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DRAINAGE WATER QUALITY ON TWO WAIKATO PEAT DAIRY FARMS

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Abstract

Farm drains on two Waikato dairy farms located on peat (Organic) soils were monitored over two winter drainage seasons in 2016 and 2017. The purpose of this monitoring was to provide insight into the scale of contaminant losses (nutrients and faecal microorganisms) to surface water from farm paddocks on two peat soils of contrasting development status. Development status increases with increasing time under pastoral land use. The farm near Motumaoho had relatively well developed Kaipaki peat loam soils with a moderately high anion storage capacity (ASC) of 49%. The other farm, near Orini, had less developed Rukuhia peat soils and a low ASC of 19%. Soils with low ASC have limited ability to hold negatively charged ions in the soil and to prevent nutrients leaching beyond the root zone (typically to ground water). Well-developed peat soils have higher ASC than the less developed peats, and typically have characteristics more similar to mineral soils.

On each farm, a block of approximately 120 hectares was selected, where measurements were made of drain flow. Water samples were collected periodically for analysis of nitrogen (N), phosphorus (P) and *E.coli* concentrations. At the Orini farm, measurements were also made of depth to groundwater and water samples were analysed for N and P concentrations.

Results of water quality testing are presented with comparisons to regional council guidelines for water quality for E. coli, total phosphorus (TP), ammonium N (NH_4-N) and total inorganic nitrogen (TIN).

Using drain flow and contaminant concentration data, estimates of the amount of nutrients removed in the drains in each of the two seasons was calculated.

Cumulative TP loadings (kg P/ha/year) in drains at the less developed site were on average over 10 times those at the well-developed site. Cumulative TIN loadings (kg N/ha/year) in drains at the well-developed site were on average about five times higher than those at the less developed site.

We hypothesise that the large differences in cumulative TP and TIN loadings in drainage water between the two sites are attributable to the respective soil ASC and C:N ratios.

Introduction

There are around 94,000 ha of Organic, or peat soils in the Waikato (O’Connor *et al.*, 2001), 80% have been developed and are under intensive agriculture. Dairy farming is the predominant intensive land use on Organic soils and the Waikato region contains one of the largest areas of Organic soils under dairy farming. In general, Waikato has warm, humid summers and mild winters. While rainfall is, on average, well spread through the year, soils are typically wet through the winter months due to low evapotranspiration rates and a somewhat higher average monthly rainfall. Pasture consists mainly of perennial ryegrass

(*Lolium perenne L.*) with some white clover (*Trifolium repens L.*) and large areas of maize are also grown, mostly for on-farm silage feed.

Farming the peatlands has been made possible by district drainage schemes. Large drains, built and maintained by local drainage boards and the Waikato Regional Council, take drainage water away to local rivers. Property owners drain their farm land through a network of open drains which empty into the board drains.

When peatland is developed for agricultural use, the draining of Organic soils causes a major disruption to the hydrology of the soil (Holden *et al.* 2006). It changes the aerobic state of the soils which leads to organic matter losses and subsidence or "peat shrinkage". In Waikato, average subsidence rates have been measured as 3.4 cm/year (Schipper 2002).

The properties of peat soils (e.g. carbon content, pH, bulk density and water holding capacity) change with development from raw to consolidated forms. Time since development (or development status) has been found to influence the rate of phosphorus (P) loss (Simmonds *et al.* 2015) and rate of subsidence (Pronger *et al.* 2014). Anion storage capacity (ASC) values have previously been used as an indication of development phase, (O'Connor *et al*., 2001). ASC is highly influenced by the amount of mineral soil contained within the peat. Peat soils formed near the edge of a peat bog have a higher mineral content than those formed in the middle of a peat dome. Well-developed peat soils have higher ASC than the less developed peats, and can be said to have characteristics more similar to mineral soils. Soils with a low ASC have limited ability to hold negatively charged ions (nutrients) in the soil and prevent leaching to ground water.

The purpose of this monitoring work was to provide insight into the scale of nutrient losses and faecal coliform contamination from farm paddocks on two different peat soils, and to test the following hypotheses:

1. Nitrogen (N) losses are lower from farmed peat soils than from mineral soils as a result of denitrification occurring in the saturated soil horizons, therefore the less developed peat will have lower N losses than the well-developed peat.
2. Phosphorus (P) losses are greater on peat soils than mineral soils due to the lower anion storage capacity (ASC) and low pH of peats. Less developed peat will have higher P losses than the well-developed peat.
3. *E.coli* losses are relatively high from farmed peat soils due to the high groundwater level and movement of water from the soil surface to drains. However, the influence of peat type on concentrations of *E. coli* may be outweighed by other factors such as weather events, local environment and management factors.

Methods

Location

This study took place on two separate farms north of Hamilton, New Zealand. The farm near Motumaoho has relatively well developed Kaipaki peat loam soils which drain into the Piako River. The other farm, near Orini, has less developed Rukuhia peat soils which drain into the Mangawara River. Selection of monitoring sites was based on assesments of peat soil characteristics and suitability to consistently measure flow volume and collect water samples.

Site details

On each farm a block of approximately 120 hectares (ha) was selected with a single main exit drain for the area. Within the large block, two small side drains were selected, which drain a small area (c.a. 2 ha), one area within the farm effluent irrigation area, and the other outside. Drain monitoring sites were set up at the lower end each drain. In the case of the Orini monitoring paddock (OMP) and effluent paddock (OEP) drains the monitoring sites were at farm culverts, which provided the opportunity to directly measure drain flow. At the Motumaoho farm the monitoring paddock (MMP) and effluent paddock (MEP) drains have very little fall, making measuring water flow more difficult due to drains backing up, and flow often being affected by wind direction. Continuous drain water level height measurements were made at OWF and MWF with Odyssey pressure transducer loggers, and in other drains Odyssey capacitance loggers.

Table 1. Monitoring site characteristics. ASC and Olsen P are from soil tests 0-75 mm depth taken in spring 2016.

Monitoring site	Abbreviation	Area (ha)	ASC	Olsen P
Orini whole farm	OWF	125	19	24
Orini monitor paddock	OMP	2.1	---	---
Orini effluent paddock	OEP	1.7	---	---
Motumaoho whole farm	MWF	120	49	61
Motumaoho monitor paddock	MMP	2.1	---	---
Motumaoho effluent paddock	MEP	2.6	---	---

On the Orini farm, a site was established for measurements of groundwater height and quality. The measurement site (Figure 1), near the OMP monitoring drain, was instrumented with a total of four groundwater sampling "nests"; each with a dipwell with an Odyssey capacitance logger for measuring water table height and 6 teflon cup samplers to sample ground water at two different depths (35 and 50 cm). Nests were 10 and 20 m from the side drain and at least 50 m from the main drain. Leachate samples were collected from the Teflon cup samplers for laboratory analysis.

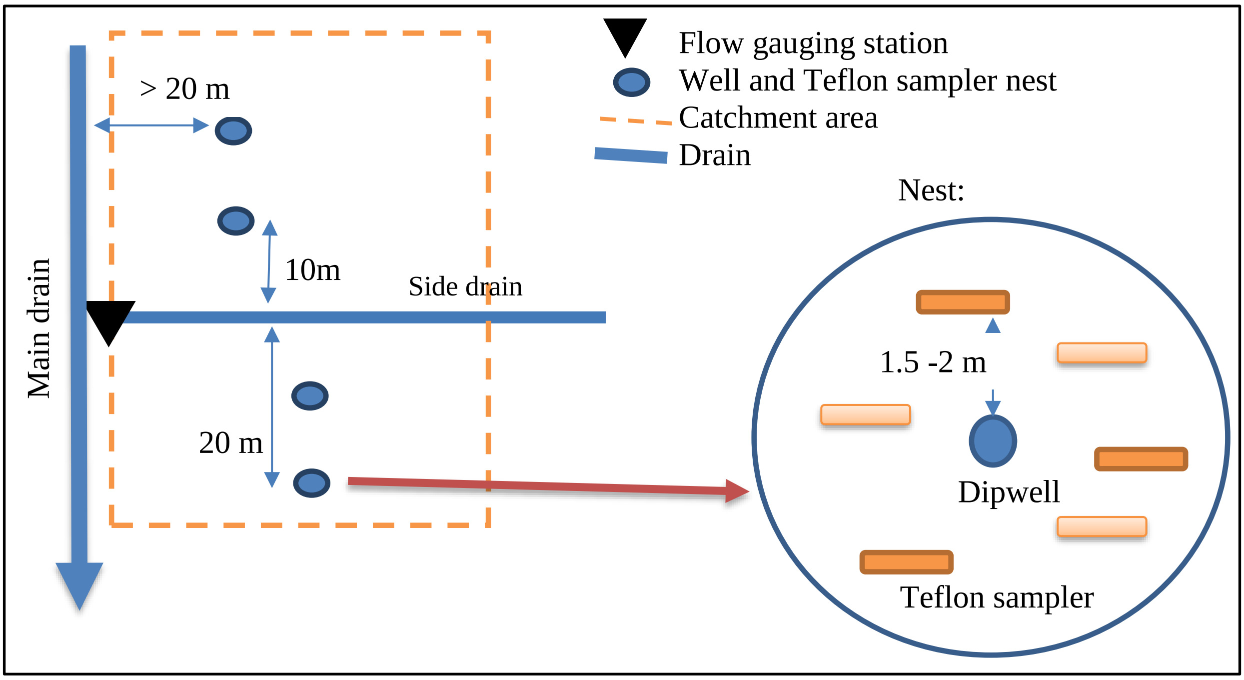

Figure 1. Diagram of the drain and in-paddock instrumentation of the Orini monitor paddock

At the end of the 2016 drainage season the monitoring paddock was sprayed out and cultivated for a maize crop. For 2017 an alternative nearby site was selected. Groundwater level was monitored, but ceramic cups were not installed and no groundwater samples were collected or analysed.

Measurements

Monitoring commenced on 2 August 2016. The drainage season had begun in early June, thus results presented are for only a part of the drainage season. Drain monitoring stopped for the year on 11 November when there was no longer a measurable flow in the drains. The total measurement period was 99 days.

In 2017 monitoring started on 19 April. There had been heavy autumn rains and flow in the drains was logged in mid-March and early April, but monitoring could not begin until after the farms had removed seasonal dams from drains in mid-April. Measurements ceased on 26 October when the drains had stopped flowing. The total measurement period was 191 days.

For clarity, the drainage season will be defined for this paper as between 1 April and 31 October. Although in some years water flows in the drains outside of this time, these dates represent periods that drain flow would normally be expected. Monitoring in 2016 thus represents approximately a half a drainage season.

Table 2. Measurements collected during the two years of monitoring.

Drain flow measurement • Water level height measurements with Odyssey loggers (pressure transducers) at main drains • Calibration measurements (water level height and flow rates) measured at logger sites • Cross area transects of drains • Timed flow into bucket on small drains at OMP and OEP • Estimates of drain flow at MMP and MEP • Measurement of drain catchment area • Calculations of drain flow rates
Drain water quality sampling • Analysis of water samples for: *E. coli,* dissolved reactive phosphate (DRP), particulate phosphate (TPP), dissolved organic phosphate (DOP), total phosphorus (TP), nitrate+nitrite nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), total inorganic nitrogen (TIN)
Groundwater measurement- Orini farm only • Groundwater (water table) height measurement with Odyssey loggers (capacitance) at four sites near the non-effluent side drain • Manual measurement of water height • Groundwater sampled with six Teflon cup samplers at each logger site, at two depths in year one only • Analysis of groundwater samples for DRP, TPP, TP, NO_3-N, NH_4-N, TIN • Manual soil moisture measurement by soil coring to 90 cm

Results and discussion

Drain flow

The beginning of the 2016 drainage season was dry, but with normal rainfall over the winter and spring. Accumulated rainfall during the drainage season was 751 mm. The 2017 drainage season began having followed earlier wet conditions from heavy rain in February and March. Accumulated rainfall during the drainage season was 979 mm.

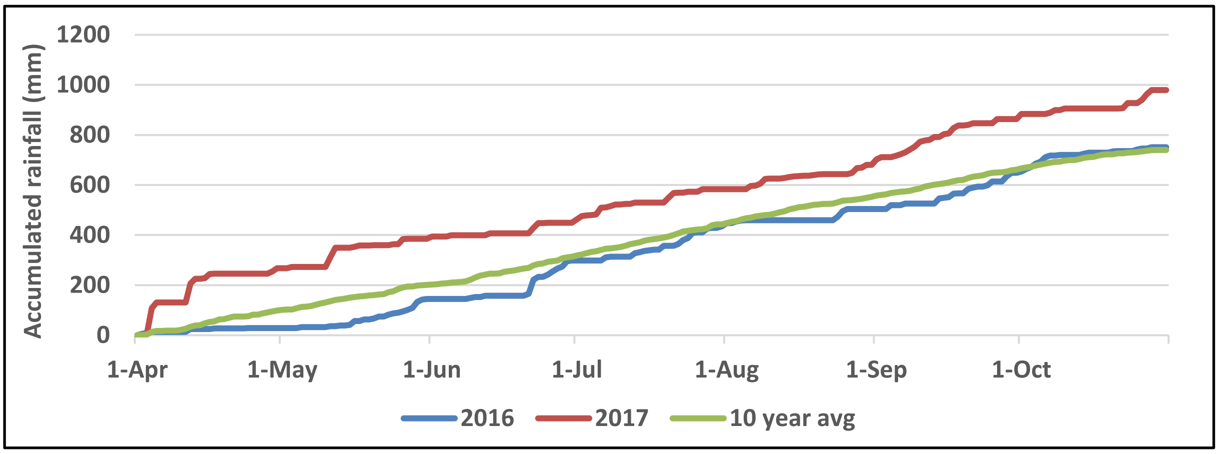

Figure 2. Accumulated rainfall during the two drainage seasons as derived from NIWA Virtual Climate Station data at a site located midway between the two farms.

Difficulty in the measurement of drain flow, and size of catchment area are possible sources of error in calculating drainage figures. In the very flat landscapes of the peat paddocks it is very difficult to know in which direction surface water flow will move. Movement of sub-surface water flow into drains is also difficult to predict.

Calculated drainage figures for the farm drains are shown in Table 3. Results for 2016 for the OMP, OEP, MMP and MEP are not shown as there were not enough flow measurements in 2016 in the appropriate range to reliably estimate drain flow. Average daily drain flows and cumulative drainage for the 2016 and 2017 seasons are shown in Table 3. Due to difficulty in measuring drain flows at the MMP and MEP sites, the flow data for these sites are an estimate based on periodic manual flow measurements and a linear regression with flow measurements from the MWF site.

There is a large difference between the cumulative whole farm drainage volumes between OWF and MWF. This may be a result of local weather, differences in soil type, or in drainage infrastructure between the two farms. Monitoring in 2016 represents approximately a half season of monitoring, in time and water volume as measurements did not commence until 2nd of August. This is reflected in lower cumulative drainage values of 1573 and 4536 m^3/ha/year for 2016 compared with 5358 and 9733 m^3/ha/year for 2017 for the OWF and MWF sites, respectively.

Table 3. Calculated drainage figures for monitoring sites.

Year	Calculated drainage figures	OWF	OMP	OEP	MWF	MMP	MEP
2016	Average drainage (m^3/day)	1987	---	---	5495	---	---
99 days	Cumulative drainage (m^3/ha/year)	1573	---	---	4536	---	---
2017	Average drainage (m3/day)	3507	30	9	6115	29	42
191 days	Cumulative drainage (m^3/ha/year)	5358	2657	1039	9733	2672	3112

Water quality in relation to regional council guidelines

Results of water quality testing for *E. coli*, TP, NH4 and TIN are compared to Waikato Regional Council (WRC) guidelines and standards for water quality as shown in Table 4 below.

Table 4. Comparison of water quality measurements with Waikato Regional Council guidelines.

E.coli (no./100 ml)	Excellent < 55			Satisfactory < 550			Unsatisfactory ≥ 550			
	2016				2017					
Name	16-Jul	26-Aug	29-Sep	17-Oct	12-Jun	27-Jun	24-Jul	11-Aug	8-Sep	26-Oct
OWF		4898	2884	47	33	20	350	170	180	410
OMP		30200	52	<2	<2	10	<2	7	30	<1
OEP		49	115	27542	8	160	240	5	1400	110
MWF		6457	61660	490	5	2	79	1700	390	240
MMP		17	195	3	5	10	140	33	270	29
MEP		209	1318	10	<2	10	33	780	700	50
TP (g/m^3)	Excellent < 0.01			Satisfactory < 0.04			Unsatisfactory ≥ 0.04			
	2016				2017					
Name	16-Jul	26-Aug	29-Sep	17-Oct	12-Jun	27-Jun	24-Jul	11-Aug	8-Sep	26-Oct
OWF	8.69	8.59	8.59	8.50	8.47	8.26	8.83	9.16	8.85	7.98
OMP	10.00	9.05	8.74	9.80	8.61	8.60	8.15	10.15	7.53	7.87
OEP		13.69	13.64	11.66	10.43	10.30	9.53	8.45	10.33	10.13
MWF	0.04	0.09	0.17	0.07	0.17	0.17	0.32	0.35	0.37	0.30
MMP		0.08	0.05	0.04	0.12	0.33	0.27	0.14	0.29	0.16
MEP		0.09	0.03	0.05	0.05	0.15	0.12	0.17	0.24	0.11
NH_4-N (g/m^3)	Excellent < 0.1			Satisfactory < 0.88			Unsatisfactory ≥ 0.88			
	2016				2017					
Name	16-Jul	26-Aug	29-Sep	17-Oct	12-Jun	27-Jun	24-Jul	11-Aug	8-Sep	26-Oct
OWF	0.42	0.19	0.20	0.18	0.67	0.48	0.47	0.70	0.56	0.14
OMP	0.00	0.00	0.01	0.07	0.66	0.58	0.48	0.14	0.22	0.46
OEP		0.01	0.01	0.09	0.41	0.43	0.22	0.83	1.13	0.37
MWF	0.85	0.17	0.30	0.82	1.52	1.20	0.62	0.78	0.72	1.37
MMP		0.00	0.12	0.11	0.67	0.57	0.23	0.35	0.24	0.48
MEP		0.13	0.04	0.08	0.01	0.61	0.42	0.42	0.03	0.32
TN (gN/m^3)	Excellent < 0.1			Satisfactory < 0.5			Unsatisfactory ≥ 0.5			
	2016				2017					
Name	16-Jul	26-Aug	29-Sep	17-Oct	12-Jun	27-Jun	24-Jul	11-Aug	8-Sep	26-Oct
OWF	0.90	1.19	0.40	0.27	0.75	1.32	1.79	1.05	1.03	0.31
OMP	0.09	0.16	0.05	0.07	0.60	0.55	0.47	0.84	0.35	0.60
OEP		0.53	0.25	0.11	0.46	0.57	0.31	0.18	1.24	0.56
MWF	2.05	3.40	1.29	0.91	1.75	1.75	1.92	2.53	1.15	1.70
MMP		2.35	0.44	0.12	0.68	0.59	0.46	1.06	0.66	0.63
MEP		4.41	0.96	0.15	-0.03	0.86	1.39	1.80	0.27	0.50

E. coli results show no clear differences between the two farms. There are "spikes" with high levels of *E. coli* on both farms, but in 78% of samples taken for both farms over both seasons *E. coli* levels were excellent or satisfactory according to the WRC guidelines. Levels of *E. coli* are often affected by factors such as time of sampling in relation to heavy rainfall events, the presence and location of cows grazing in the drain catchments, the level of sunlight which affects *E. coli* survival, and presence of waterfowl in the drain.

On both farms the monitor paddock drains (OMP and MMP), which are outside of effluent irrigation areas, had *E. coli* levels within the excellent or satisfactory range with just one exception. The effluent paddock drains (OEP and MEP) and the whole farm drains (OWF and MWF) had *E.coli* numbers in the unsatisfactory range during 28% of the sampling occurrences. At both sites the whole farm drains have long stretches of frequently used farm races along their lengths, after heavy rainfall these may be a source of contamination, although the drains are fenced and have grass buffer zones.

Results for TP concentrations in samples exceeded the WRC guidelines in 97% of samples taken. Concentrations of TP in the Orini samples are on average over 100 times higher than the Motumaoho samples. This is likely a result of the very low ASC of the less developed peat soil. NH_4-N concentrations were excellent or satisfactory according to the Waikato Regional Council standards and guidelines in 93% of samples taken. Both whole farm drains OWF and MWF tended to have higher levels of NH_4-N than the smaller drains.

Results for TIN were unsatisfactory according to the Waikato Regional Council standards and guidelines in 68% of samples collected. The average TIN concentration of samples at the Motumaoho site was 1.5 times higher than at the Orini site.

Nutrient loadings in drain discharge

Using drain flow data and the analysis of water sample concentrations, estimates of the nutrients removed in the drains for each of the two seasons were calculated.

Cumulative TIN loadings (kg N/ha/year) in drains at the Motumaoho site are on average about five times higher than those at the Orini site (Figure 3). This is due to both higher TIN concentrations and higher drainage flows at Motumaoho. In 2016 NO_3-N was the predominant form of N, whereas in 2017 NH_4-N was the predominant form. This may be due to the early onset of very wet soil conditions in autumn 2017.

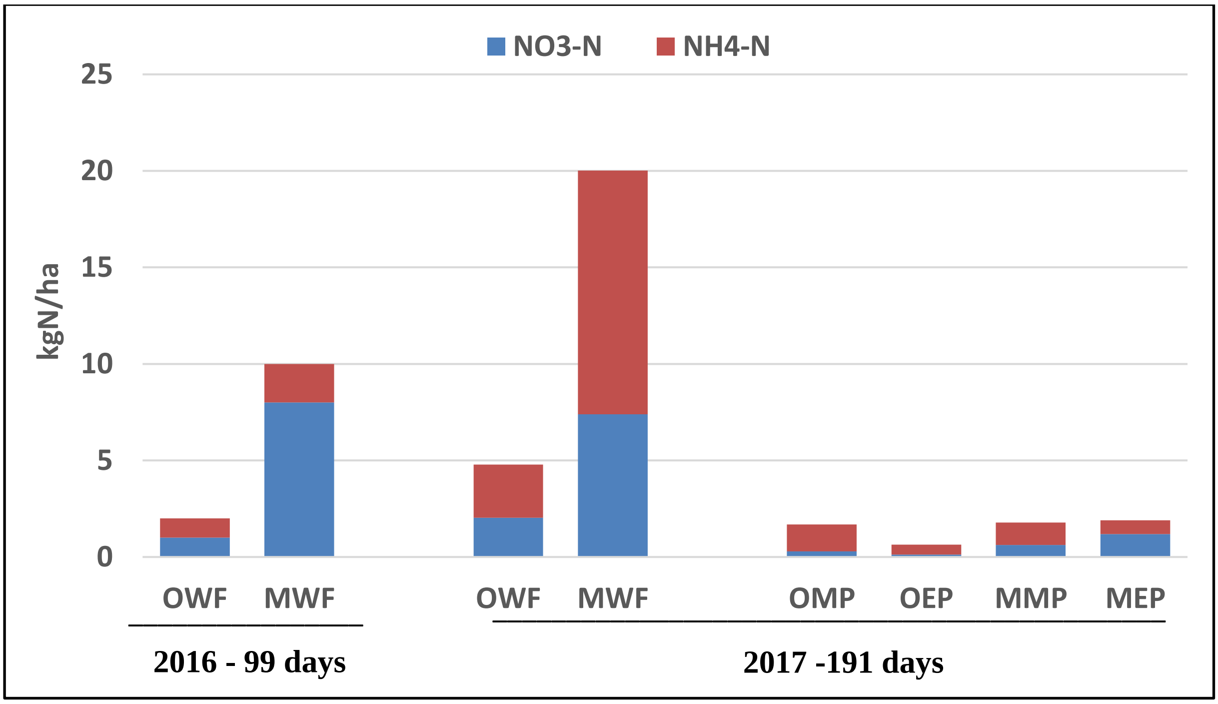

Figure 3. Cumulative NO_3-N and NH_4-N loadings measured in drains.

Cumulative TP loadings (kg P/ha/year) in drains at the Orini site are on average over ten times those of the drains at the Motumaoho site (Figure 4). The larger drains tended to have higher TP loadings due to higher flows. DRP accounted for 84% of the P forms measured in all drains.

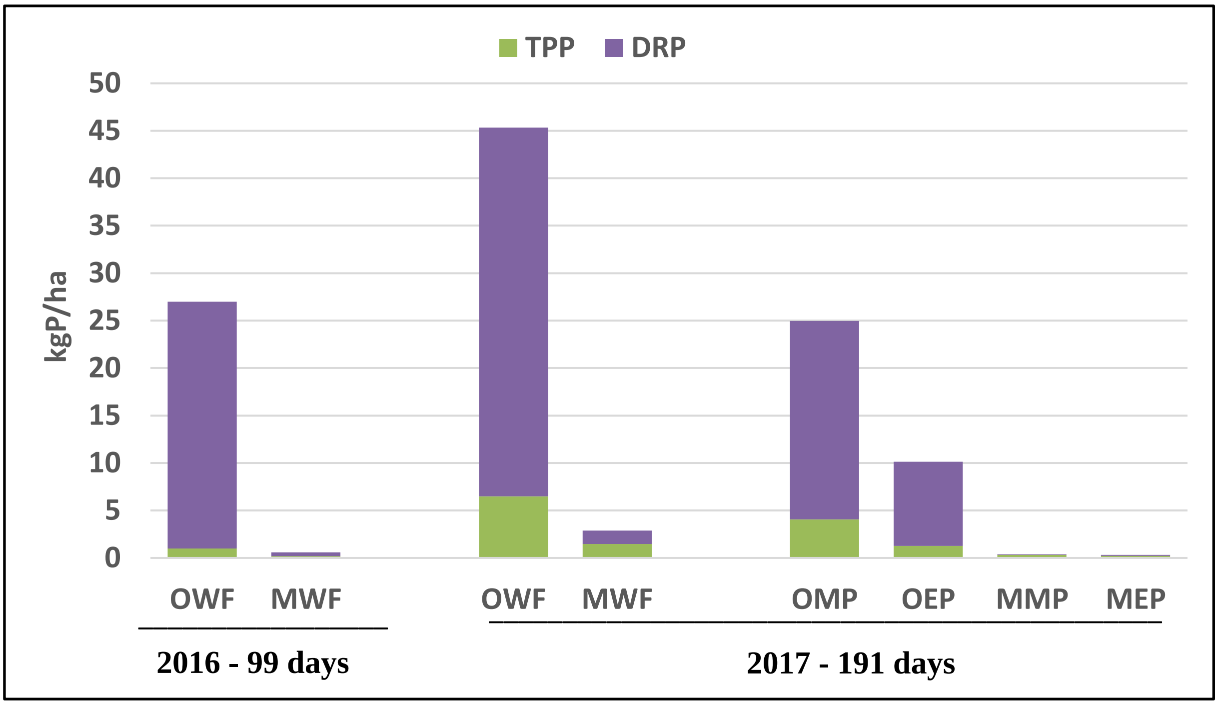

Figure 4. Cumulative TPP and DRP loadings in drains.

Groundwater

Results of groundwater level monitoring are shown in Figures 5 and 6. There was a change in site to nearby paddocks after the 2016 year.

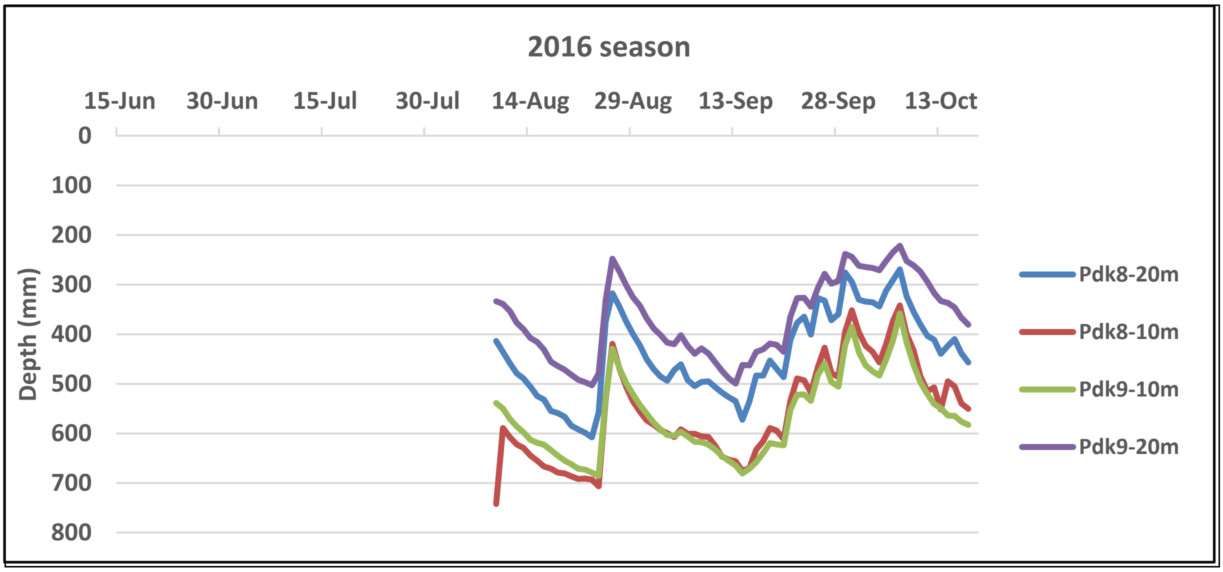

Figure 5. Depth to groundwater from soil surface at two distances (10m and 20m) from the OMP drain, in the 2016 drainage season.

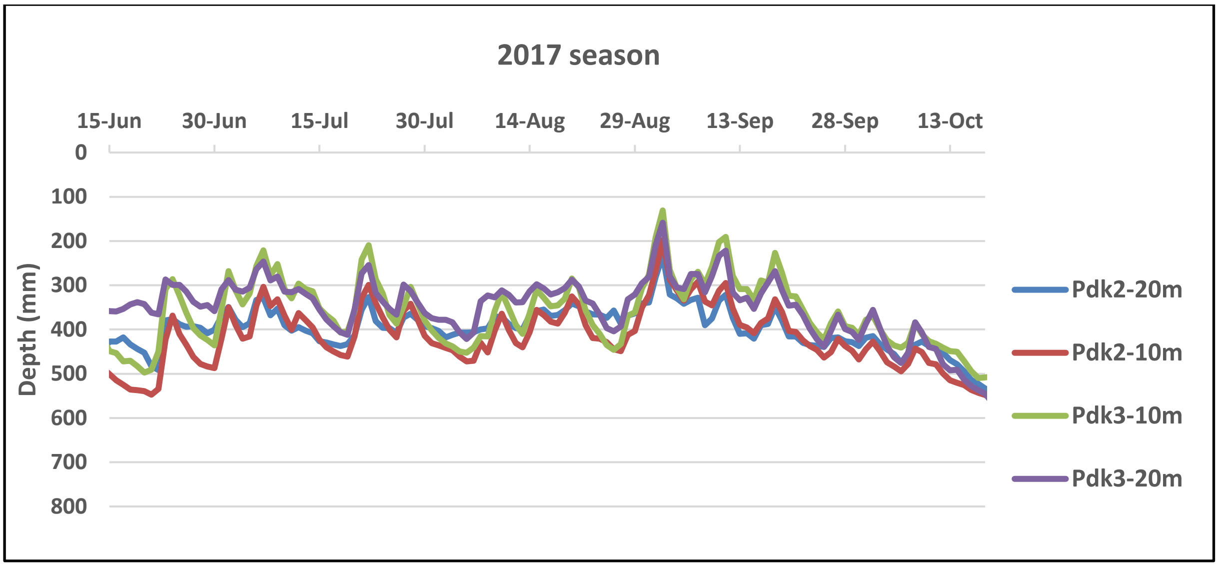

Figure 6. Depth to groundwater from soil surface at two distances (10m and 20m) from the OMP drain, in the 2017 drainage season.

Depth to groundwater depth in drained conditions (e.g. spring) average approximately 600 mm below the soil surface, however during the wet periods ground water depth averages approximately 300mm. Depth to groundwater decreases as the distance from the nearest drain increases reflecting the decreasing influence of the drainage networks on soil water transmission.

TIN concentrations measured in the groundwater during 2016 (Figure 6) were greatest at 35 cm sampling depth / 10 m distance to the drain. At all measurements points, N concentrations were lower at 50 cm when compared with 35 cm depth sampling points. Concentrations were also generally higher the further the sampling point was from the central drain. NH_4-N concentrations were greater than NO_3-N, except at 35 cm depth / 10 m distance to the drain. This suggests that at the better drained locations (shallow depth and near the drain) there is a more aerobic environment which promotes nitrification of NH_4-N to NO_3-N.

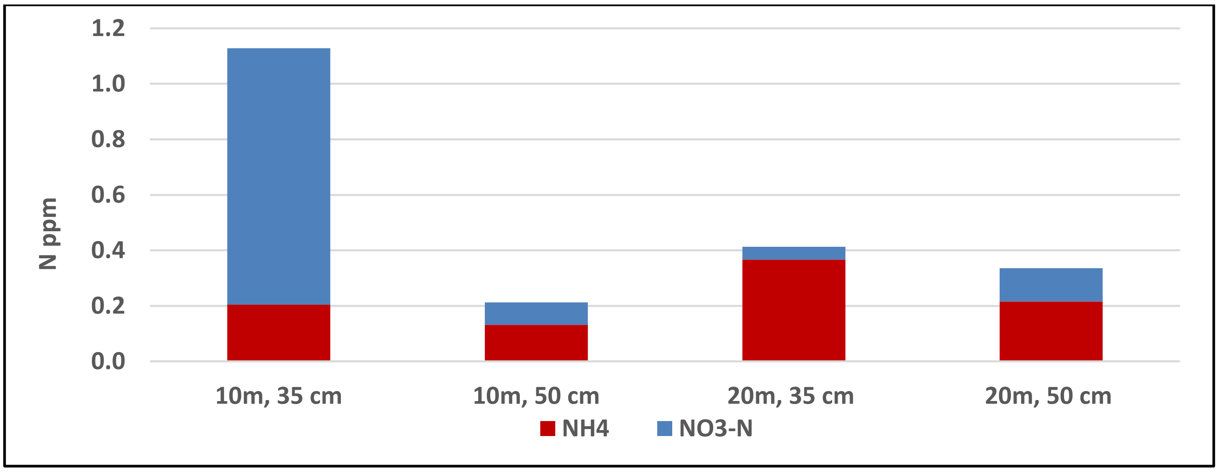

Figure 7. Average concentrations of NH_4-N and NO_3-N in groundwater at two depths (35cm and 50 cm) and two distances from the OMP drain (10m and 20 m).

TP concentrations measured in the groundwater were very high (Figure 7), especially at 35 cm depth with 10 m distance to the drain, which could be a result of fluctuations in water table height accentuated by the proximity to the drain. Further from the drain there appeared to be little difference associated with groundwater depth.

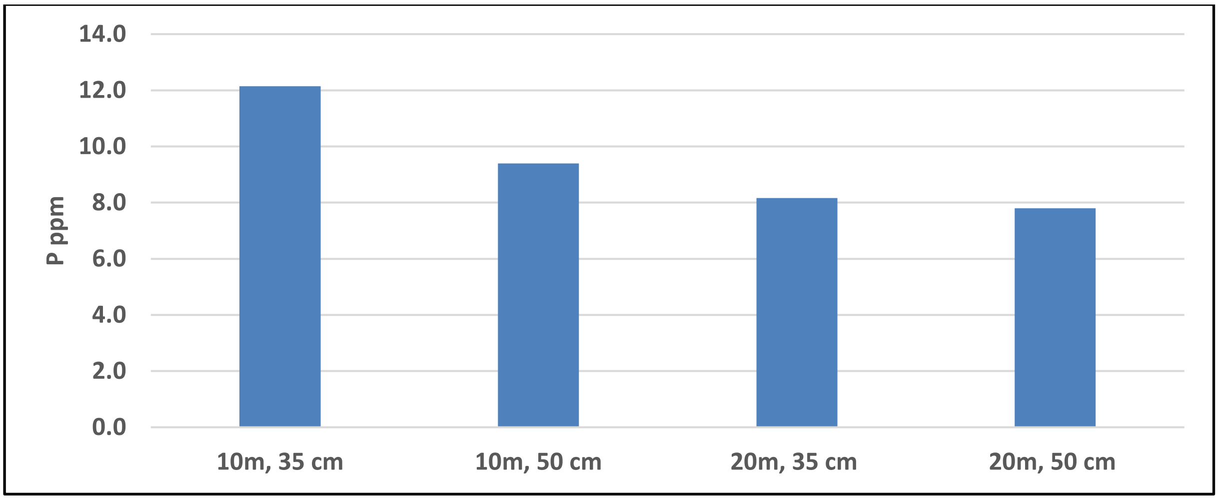

Figure 8. Average concentrations of TP in groundwater at two depths (35cm and 50 cm) and two distances from the OMP drain (10m and 20 m).

The concentrations of TIN and TP from groundwater in the monitor paddock are very similar to those measured at the OMP drain monitoring site, suggesting a very strong relationship between groundwater and drain water in this environment.

Conclusions and recommendations

Cumulative TIN losses measured from drains on the less developed peat are relatively low, at less than 5 kg N/yr. In comparison the well-developed peat had losses of approximately 20 kg TIN/ha/yr. This is in a similar range to average TIN losses on farms with mineral soils (Wilcock *et al.*, 2007). On both soil types the concentration of TIN in the drainage water was considered 'unsatisfactory' compared to regional council standards in 68% of samples taken. This suggests that even with relatively low TIN losses from land, water quality in the farm drains does not meet environmental standards much of the time.

Cumulative TP losses measured from drains on the less developed peat are very high, up to 46 kg P/ha/yr. P losses of less than 1 kg P/ha/year are considered normal for dairy farms with mineral soils, and up to 3 kg P/ha/year on heavy soils with artificial drainage (Roberts and Morton, 2009). The well-developed peat soil had TP losses similar to the high range for mineral soils. Soil ASC is likely the major factor in this wide range of P losses (Rajendram *et al.*, 2012). Losses of 87 kg P/ha/year have been reported on newly developed peat soils with very low ASC in Southland (McDowell, 2015). Best management practices to minimize P losses to water (McDowell *et al.*, 2008) include:

- Apply P fertiliser at rates to keep within the target Olsen P range
- Minimize soil disturbance near drains
- Do not apply fertiliser within 10 metres of drains
- Use of a less soluble P fertiliser source
- Fence off drains with a buffer strip of vegetation

However, it is doubtful, that on soils with a very low ASC, these strategies will successfully mitigate these losses to an environmentally acceptable level due to the inability of the soil to retain P and due to the direct connection between soil solution concentrations and surface water bodies.

E. coli levels in the drains are highly variable, with no discernible differences between the two farms on different soil types. Higher *E. coli* levels in the larger whole farm drains could be influenced by movement of animals along farm races or culvert crossings near the drains.

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