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State and potential management to improve water quality in an agricultural catchment relative to a natural baseline

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ABSTRACT

Land use change and the expansion of dairying are perceived as the cause of poor water quality in the 1881 km^2 Pomahaka catchment in Otago, New Zealand. A study was conducted to determine the long-term trend at four sites, and current state in 13 sub-catchments, of water quality. Drains in 2 dairy-farmed sub-catchments were also sampled to determine their potential as a point source of stream contamination. Data highlighted an overall increase in the concentration of phosphorus (P) fractions at long-term sites. Loads of contaminants (nitrogen (N) and P fractions, sediment and *Escherichia coli*) were greatest in those sub-catchments with the most dairying. Baseline (without human influence) contaminant concentrations suggested that there was considerable scope for decreasing losses. At most sites, baseline concentrations were <20% of current median concentrations. Contaminant losses via drainage were recorded despite there being no rainfall that day and attributed to applying too much effluent onto wet soil. Modelling of P concentrations in one dairy-farmed sub-catchment suggested that up to 58% of P losses came from point sources, like bad effluent practice and stock access to streams. A statistical test to detect "contaminated" drainage was developed from historical data. If this test had been applied to remove contaminated drainage from samples of the two dairy-farmed sub-catchments, median contaminant concentrations and loads would have decreased by up to 58% (greater decreases were found for *E. coli*, ammoniacal-N and total P than other contaminants). This suggests that better uptake of strategies to mitigate contamination, such as deferred effluent irrigation (and low rate application), could decrease drainage losses from dairy-farmed land and thereby improve water quality in the Pomahaka catchment.

1. Introduction

The Pomahaka is a large catchment (1881 km^2) in Otago, New Zealand that contains a nationally significant recreational fishery. However, water quality as measured by the concentration of nutrients, sediment and faecal indicator bacteria in parts of the Pomahaka River and its tributaries is currently considered poor (Otago Regional Council, 2007). The state of the river has been attributed to a combination of factors such as: land use change from sheep to dairy farming and the use of artificial drainage (Harding et al., 1999). However, there is a perception that natural background contaminant concentrations may be naturally high (Otago Regional Council, 2010).

During land use change to dairying, paddocks may be modified either by resizing and adjusting fencing, or ploughed and new grasses sown together with a large application of fertiliser (especially phosphorus, P). This can result in a sudden increase in sediment and nutrient loss that decreases with time (Withers et al., 2007), but when aggregated can cause significant contamination on a catchment scale. Others have also highlighted areas like loafing pads and barnyards that can be a significant source of contaminant loss (Edwards et al., 2008; Withers et al., 2009).

Grazed pastoral farming in the Pomahaka catchment is characterised by the widespread use of artificial drainage. These drains respond quickly via macropores or artificial mole channels and preferential flow to remove excess water, but also act as a direct conduit for contaminants to enter streams. Common practice on dairy farms in the catchment is to land apply dairy shed effluent, often on a daily basis during the lactation season. The application of effluent on artificially drained land can, via macropores or ancillary drains connected to main drains, result in effluent reaching the stream (Monaghan and Smith, 2004; Houlbrooke et al., 2008). This loss can occur when drains would not typically be flowing in summer or autumn when ecosystem effects and recreational use are greatest (Jarvie et al., 2006). While past work has indicated that

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effluent application combined with artificial drainage can act as a source of contaminant loss, isolating this on a farm-by-farm or catchment scale is problematic, especially if natural background losses of contaminants are high.

Setting a natural background contaminant loss allows, by difference from current losses, the manageable proportion to be estimated and the value of mitigation strategies to be judged. If a natural loss is already similar to current losses, there may be limited opportunity for mitigation strategies. Techniques to define a natural loss include the measurements of contaminant concentrations or loads in reference catchments without development, but with a similar topographic and edaphic classification (e.g. ecoregion) to the impacted catchments, or the use of a metric like the 25th percentile of contaminant fluxes registered in that ecoregion (Lewis, 2002; Smith et al., 2003). Dodds and Oakes (2004) point out that these approaches are limited by either the availability of reference streams in an area, or may lead, as in the case of a 25th percentile, to overestimation of background losses. As an alternative, Dodds and Oakes (2004) developed a regression technique for estimating reference conditions based on the relationship between contaminant concentrations and the degree of anthropogenic land use within streams of a similar type as defined by a classification.

As part of a catchment management programme to improve water quality in the Pomahaka River and its tributaries, we set out to establish if there has been a significant trend over time in contaminant concentrations, and then rank contaminant contributions from sub-catchments of the Pomahaka River. These two datasets are then compared to background losses using the method of Dodds and Oakes (2004) to define the manageable contaminant loss rate. Although past work has established that contaminant losses from artificial drainage can be substantial, especially when effluent is being applied when soil is wet (e.g. Houlbrooke et al., 2008; McDowell et al., 2005), there is uncertainty over the definition of when drainage is contaminated via bad practice, and therefore acting as a point source of contaminants, and not background losses. Hence, a combination of historical data and a survey of drains in the catchment was used to: (a) establish a statistical test for contamination caused by bad practice associated with effluent application; and (b) using the test as an indicator, determine what influence mitigation may have, if any, on the manageable proportion estimated from measurements of drainage in two dairy-farmed sub-catchments of the Pomahaka River.

2. Materials and methods

2.1. Site description and sampling

The Pomahaka River drains a catchment of 1881 km^2 and supports a wide variety of land use typified by either red tussock, native forest, plantation forestry (largely *Pinus radiata*) or extensive rangeland farmed with drystock (red deer, sheep and beef) in uplands, while lowlands are dominated by a mixture of drystock and increasingly, dairying. Some tributaries, such as the upper Waipahi River, have also seen the conversion and drainage of large wetland areas in the last 10 years.

Rainfall varies from ca. 1250 mm in the headwaters draining altitudes of up to 1440 metres above sea level (msl) to ca. 650 mm near the catchment outlet at about 60 msl. Slopes tend to be steep (>20°) in the headwaters and often < 2° in the lowlands. Soils within the catchment are dominated by Pallic soils (NZ soil classification (Hewitt, 1998); encompassing Fragiudalfs and Haplustalfs in USDA taxonomy) of moderate natural fertility, but characterised by summer dry and winter wet soil moisture conditions, a high soil bulk density (>1.3 $g\,cm^{-3}$) and imperfectly to poorly drained. In low lying areas, profile drainage is facilitated by a network of mole

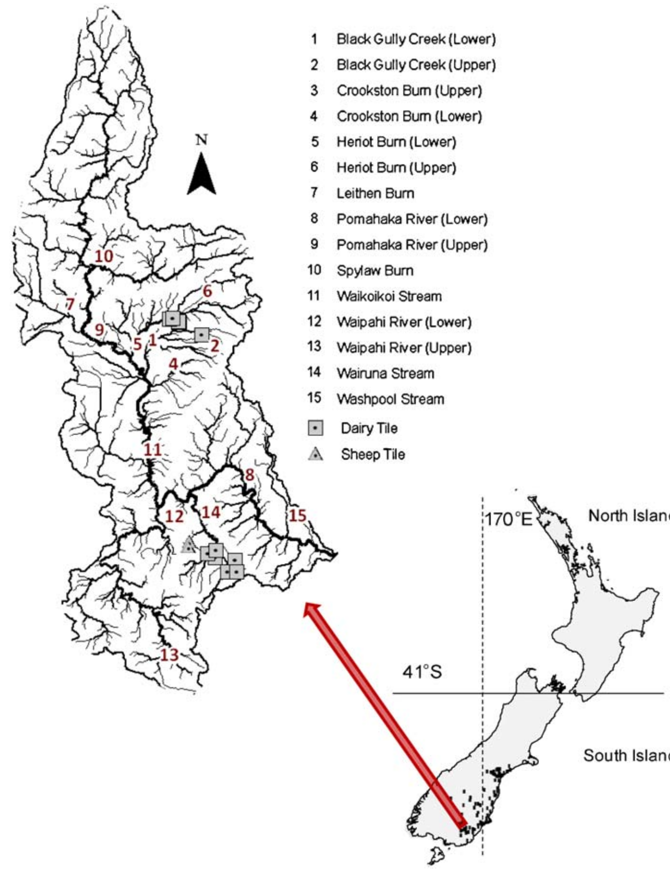

Fig. 1. Map of New Zealand showing the location of state of the environment reporting sites used to determine background median concentrations (rectangles) and the long-term, short-term and artificially (tile) drained sites in the Pomahaka River catchment.

channels (about 40–50 cm deep) that feed into tile or pipe drains at about 70–100 cm below the soil surface (collectively termed artificial drainage).

Since April 1997, water quality and continuous flow have been measured bi-monthly at four long-term "State of the Environment" sites on the Pomahaka and Waipahi Rivers as part of regular assessments made by regional government. For 14 months, beginning in October 2008 this was supplemented by fortnightly sampling ($n = 30$) and continuous flow measurements (gauged fortnightly) of the long-term sites and 11 other "short-term" sites on the Pomahaka and its tributaries. On the same day as sampling short-term sites, an additional 20 drains (7 draining dairy- and 6 draining sheep-farmed land in the Wairuna Stream, and 7 draining dairy-farmed land in the Heriot Burn) were also sampled and flow gauged (Fig. 1). All long- and short-term sites were classified as belonging to either Low-elevation (L) or Hill topography (H) according to the River Environment Classification (REC) (Snelder and Biggs, 2002). The REC is often used to explain broad patterns in water quality data as part of analysis and reporting (e.g., Larned et al., 2004).

2.2. Sample analysis

In the laboratory, samples (2 L) were immediately filtered (<0.45 μm) and analysed for dissolved reactive phosphorus (DRP) within 24 h, and an unfiltered sample digested with persulphate and total P (TP) measured within 7 days. The P analyses were made using the colorimetric method of Watanabe and Olsen (1965). Suspended sediment (SS) was determined by weighing the oven dry (105 °C) residue left after filtration through a