INFLUENCE OF LIVESTOCK GRAZING ON WETLAND ATTENUATION OF DIFFUSE POLLUTANTS IN AGRICULTURAL CATCHMENTS

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Abstract

Pastoral seepage wetlands are common features in the hilly and undulating parts of New Zealand. The potential of these wetlands to attenuate upslope derived pollutants is starting to be recognised, however, there have been few attempts to quantify their effectiveness. In many cases, cattle have unrestricted access to these wetlands and are attracted to the water and forage material available within wetlands. Livestock access can adversely affect wetland biodiversity, reduce vegetation biomass, change plant composition, and deposit faeces and urine directly into water. Extensive stock trampling can also entrain wetland material, resulting in increased fluxes of sediment and organic material entering streams.

The aims of this study were to: i) quantify the efficiency of a pastoral wetland at attenuating pollutants (e.g., TSS, *E. coli*, N and P), and ii) measure the water quality effects of unrestricted cattle grazing within the wetland. Wetland flow was recorded at the wetland outlet and near the top, directly downstream of a spring area. Water quality samples were obtained from both sites during baseflow and storm flow conditions. Results indicate that the concentrations of all analytes are lower at the lower weir than the upper weir, regardless of flow conditions or season. Flow monitoring, however, indicates that only a small amount of flow enters through the upper weir and suburface pathways probably dominate the flow exiting the lower weir. Limited water quality analysis suggest highly spatially variable concentrations of N and P entering in the groundwaer. Further analysis of groundwater is required to determine the significance of these pathways. Despite this, sampling to date has given us confidence that the wetland is very efficient at denitrifying NO_3-N entering in subsurface flow.

Data obtained from time-lapse cameras indicate that cows do not spend much time grazing within the wetland. Limited cattle entry into the wetland may be due to cattle being wary of becoming entrapped due to wetland substrate depth. This is exaccerbated by the steep terrain adjacent to much of the wetland which makes both entry and exit difficult. Despite the limited grazing, fluxes of cattle derived pollutants and damage to wetland margins and vegetation have been detected.

Introduction

Pastoral seepage wetlands are a relatively common feature in the hilly and undulating parts of New Zealand. These wetlands, which are also known as seeps, flushes, valley bottom or riparian wetlands, generally occur within the headwater areas of catchments and along the sides of streams. They are primarily fed by shallow subsurface flow that re-emerges via springs or seeps and their water content status may range between temporary dryness and permanent saturation. Pastoral wetlands are often small (< 1 hectare) and consequently they are rarely identified in regional wetland inventories or managed any differently from surrounding pasture (Merot et al., 2006; Ausseil et al., 2011). Although they are individually small, they may represent a large proportion of headwater catchments and as they occur at the land-water interface they have the potential to attenuate contaminants in the processes of being transported into waterways

Wetlands can provide suitable conditions for deposition of all particulates and associated contaminants. Perhaps of most importance is the capacity of wetlands to process nitrogen. The dominant nitrogen processes are:

- denitrification of nitrate by organic, anaerobic soils
- uptake of ammonium and nitrate by aquatic plants
- settling of particulates
- adsorption of fine particulates onto the surfaces of plants and detritus
- mineralisation of particulate organics to release ammonium and nitrate.

Nitrogen can be lost from wetlands as inorganic N (mineral N, nitrate N, nitrite N, ammonium N) or organic N (particulate OrgN, dissolved OrgN), and the relative losses of each form will vary under baseflow, stormflow, and disturbed conditions. Short- and longer-term studies suggest that nitrate removal by pastoral wetlands under baseflow conditions can exceed 75% (Cooper, 1990; Downes et al., 1997; Rutherford and Nguyen, 2004). Lower removal rates are expected during events or when channels occur in the wetlands, resulting in larger proportions of flow and nutrients bypassing the wetland substrate material (Burns and Nguyen, 2002; Nguyen et al., 1999). Nguyen et al., (1999) found that while small wetlands can be sediment sinks during low flows, fine sediment and particulate organics can be remobilised during storm events.

Although the potential of these wetlands to attenuate upslope derived pollutants is well appreciated (Merot et al., 2006), there have been few attempts to quantify their effectiveness (e.g., Rutherford and Nguyen, 2004). Furthermore, in many cases, livestock have unrestricted access to these wetlands in pastoral areas, and as has been found with streams and riparian zones (e.g., Collins and Rutherford, 2004; Smith et al., 1992; Trimble and Mendel, 1995) cattle are attracted to the water and forage material available within wetlands. Collins, (2004) used faecal pat numbers to confirm that cattle freely graze shallower wetlands (~30 cm deep) but, probably due to the fear of entrapment, largely remain around the margins of deeper wetlands (~1 m deep). Livestock access can adversely affect wetland biodiversity, reduce vegetation biomass, change plant composition, and deposit faeces and urine directly into water (Steven and Lowrance, 2011). Extensive stock trampling can also entrain wetland material, resulting in increased fluxes of sediment and organic material entering streams. While the impacts of livestock (e.g., sheep, cattle, and deer) grazing on riparian zones, streams, and water quality have been widely investigated, most wetland research has had an ecological, rather than physical, focus (e.g., Jansen and Healey, 2003; Menard et al., 2002). The few studies that have examined the physical impact of stock access to wetlands indicate that it may be a significant issue. McKergow et al., (2012) detected cattle-induced increases in nitrogen and turbidity at the outlet of a pastoral wetland near Lake Taupo, and although cattle only spent 10% of a year in the wetland paddock they were directly responsible for 30% of the total nitrogen export (mostly as organic N). Collins, (2004), also found that unrestricted stock access to a small, shallow wetland in Waikato hill-country contributed to high levels of faecal bacteria.

Pastoral wetlands are numerous on many New Zealand farms and they have been widely viewed by farmers as suitable areas for grazing. This is particularly the case of shallow wetlands where there is no risk of animal entrapment. Farmers require more guidance on the value of wetlands for attenuating contaminants and the potential of unrestricted wetland grazing to compromise their functioning. For deeper wetlands, excluding stock from wetlands would also benefit farmers with less time spent retrieving stuck cows and/or less stock mortality from wetland entrapment.

The aims of this study were to: i) quantify the efficiency of a pastoral wetland (Toenepi catchment Waikato) at attenuating pollutants (e.g., TSS, E. coli, N and P), and ii) measure the water quality effects of unrestricted cattle grazing within the wetland.

Study site and methods

The study wetland is located on a dairy farm approximately 2 km southeast of the village of Kiwitahi in the headwaters of the Toenepi River catchment in the eastern Waikato Region (Figure 1). The Toenepi catchment is intensively farmed with approximately 75% of the catchment area occupied by dairy farms with a stocking rate of ~ 3 cows/ha (Wilcock et al., 2006). The mean annual rainfall of the area is 1,377 mm and the wetland's catchment is comprised almost exclusively of Morrinsville clays (NZ Soil Classification: Typic Orthic Granular Soil, Müller et al., 2010). The upper Toenepi catchment is hilly with ~80% of the area classified as either rolling or steep (>10% gradient; Müller et al., 2010).

The wetland is located within a small fenced paddock area. The entire fenced area (with exception of the wetland itself) is very steep and considered to be of low productivity for dairy farming (pers. comm. J. Armstrong, dairy farm owner). Accordingly, the paddock is only used for grazing approximately 1 day in 40 during winter and summer and 1 in 20 days during spring and autumn. The wetland substrate is deep (>1 m) and perennially saturated. The wetland vegetation is dominated by glaucous sweet grass (*Glyceria declinata*), jointed rush (*Juncus effusus*), sedge (*Carex sp.*) and lotus (*Lotus pedunculatis*) (Wilcock et al., 2012).

The site has two 45° v-notch weirs installed that are used to measure stage height and instrumentation sites. One weir is located in the head of wetland in area thought be a significant ground water seepage area (Figure 1). The catchment area above this upper wetland is ~2.9 ha. The second weir is located within a constricted part of the lower wetland (Figure 1). The wetland above the lower weir has an area of ~1500 m^2 and it has a catchment area of ~5.2 ha. Stage height is measured by NIWA Hydrologger water level recorders (1 mm resolution). Turbidity is recorded by Campbell Scientific OBS3 turbidity probes (back scattering type; nominal range 0 – 1000 NTU). Rainfall is also measured at the lower weir at 10 minute interval by an OTA tipping bucket rain gauge.

Over the course of the study, water samples have been collected from the two weirs and various piezometers throughout the wetland catchment. Baseflow samples have been collected approximately every 4-6 weeks from the upper and lower weirs. Autosamplers also collected samples during flow events at both weirs. The upper weir autosampler is programmed to collect samples on a stage-based trigger. The lower weir sampler is programmed to trigger sample collection on the basis of stage height and turbidity measurement. The turbidity-based sampling trigger at the lower site was implemented in an attempt to collect water quality samples at time of stock disturbance. Groundwater samples have also been periodically collected from various piezometers situated within or adjacent to the wetland.

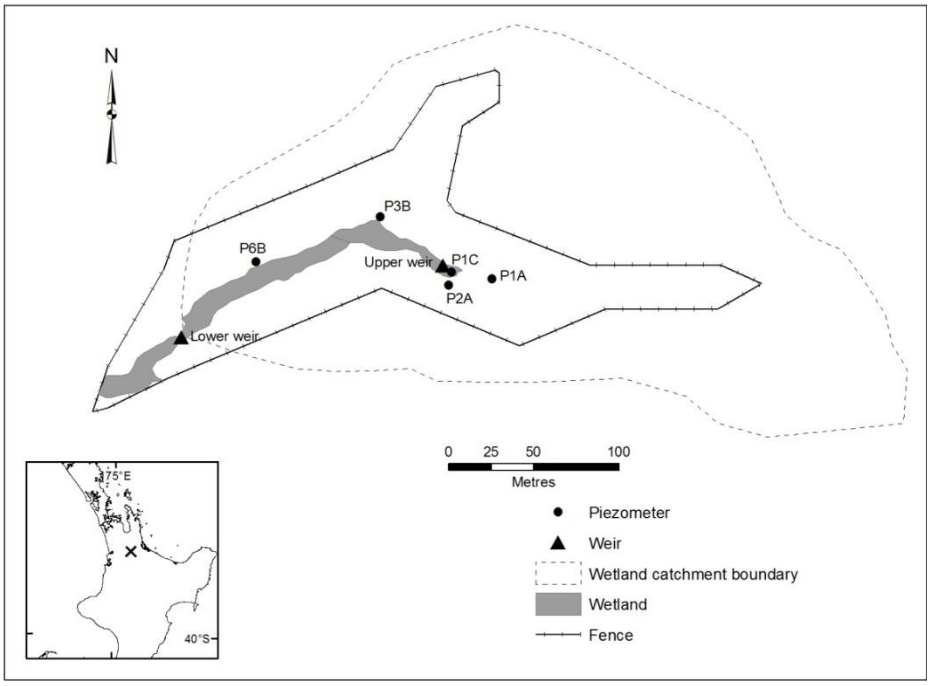

Figure 1 Kiwitahi wetland location map.

Results

Hydrology

The two weirs within the wetland were installed in the wetland in May 2001, however, due to a number of problems (mainly leaks due to the unconsolidated nature of the wetland substrate), accurate continuous flow records are only available for the period from 1 November 2011 to 8 July 2012 (Figure 2). The total flow recorded over this period at the upper and lower weirs was 0.51 ML and 6.00 ML, repectively. This indicates that less than 10% of the flow at the lower weir can be attributed water that has entered the upper wetland as surface flow or subsurface flow reaching the wetland surface. This is a particularly interesting finding given that the area above the upper weir accounts for ~50% of the wetland catchment area and there is a gully immediately upstream of the upper weir which is an obvious conduit of overland flow during rainfall events. This suggests that most of the water enters the wetland from subsurface and groundwater flow. Subsurface flow appears to dominate regardless of conditions and time of year. Comparison of flows from the upper and lower weirs during flow events indicates the relative contribution of the upper weir is highly variable (depending on time of year and size of event) but never exceded ~20% of the flow recorded at the lower site.

Figure 2 also indicates that while the lower weir flowed for the entire period the upper weir stopped flowing in mid-summer (6 February 2012) and did not record any significant flow again until mid-winter (3 July 2012), over 5 months later.

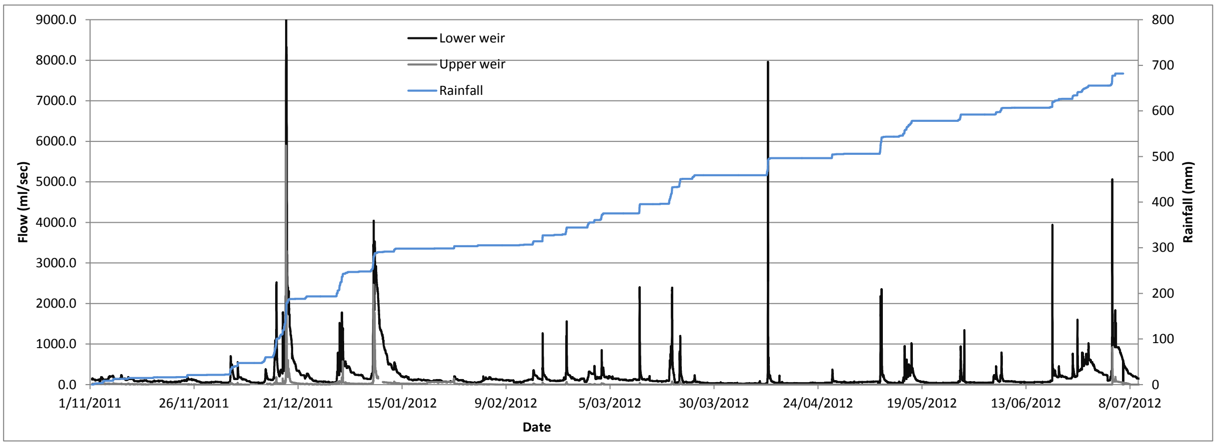

Figure 2 Flow and rainfall records for the upper and lower weir sites between 1/11/2011 and 8/7/2012.

Surface water quality data

To date 62 water quality samples from the upper weir and 101 samples from the lower weir have been analysed. Baseflow samples have been collected throughout the study period and flow events have been sampled over a range of both summer and winter conditions. For the purpose of this report the water quality data has been grouped together into summer/autumn (Dec-May) and winter/spring (Jun-Nov) (Figure 3; Figure 4)

Preliminary analysis of the water quality datasets from the upper and lower weirs indicates that that all of the measured variables are present in higher concentrations at the upper weir, regardless of flow conditions or seasonality. Although detailed statistical analysis is required to confirm the significance of the differences between the measured variables, in many cases the median pollutant concentrations measured at the upper weir are one or two magnitudes higher than those measured at the lower weir. Clearly this indicates the area contributing to the upper weir is a significant source of poor quality water. The results also indicate that concentration of most measured variables (e.g., TSS, DRP, TP, NH_4-N, TON and TN) are highest during summer. This is likely to be due to a combination of i) reduced stock access to the wetland paddock during the wetter winter and spring months and ii) the generally wetter antecedent conditions during the winter and spring months that may result in dilution of the readily transportable pollutants. At this stage, it is difficult to determine the significance of this relatively poor quality water entering the wetland from the upper weir as this upper wetland area contributes a relatively small amount of the total wetland flow (<10%). The disparity between the water quality at the lower and upper weirs may indicate that the wetland is very efficient at attenuating the poor water quality entering from upstream. However, further information on the nature of the water entering the wetland from downstream of the upper weir (presumably mostly subsurface flow) is required before we can quantify the wetlands water quality attenuation efficiency.

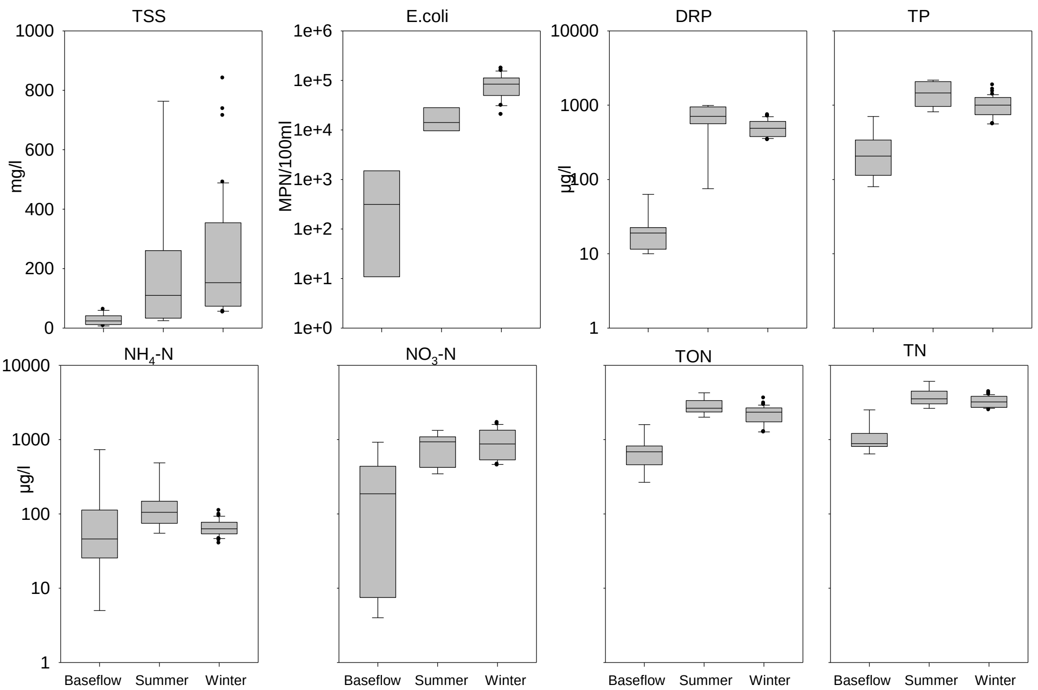

Figure 3 Box plots of TSS, *E. coli* and different forms of P and N at the upper wetland weir. The box defines the 25th and 75th percentiles and median, whiskers indicate the 90th and 10th percentiles, and outliers are represented by dots.

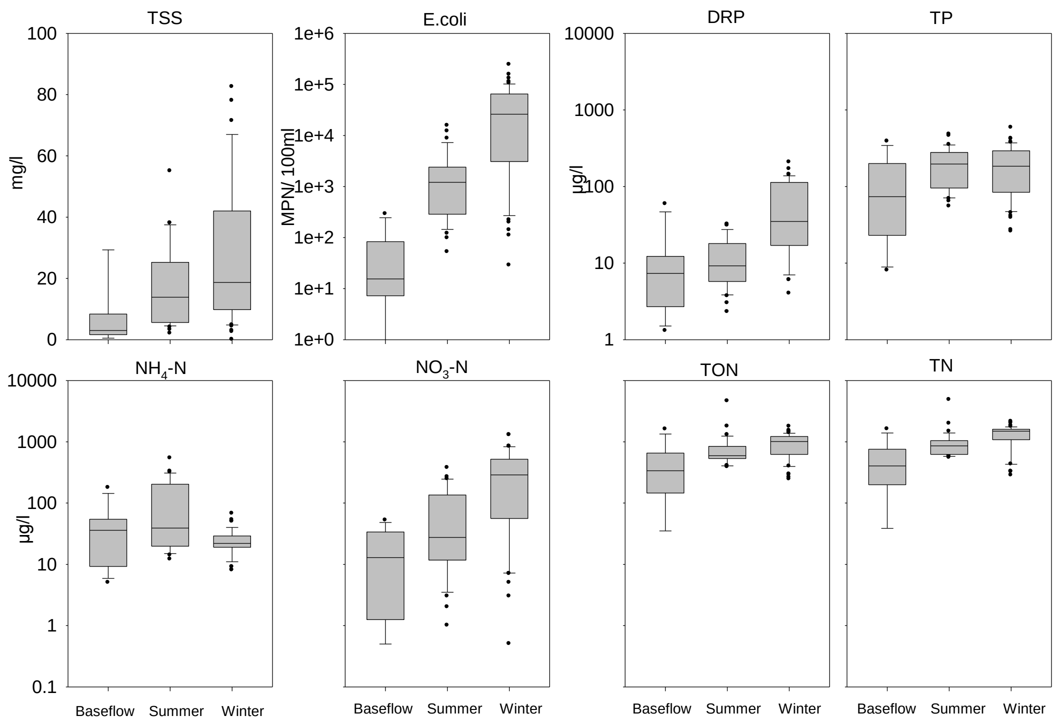

Figure 4 Box plots of TSS, *E. coli* and different forms of P and N at the lower wetland weir.

Despite the necessity for further data collection, sampling to date has given us confidence that wetland is very efficient at denitrifying NO_3-N entering in subsurface flow (Figure 5). Baseflow sampling from the piezometer located in the upper wetland (site P1C), which taps into the subsurface flow before it makes contact with the wetland material, indicates a median nitrate concentration of ~3300 µg/l. The median NO_3-N concentration of the water flowing through the upper weir during baseflow conditions is < 200 µg/l.

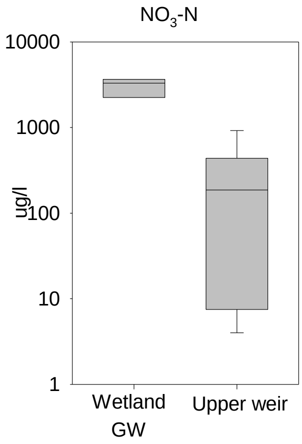

Figure 5 Box plots of NO_3-N during baseflow for the wetland subsurface flow immediately upstream of the upper weir and for the upper weir.

Groundwater and overland flow water quality data

To date, only twenty groundwater samples have been analysed. Eight of those were collected from two piezometer locations (P1C and P1A; Figure 1) upstream of the upper weir. One is located in the head of the wetland (P1C) where the convergent gully area drains into the wetland and is assumed to represent inflow from a small spring at the head of the wetland-gully system. The other (P1A) is approximately 20 metres further up the gully. The other twelve samples were collected from piezometers P2A, P3B and P6B (Figure 1). Site P3B is located in a swale area, while sites P2A and P6B are located on a steep hillslopes which are typical of much of the terrain immediately adjacent to the wetland. A total of 8 overland flow samples have been collected from two sites. One overland flow (OLF) site is within the gully immediately upstream of the upper weir at approximately the same location as piezometer P1A. The second OLF sample site is in the swale area at approximately the same location as piezometer P3B. Figure 6 summarises the groundwater and OLF water quality data collected from these sites to date. Due to the small samples sizes, detailed statistical analysis at this time is considered inappropriate.

Although there are only a limited number of samples, it is apparent that the water entering the wetland from OLF has the most elevated levels of all measured pollutants (TSS, E. coli and P and N). With the exception of NO_3-N, the median concentrations of all measured pollutants are highest in OLF-derived water. Given, that OLF is the primary pathway for particulate matter (i.e., sediment, faecal matter, and other organic material) this perhaps to be expected. Despite, the high pollutant concentrations measured in the intermittent OLF, the hydrology data suggests that the vast majority of flow at the lower weir is derived from non-OLF sources therefore the input of water from subsurface and groundwater is probably of more significance with regards to downstream water quality. The limited groundwater samples we have to date show that while there is some disparity in the water quality characteristics between the sampling sites, groundwater may be an important source of NO_3-N into the wetland. While we have installed a number of groundwater sampling piezometers, it has been difficult to obtain enough sample from many of these sites during times of lowered groundwater (summer and autumn). Due to the importance of subsurface inputs in the wetland, it is recognised that more effort will be made in the future to obtain information on the spatial and temporal variability of groundwater water quality.

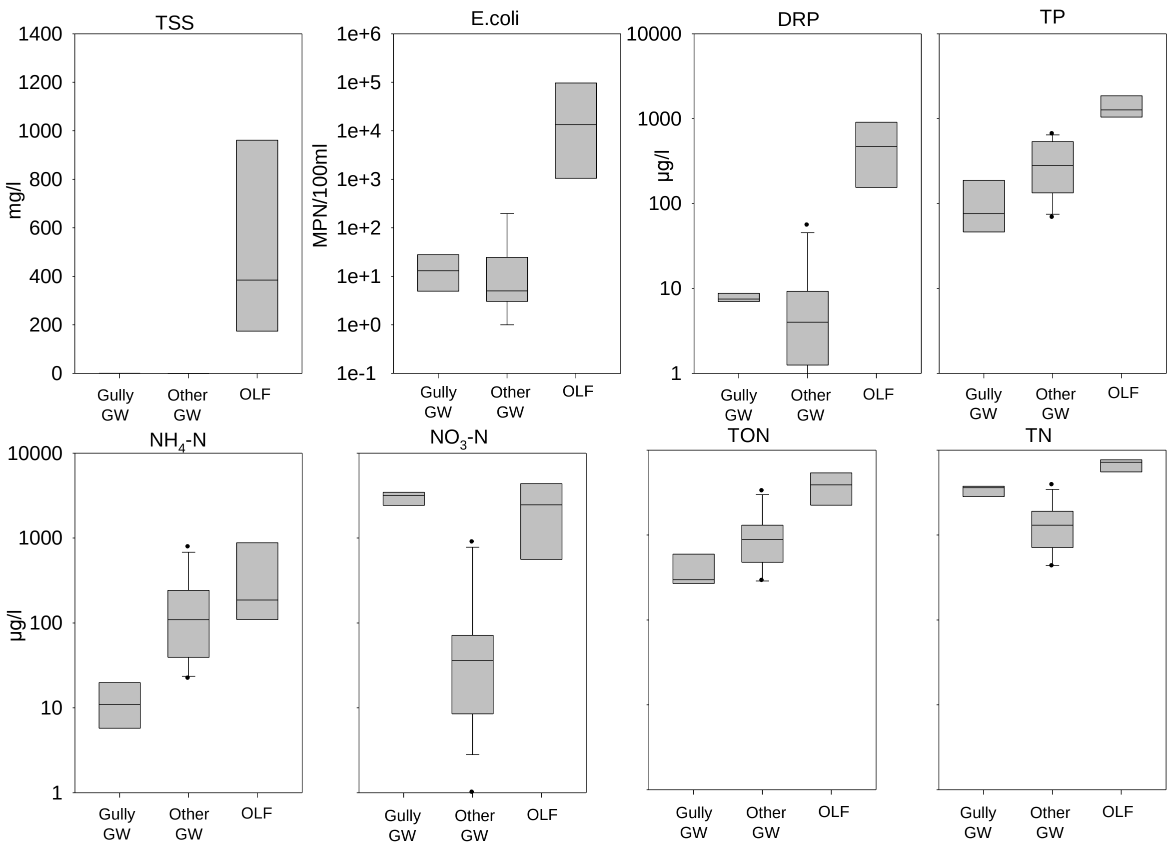

Figure 6 Box plots of TSS, *E. coli* and different forms of P and N for the gully groundwater, other groundwater locations and overland flow samples (GW = groundwater).

Cattle access to wetland

Stationary time-lapse cameras were positioned within the wetland catchment at two locations (Figure 7; Figure 8). The cameras were installed on 15 July 2011 and up until September 2012 cows (a herd of ~100 cows) were detected in the wetland paddock on nine days.

The data from the two cameras indicate that, while the cows do actively enter and graze within the wetland, they do not spend a great amount of time in it. On the nine recorded cow access days, the cows entered the wetland early in the morning (~6 am) and exited in the afternoon (~3 pm). The cows therefore usually spent ~ 9 hours in the wetland paddock. For the upper wetland area there were no cows present in the wetland between 44-73% of the time and only one 1 cow in the wetland between 64-76% of the time. There were never more than 10 cows in the upper wetland at any one time, although this only occurred on one occasion and a maximum of number of 5-6 cows was more common. For the lower wetland area there were no cows present in the wetland between 47-89% of the time and only one cow in the wetland between 62-99% of the time. There were never more than 11 cows in the lower wetland at any one time, although this only occurred on one occasion and a maximum of number of 2-3 cows was more common. The limited grazing by cows within this deep wetland is consistent with limited previous observations based on the cow pat density (Collins, 2004).

Although the cows do not spend much time in the wetland, there does appear to be a preference for the upper wetland area. More cows enter the upper wetland (and spend more time grazing) than the lower wetland. This is despite the upper wetland area only accounting for ~35% of the total wetland area. This is likely to be due to the easier access afforded in the upper wetland area with some flat areas immediately adjacent to the wetland. The terrain adjacent to the lower wetland is very steep with no easy access points. Furthermore, it may be the wetland material is in fact deeper in the lower wetland. The cameras have recorded cows getting entrapped (and requiring manual removal) on two occasions in the lower wetland (18/12/2011 and 16/01/1012). Wetland depth measurements will be required to confirm any disparity between the depth of the upper and lower wetland areas.

There is not enough data to draw any definitive conclusions about what time of the year (or conditions) cows are more likely to enter the wetland. However, it is apparent that during late summer (12/2/2012) there were cows in both the upper and lower wetland for more than 50% of the time (the only time this occurred). Furthermore, on this occasion more cows were observed in the wetland than any other day, with a maximum of 10 cows in the upper wetland and 11 in the lower wetland. The median maximum number of cows in the upper and lower wetland at any one time was five and three, respectively. A possible explanation for this preference for wetland grazing on this day may be due to less grass availability on the hillslopes during late summer because of limited water availability for grass growth. Cows may therefore be enticed to enter the wetland to obtain good quality grass for grazing. The lower water levels during the summer months may also result in the wetland being more readily accessible to stock.

Figure 7 Upper camera view of wetland during cow access ‘event’ on 18/12/2011. Yellow line shows the approximate boundary of wetland.

Figure 8 Lower camera view of wetland during stock access 'event' on 18/12/2011. Yellow line shows the approximate boundary of wetland.

The direct effects of stock grazing

The automatic water sampler at the lower weir was programmed to collect samples on both stage and turbidity-based triggers. Elevated turbidity levels, in the absence of increased flow, are likely to be the result of a disturbance within the wetland (such as stock access). To date, there have been no occasions when the auto-sampler has been activated solely due to increased turbidity levels. Analysis of the turbidity data on the nine days of known stock access indicated that there was only one occasion when the presence of stock resulted in a detectable increase in turbidity (18/12/2011). This (double) turbidity spike only reached 65 NTU (TSS = 63 mg/l). This turbidity spike (converted to total suspended solids (TSS) by calibration with analysed samples) is illustrated in Figure 9. Analysis of the time-lapse photography indicated that the stock were in the wetland paddock from 6 am on 18/12/2011 to 6am on 19/12/2011. Despite the stock grazing the wetland for the entire day, the double turbidity peak only occurred late in the day with the first peak occurring at ~6:00 pm and the second at 8:40 pm. The photographs show that at ~ 5:40 pm there were 10 cows in the lower wetland, including five within ~5 metres of the lower weir. At 5:50 pm one cow became entrapped in the wetland but all other cows moved back on to the adjacent hillslopes. By 7 pm four cows had re-entered the lower wetland. By 8 pm, the low ambient light conditions meant that the time-lapse camera stopped operating. The camera began taking photographs again at 4:10 am on 19/12/2011, by which time the entrapped cow was gone. When cows are entrapped in the wetland and separated from the herd they become distressed and call all out continuously. Presumably, the farm owner retrieved the entrapped cow from the wetland relatively soon after sunset (at around the time of the second turbidity peak).

This sequence of events appears to indicate that the action of a cow becoming entrapped, together with its manual extrication, generated enough of a disturbance to increase turbidity. The only other time a cow was entrapped in the wetland (16/1/2012) no turbidity spike was detected. Significantly, on this second occasion the cow was entrapped ~ 10 m further up the wetland and it occurred during a time of low flow conditions. Fortuitously, due to it coinciding with a flow triggered sampling event, water quality samples were collected over the time of the cow entrapment on 18/12/2011. Figure 9, Figure 10 and Figure 11 illustrate the concentrations of *E. coli*, TSS, nitrogen species and phosphorus species over the 18/12/2011 flow and stock access events. Baseflow, immediately prior to this event was ~ 0.4 l/s and the peak flow reached ~9 l/s. During this event there were small increases in the concentrations of TSS, *E. coli* (Figure 9), dissolved reactive phosphorus (DRP), total dissolved phosphorus (TDP) and total phosphorus (TP; Figure 11). There were no meaningful increases in any forms of nitrogen (Figure 10). In contrast, during the period of cow entrapment and extrication there were large increases in TSS, *E. coli* (Figure 9), TKN, particulate nitrogen (PN; (Figure 10), and TP; Figure 11).

Clearly, the disturbance caused by a cow becoming entrapped then being extricated (during a period of elevated flow) results in an increased flux of most forms of pollutants. Interestingly, some of the pollutants (TSS, *E. coli*, TKN, PN, and TP) remain elevated for at least 7 hours after the cow was extricated. In order to quantify this effect, pollutant loads were calculated using the water quality and flow data over the period of the cow entrapment (Table 1). Hypothetical "non-stock access" loads were also calculated for the same period assuming no change in TSS or nutrient concentrations after the sample collected at 5:21 pm on 18/12/20011 (Table 1). The results show that that while there were large (one order of magnitude) increases in the loads of most pollutants, the actual contaminant fluxes were small.

The data we have collected to date, therefore, indicates that, under most conditions, cows entering the wetland have little or no immediate effect on the quality of the water exiting the wetland. The only occasion where any degraded water quality was detected occurred during very specific conditions (animal entrapment and extrication during a period of elevated flow). Further monitoring is required to improve our understanding of how often these conditions occur and if there are other specific conditions that may be important.

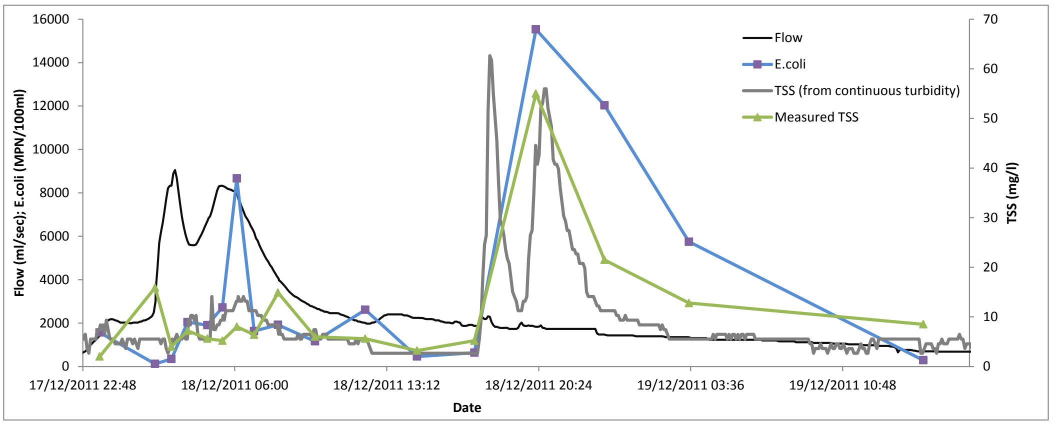

Figure 9 Flow, *E. coli* and TSS concentrations recorded at the lower weir for the flow and stock access events of 18/12/2011.

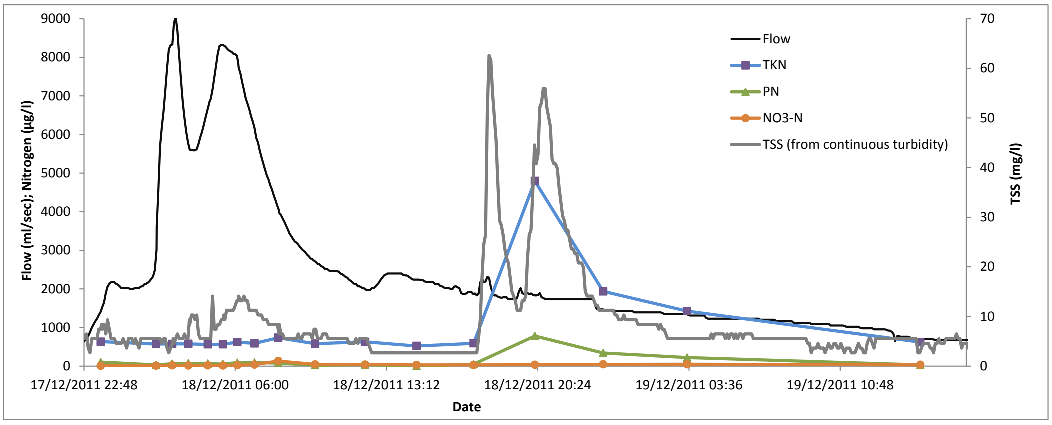

Figure 10 Flow and concentrations of TSS, TKN, PN and NO_3-N recorded at the lower weir for the flow and stock access events of 18/12/2011.

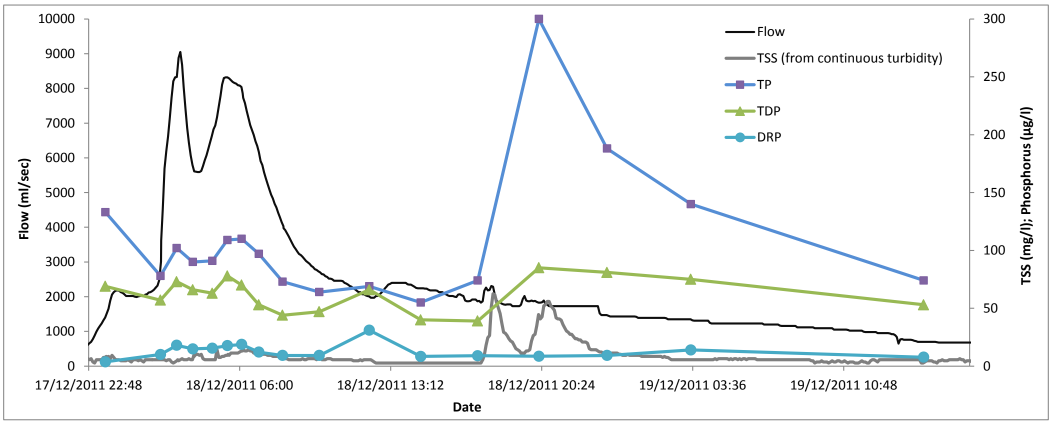

Figure 11 Flow and concentrations of TSS, TP, TDP and DRP recorded at the lower weir for the flow and stock access events of 18/12/2011.

Table 1 Sediment and nutrient loads at lower weir for 18/12/2011 stock access 'event'. Loads are totals for the ~20 hour period between 17:21 18/12/2011 and 14:37 19/12/2011. The 'without cows' loads were calculated by assuming no change in TSS or nutrient concentrations after the sample collected at 17:21 18/12/2011.

Analyte	Load - without cows (g)	Load -with cows (g)
TSS	278.5	1503.7
NH_4-N	1.9	13.1
NO_3-N	2.9	4.1
TDN	59.1	180.3
TON	59.3	196.2
TKN	61.2	209.2
TN	64.1	213.4
DRP	0.9	1.1
TDP	4.1	7.4
PN	5.0	33.1
TP	7.7	17.4

Although there does not appear to be much immediate impact on water quality of cow access to this wetland, there may be an on-going, long-term effect on water quality of stock access to the wetland. This may be in terms of the cumulative effect of the direct deposition of urine and faeces into the wetland through to the physical damage caused by large, heavy cattle accessing a saturated area from steep access points (Figure 12). The physical damage to the wetland margins is likely to contribute to the pollutant loads discharged from the wetland in much the same way that has been observed in river systems (e.g., Trimble and Mendel, 1995).

Figure 12 Cow induced-mechanical erosion of the wetland edge.

Summary and future wetland monitoring

It would appear that the *direct* effect of cows grazing within this wetland is minor and transitory in nature. This wetland is not grazed very often, with the cows allowed access for only around 1 day per month. Even when cows have access to the wetland, the majority of cows do not enter it, presumably because of the risk of entrapment. The effects on sediment and nutrient exports of unrestricted cow access to shallow wetlands have been previously observed (see McKergow et al., 2012). However, in deeper wetlands it appears that cows do not spend enough time in the wetland to result in large-scale disturbance of the wetland substrate or large-scale direct deposition of faeces and/or urine to have a notable effect on the contaminant loads.

The direct effect of cows grazing in this deep wetland have proven to be relatively limited, in terms of immediately detectable increases in pollutants. However, cows clearly affect the margins, causing direct input of sediment from mechanical erosion. However, unlike a stream channel, flowing surface water within the wetland is uncommon and suspended sediment tends to be settle within the dense wetland vegetation. The low sediment concentrations observed at the lower weir (median storm concentration = 13 mg/l; peak storm concentration = 67 mg/l) support this hypothesis. It is likely that the grass-dominated vegetation within the wetland is very effective at trapping sediment. The grass increases the hydraulic roughness of the flow surface, reducing the flow velocity and thus the sediment transport capacity.

Currently, automatic water samplers are set up to sample during flow events and when a turbidity trigger is reached. However, it is clear that the due to a combination of few cows entering the wetland, together with the sediment trapping ability of the wetland grasses, significant turbidity fluxes are unlikely to occur. To get a better handle on the direct effect of stock entering the wetland it may be useful set up the autosampler at the lower weir to take time-based samples on a day when it is known the cows will be placed in the wetland paddock. Such an approach would be useful to assess whether water quality is affected by stock entering the wetland under baseflow conditions and whether cow entrapment is required before any significant adverse effect is detectable.

The hydrology data collected from the two wetland weirs indicate that most water enters the wetland below the upper weir, presumably as subsurface flow and groundwater. To date, we have limited data on the nature of the water entering the wetland through these pathways. Future sampling will need to focus on these sources.

Acknowledgements

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