abstract

Farm drainage systems are used to prevent excessive soil water levels during wet periods, thus protecting soil quality and enhancing plant productivity. Although beneficial, drainage systems are also known to be a significant loss route for dissolved nutrients as they by-pass nutrient attenuation areas such as wetlands and riparian zones. A potential way of reducing nutrient loss through drainage systems is to use to strategically placed weirs in drainage channels to control water movement out of the soil profile by restricting drainage to only the excess water that will damage crops, or limit grazing or farm equipment access to paddocks. Such systems are used in cropping areas of Europe, Canada and the USA (where it is designated as a “beneficial management practice”) with significant benefits for water quality, agricultural productivity and nutrient- and water-use efficiency. Improvement to water quality arise by decreasing total drainage outflows, promoting higher nutrient use efficiency and increased N retention and NO_3-N attenuation. Crops have the potential to utilise nutrients held in the root-zone and reduce plant moisture stress during drier periods. Raising the water table may also promote in-situ denitrification. The practicality of using controlled drainage under New Zealand farming conditions however is less clear, with only 2 studies having been undertaken that we are aware of.

In order to locate suitable sites for a controlled drainage study, review of controlled drainage literature was used to inform a GIS pre-screening process to identify areas with appropriate soils (loam or clay loam) and slope (<1.5 degrees).

In selecting specific sites, additional factors that needed to be considered were sites needed accessible drainage systems where control weirs could be installed, and sites needed to have two near-identical paddocks to set up as paired monitoring sites to allow a valid comparison between a paddock where controlled drainage was undertaken and an adjacent paddock where normal drainage was allowed to occur. Two dairy farms were identified as suitable sites- one at Tatuanui (3 km east of Morrinsville) and the other near Waharoa in the Waikato region.

Site set-up and control structures include individually designed and constructed weir/flume arrangement due to the low gradients present at the sites.

Soil moisture sensors will be placed at two depths at different locations of each experimental paddock to assess the effectiveness of the weirs in controlling soil moisture levels within the paddocks. Outflows from each paddock will be measured for flow volume, and be sampled for water quality (particularly nitrogen species). Pasture productivity and nutritional value will also be assessed.

Introduction

Controlled drainage operates by restricting or preventing soil water from leaving via the drainage system. This is done using a weir or other water flow control structure to raise the water level in the drainage outlet and holding water in the drain during times of water deficit. This reduces subsurface drainage rates, annual drainage volumes and thus net nutrient export. Controlled drainage is a flexible management system that can be set to accommodate specific crops, topographic and soil characteristics, and the water flow control structures can be adjusted to allow drainage once a critically high water table is achieved in the system to reduce the potential of anoxia stress to crops.

Controlled drainage is an attractive option for producers because it allows soil to be drained during the wetter months, while retaining water within the soil during the growing season to prevent plant moisture stress. Raising the water table during the growing season has the potential to retain nitrate (NO_3-N) as well as other nutrients, thus allowing them to be more available to the crop root zone during the growth period. It may also promote the potential removal of NO_3-N via in situ processes such as denitrification (Smith and Kellman 2011).

Important requirements for successful controlled drainage are a flat landscape (<1.5° slope), free draining soils (e.g. ash), underlain by a low hydraulic conductivity soil (e.g. clay) at a depth of 1-3 m.

NZ and International Research Outcomes

In one of the two NZ studies we are aware of, Singleton et al. (2001) carried out a lysimeter study in which two levels of controlled drainage and a conventionally drained system were investigated in soils irrigated with farm dairy effluent over a two year period. In the first year, effluent was applied at a rate of 511 kg N/ha, while in the second year, the application was increased to 1518 kg N/ha. Average NO_3-N leaching decreased from 26.2 kg NO_3-N/ha/year under conventional drainage to 11.2 and 3.7 kg NO_3-N/ha/year with the two levels of controlled drainage used (equivalent to a 57 and 86% reduction in NO_3-N being exported from the controlled drainage when compared to the conventional drainage).

The other NZ study was undertaken by Fonterra (John Russell, pers. comm.) where Hautapu dairy factory wastewater was applied to pasture to enhance NO_3-N removal. They recorded no significant difference in the NO_3-N in the drainage water between the controlled and conventionally drained treatments, however high background denitrification rates suggest that the potential for further enhancing NO_3-N removal through water table management was small.

Overseas studies have shown some notable benefits from controlled drainage. For instance, in north east Italy, Bonaiti & Borin (2010) observed reductions in drainage and losses of NO_3-N of 77% and 70% respectively for a controlled and sub-irrigated subsurface drainage system, and reductions of 47% and 72% for drainage and NO_3-N from open ditches with controlled drainage and sub-irrigation when compared with conventionally drained systems. In Ontario, Canada, NO_3-N concentrations in drain flow were reduced by 62.3 – 95.7 % at two different drainage depths over two years (Lalonde, Madramootoo et al. 1996). Some studies however indicate that lower net nutrient losses from drainage systems are due to equivalent lower water volumes. For instance, in Lithuania, Ramoska et al. (2011) recorded the outflow drainage period was 40 – 62% shorter and drainage volume was 25% lower, resulting in net NO_3-N leaching 20 – 28% lower for a controlled drainage system compared with conventional drainage. Net benefits were seen in crop yields of 6 – 10% greater.

Similarly, Gilliam et al. (1979) reported N loss reductions of 50% in drainage waters, accompanied by reductions in drainage water yields also of approximately 50%.

Conceptual Site layout

For this study, we intended to find two dairy farms with appropriate soil and drainage characteristics. An important consideration was a requirement for each farm to contain two near identical paddocks with adjacent open drains where flow control weirs could be installed. Each weir would require a gate to control flow. A stilling well and logger are used to measure water levels and flow. A power actuator on the gate allows it to be controlled remotely via a telemetry system. Each paddock has 4 locations where soil moisture sensors are installed at two depths (at the base of the root-zone and at the depth of the drainage system). Each soil moisture location requires a solar power source and battery system. Information is transmitted wirelessly (“Smarti”) to the logger. Samples from each weir are to be collected via automatic samplers. A schematic of an idealised site set-up is shown in Figure 1.

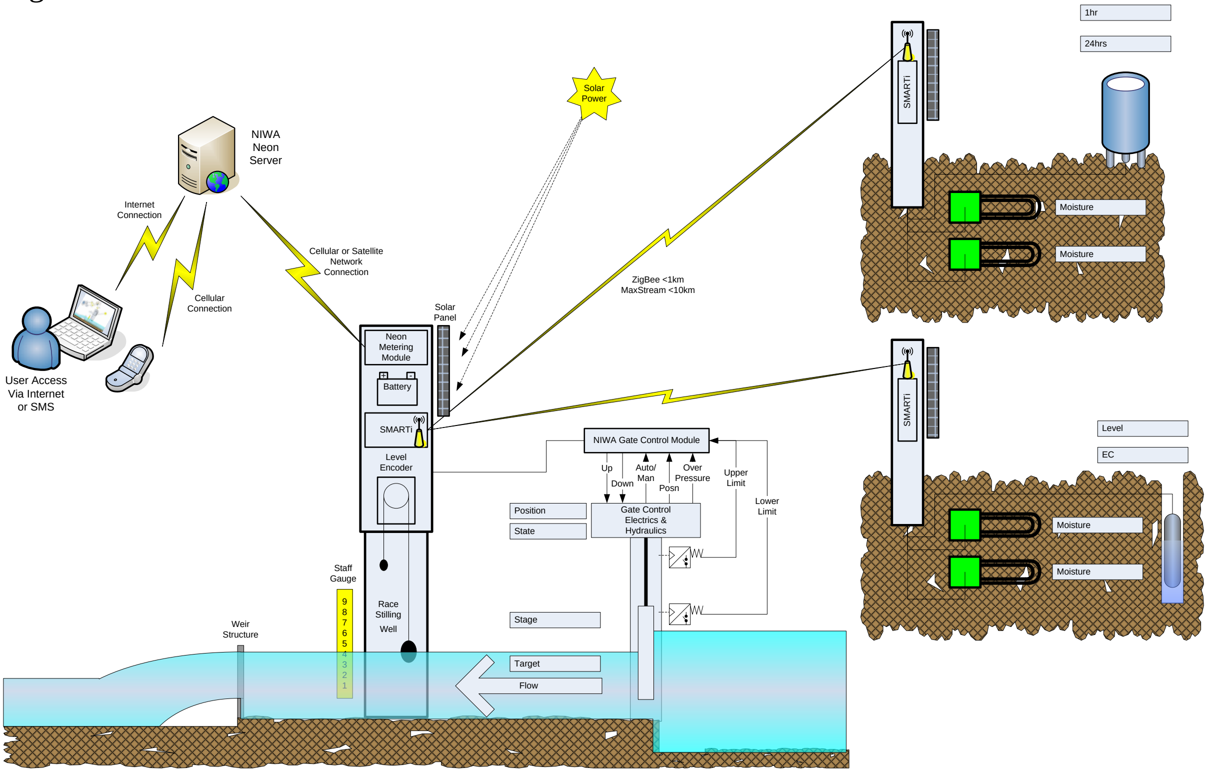

Figure 1: Schematic of site set up. Each site contains a weir, a remote controllable gate, logger and wireless connection to up to 4 separate soil moisture arrays.

Site selection process

The initial stage was to undertake a GIS assessment to define areas which may contain suitable sites using the appropriate soil and drainage criteria. Additional criteria were

Sites being within 50 km of Hamilton (for practical access reasons)

Dairy farms (where fertilizer use tends to be higher)

Non-organic soils (where retaining water would be problematic)

GIS data for area selection is shown in Figure 2.

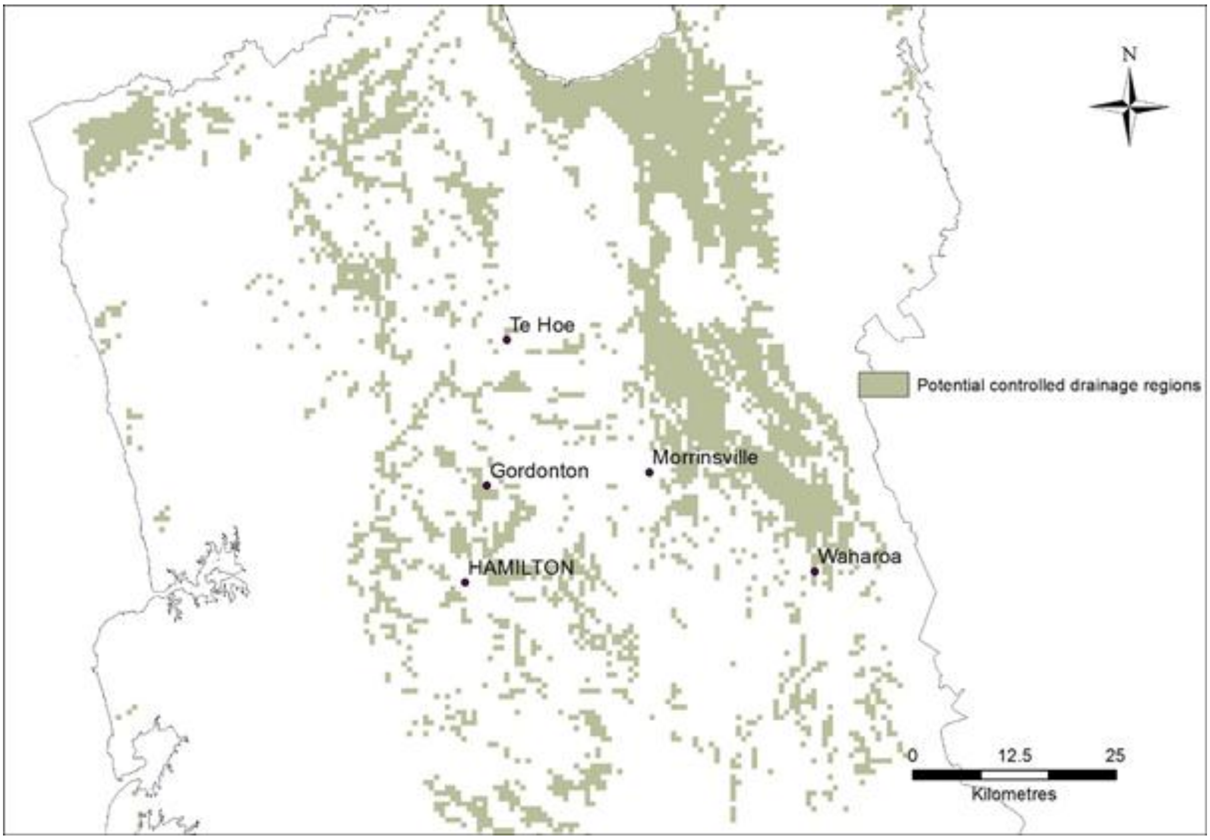

Figure 2: Potential controlled drainage areas as identified by GIS analysis. The coloured areas indicate those parts of the Waikato Region where non-organic soil types overlap with terrain that has a gradient of less than 1.5 degrees.

An additional requirement for scientific reasons was that any site had to have two near-identical sites to set up as paired monitoring sites, one with controlled drainage treatment added, and the other without controlled drainage.

Using the information in Figure 2, and with the practical assistance of an agricultural drainage engineer (Kevin Earle), two sites were eventually found after a difficult and time-consuming process.

The first site is on Claybrooke Farm, owned by Steve Allen, located at Tatuanui ~3 km east of Morrinsville (Figure 3). The second site was on a farm owned by Tony Hedley, which is located ~2.5 km east of Waharoa (Figure 3). Both farms are currently used for dairy grazing.

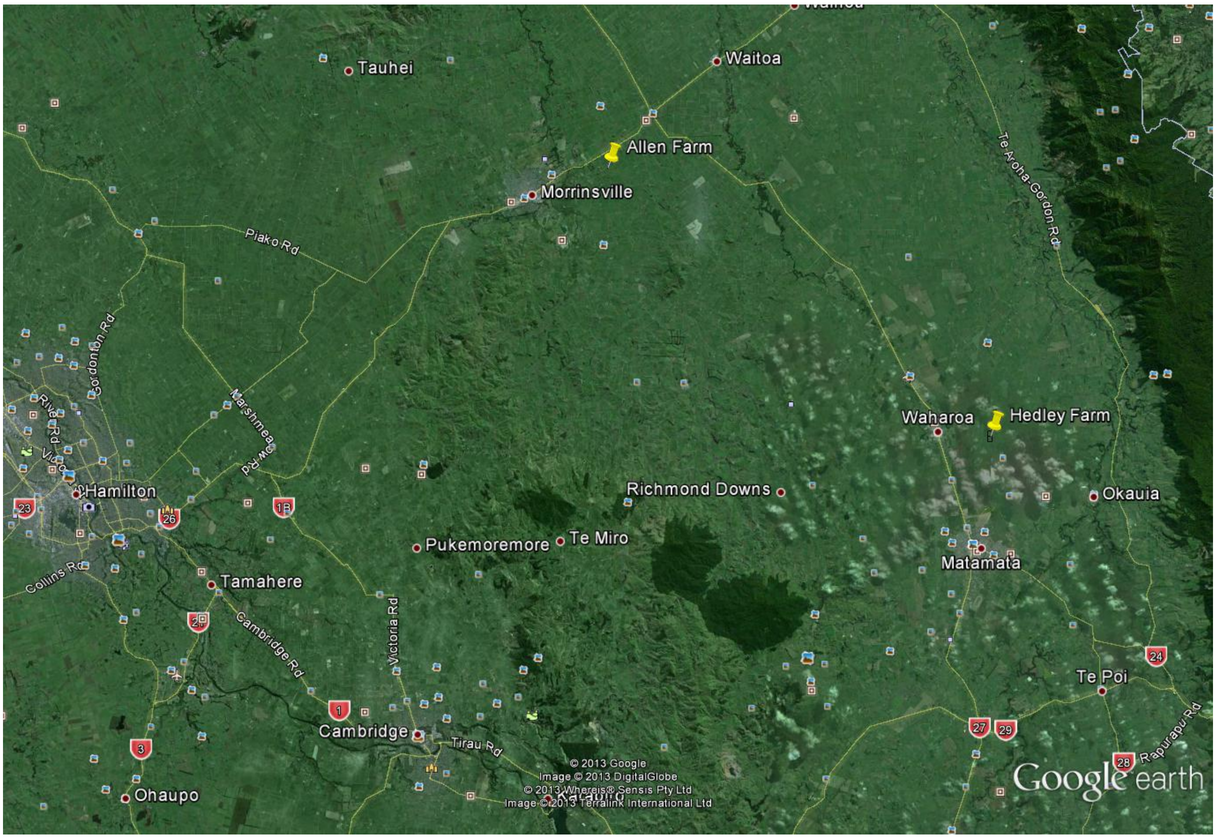

Figure 3: Controlled drainage experimental locations at Tatuanui and Waharoa.

Waharoa farm site

The experimental sites on the Waharoa farm are directly adjacent to each other and the subsurface drains from both areas drain into the same surface drain (Figure 4). The area of the upper flume catchment is 4.1 ha while the catchment area of the lower flume is 3.9 ha.

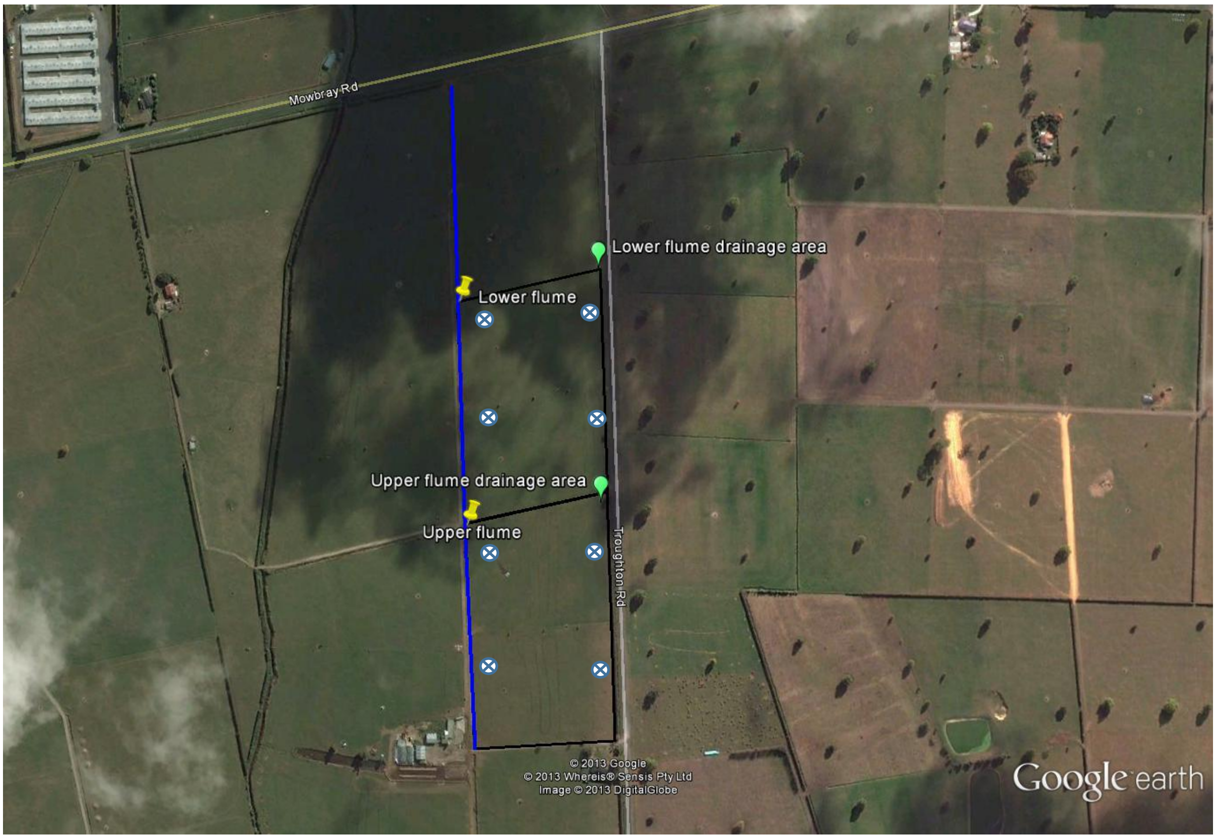

Figure 4: Flume locations and flume catchment boundaries on the Waharoa farm. The blue line indicates the position of the drain in which the experimental flumes are positioned. The drain flows in a northerly direction. Locations of soil moisture sensor pairs shown with ⊗ symbols.

Key challenges at each location was the low gradient. While necessary for successful application of controlled drainage technology, it placed considerable demands on weir design which requires sufficient fall to allow flow measurements. This meant each site presented unique challenges.

The lower site on the Waharoa farm was close to a culvert, so the flow had to be piped through the culver to a weir on the other side. Flow from further upstream had to be channelled past the weir (Figure 5- Figure 7).

Figure 5: Waharoa farm (lower site) drain water collection pipe connected to the 160 mm subsurface pipe. Water flows from out of the 160 mm subsurface pipe (which collects water from a series of 110 mm perforated subsurface drainage pipes). Because of the position of a culvert at this site water is piped to the flume box on the other side of the culvert.

Figure 6: Waharoa farm (lower site) flume box. Pipe inflow (directed under culvert) can be seen in the upper part of the flume box.

Figure 7: Waharoa farm (lower site) flume box and stilling well. Photograph was taken looking upstream.

The upper site at Waharoa was controlled at the point where it exited the subsurface drain (Figure 8).

Figure 8: Waharoa farm (upper site) subsurface drain water diversion setup. Photograph shows diversion of 160 mm subsurface drain into flume box. Wooden structure located on either side of the diversion pipe is the gate valve unit that controls level of groundwater in the experimental area.

Tatuanui farm site

As with the Waharoa farm, the experimental sites on the Tatuanui farm are directly adjacent to each other and the subsurface drains from both areas drain into the same surface drain (Figure 9). The area of the upper flume catchment is ≈ 4.3 ha while the catchment area of the lower flume is ≈ 3.8 ha.

Figure 9: Flume locations and flume catchment boundaries on the Tatuanui farm. The solid blue line indicates the position of the surface drain in which the experimental flumes are positions. The drain flows in a north-easterly direction. The dashed blue lines show the approximate position of the subsurface drains. Locations of soil moisture sensor pairs shown with ⊗ symbols.

Flow at the Tatuanui site is measured and controlled in the open drain. Low gradients required a unique flow controller which raised and lowered the outlet rather than shut it off using a gate valve.

Figure 10: Tatuanui farm (lower site) flume box. Note that the front of the flume box is open and the surface drain is blocked to allow all water from the surface drain to enter flume box.

Figure 11: Tatuanui farm (upper site) drain water intake pipe and flume box. Photograph is taken looking downstream.

Figure 12: Tatuanui farm (upper site) flume box and stilling wells. Photograph was taken looking upstream. All flow from the flume box discharges into a 150 mm pipe (black pipe) and is diverted past the lower flume site.

Other issues to be answered.

There are questions which will undoubtedly be asked by farmers, some of which will be difficult to answer, for example, at what depth should the water table be controlled, and how will water table management affect how we use the land? These are challenging questions as water table depth will differ for different soils, situations and climate types. Trafficability is an important consideration, and is essential for efficient production. Having a higher water table will perhaps mean wetter fields, and farmers may severely impair the production potential of their fields by trying to till the soil when it is too wet. Equally, wetter pastures might be less suitable for grazing animals, and may leave the soil even more vulnerable to pugging and compaction.

References

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