Assessment of water quality changes in Lunan Water Lochs, Angus, Scotland

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Introduction

Background

Rescobie Loch, Balgavies Loch and the Chapel Mires form part of a cascade of freshwater bodies in the upper reaches of the Lunan Water (Figure 1). All of these waterbodies lie within the Rescobie and Balgavies Lochs Site of Special Scientific Interest (SSSI), which lies within a catchment that is dominated by intensive agriculture. Nutrient concentrations within the system are high, and this has led to concerns about potential eutrophication problems in Chapel Mires, a wetland that receives water from the outflow of Balgavies Loch.

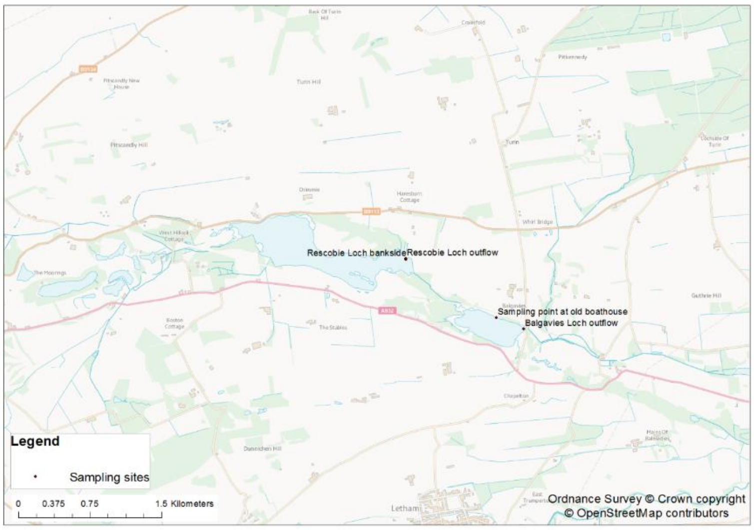

Figure 1 Map of sampling sites in the Lunan catchment.

Description of waterbodies

Rescobie Loch (Figure 2) lies at an altitude of 62 masl and covers an area of 59 ha (UK Lakes Portal). It is relatively shallow, with mean and maximum depths of 3 m and *c*.7.0 m, respectively. The volume of the loch is about 11,769,407 m^3 and its catchment covers an area of 21.7 km^2. It has an estimated turnover time of 0.35 years or 2.8 loch volumes per year (Vinten et al., 2008, p15). Water flowing

Figure 2 Rescobie Loch (Photo: Justyna Olszewska)

downstream from Rescobie Loch enters Balgavies Loch after about 0.5 km.

Figure 3 Lunan Water, upstream of Balgavies Loch (Photo: Justyna Olszewska)

Figure 4 Balgavies Loch (Photo: Justyna Olszewska)

Balgavies Loch (Figure 4) lies at an altitude of about 61 masl, and has mean and maximum depths of 3.0 m and *c*.9.4 m, respectively (Murphy and Kendall, 1988; Murray and Pullar, 1910; UK Lakes Portal). The loch covers an area of 17 ha. and has an estimated volume of about 522,503 m^3. It has been suggested that the loch has a very high flushing rate of about 14.4 loch volumes y^{-1} (Bailey-Watts et al. 1992); this equates to a water retention time of about 25 days.

Chapel Mires (Figure 5) is a wetland area 'downstream' of Balgavies Loch that receives overspill from the Balgavies Loch outflow. The aquatic plants in this wetland are believed to be under threat from eutrophication problems caused by high levels of phosphorus (P) laden water entering the system from the Balgavies Loch outflow. The open water pond area within this wetland is about 4ha.

Figure 5 Chapel Mires (Photo: Justyna Olszewska)

Proposed changes in water management and likely effects on the ecology of Chapel Mires

A new water management plan has been proposed for the upper reaches of the Lunan Water. This has suggested installing a flow restrictor at the outlet from Balgavies Loch and a tilting weir on the downstream mill lade (Vinten *et al.*, 2017a and 2017b), to enable more active management of the Lunan Water to provide flood and low flow mitigation measures. It has been suggested that this would also provide an opportunity to improve the water quality in Chapel Mires by allowing nutrient laden water to be diverted away from the wetland under certain conditions (Vinten *et al*., 2017a and 2017b). Scottish Natural Heritage and the Scottish Wildlife Trust have questioned some aspects of the proposed water management plan. In particular, they have asked whether reducing nutrient inputs into Chapel Mires would help to alleviate encroachment of sedge rich areas by more aggressive, nutrient loving species, such as *Phalaris arundinacea* and *Sparganium erectum*.

A recent study by Gunn et al. (2017) reviewed the ecology of the Chapel Mires Wetland and found that its wetland communities comprised a mixture of woodland, swamp, mire and fen communities (Vinten *et al*., 2017a). The authors concluded these exhibited a wide range of nutrient and water level tolerances and that any significant changes to water level and nutrient availability would be likely to switch the balance of species within these communities. Furthermore, the report suggested that plant species that characterise transition zones in very shallow water would be the most sensitive to changes in water level.

For a number of decades, the qualifying interests of the Rescobie and Balgavies Lochs SSSI have been compromised by eutrophication problems. The lochs and fenlands have all been affected, and there has been no improvement in recent years. Having reviewed the available evidence, Gunn et al. (2017) concluded that there is likely to be little or no negative impact on the qualifying interests of the SSSI from the introduction of a tilting weir. Moreover, they also concluded that any significant reduction in nutrients to the systems would probably be beneficial. Of particular interest in this respect is *Phalaris arundinacea*. It has been suggested that this species has been invading Chapel Mires due to eutrophication problems. However, whilst this species and *Sparganium erectum* are certainly more tolerant of fertile conditions, both are found across a very wide range of conditions. *P. arundinacea,* in particular, is almost ubiquitous along British river and lake margins and only absent at the most oligotrophic of sites (Preston and Croft, 1997). So, rather than an invasive species, Gunn et al. (2017) concluded that this should be considered a natural element of the assemblage at Chapel Mires. The authors suggested that, while a reduction in nutrient inputs could disadvantage *S. erectum*, the response from *P. arundinacea* was likely to be more muted. They also noted that fine sediment builds up around *S. erectum*, and that this would be likely to accumulate and retain nutrients. So, any response to a reduction in nutrient inputs would likely be moderated, at least initially, by the internal supply of nutrients from deposited fines. However, in the longer term, reduction of further ingress of fine sediments will reduce their impact.

In addition, the nutrient most likely to affect the species composition of plant communities in the wetland is phosphorus (P), with inputs of particulate P (PP) being most important in the winter (October – March) and inputs of all forms of P (dissolved and particulate) being important during the growing season (April – September) (O'Hare, *pers. comm.*). For this reason, the current assessment of the factors that affect nutrient inputs (loads) to the mires focuses on P.

Opportunities for diverting P laden water away from Chapel Mires

Changing the management of water flows within the Recobie-Balgavies-Chapel Mires system provides a potential opportunity to reduce eutrophication impacts on Chapel Mires by diverting P-rich water away from the mires under certain conditions. The aim of this current study was to explore the available data and determine the main factors that were controlling the timing and magnitude of P loads and concentrations in the outflow from Balgavies Loch.

Data

The James Hutton Institute (JHI) and the Scottish Environment Protection Agency (SEPA) provided data on the nutrient concentrations and hydrology of the Lunan loch system. The locations of the sampling sites from which data were collected are shown in Table 1.

Table 1 Water quality sampling sites at Rescobie and Balgavies Lochs showing years in which data were collected (shaded cells)

Sampling site	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Rescobie bankside															
Rescobie outflow															
Balgavies at old boathouse															
Balgavies outflow															
Balgavies discharge															

Although, in total, data were available from 2003 to 2017, sampling sites changed over this period and there was little overlap in data collection when this happened. However, the limited amount of data that were available suggested that values recorded at Rescobie bankside and outflow in 2012 (Figure 6), and at Balgavies old boathouse and outflow in 2011-2012 (Figure 6), were sufficiently similar for the datasets to be joined into a single series of data for the purposes of this study.

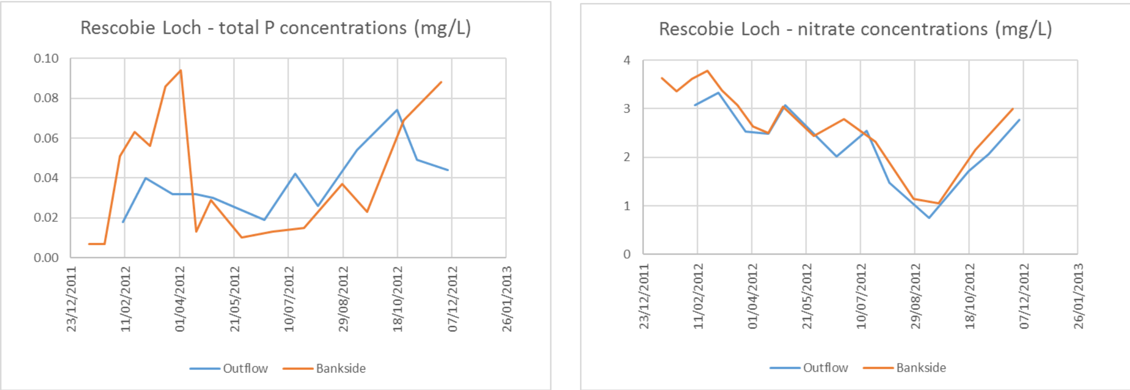

Figure 6 Comparison of total phosphorus (P) and nitrate concentrations at Rescobie Loch outflow and bankside sampling sites, 2012

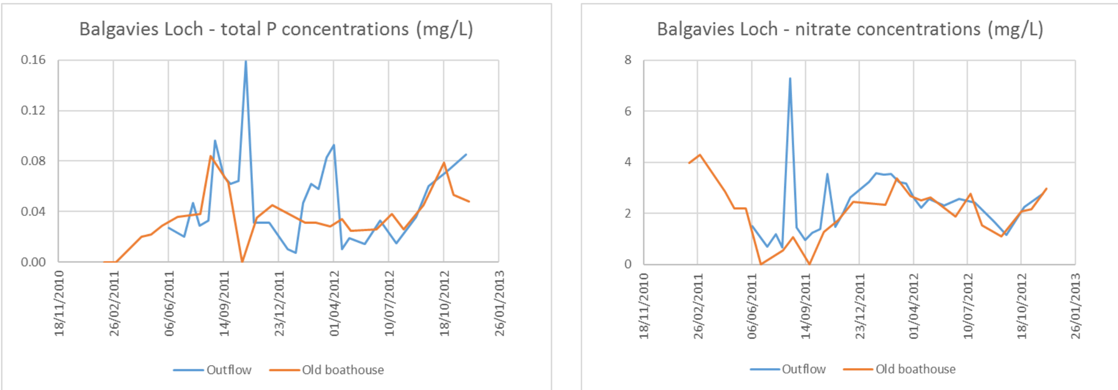

Figure 7 Comparison of total phosphorus (P) and nitrate concentrations recorded at the Balgavies outflow and old boathouse sampling sites, 2011-2012.

In addition to nutrient concentration data, daily rates of discharge from the Balgavies Loch outflow were provided by JHI. These were based on changes in loch level using an equation that had been derived from a stage discharge calibration curve. These data were available for 2013-2016, only. However, when averaged over this period they suggested an annual average rate of discharge from the loch outflow of 12,355,217 $m^3 y^{-1}$, and an corresponding flushing rate of about 24 loch volumes yr^{-1}. This equates to a water retention time of about 15 days, which is less than previously suggested by Bailey-Watts et al. (1992). However, it should be noted that the period 2013-2016 included storm Frank, which was characterised by heavy rainfall and high flows over a relatively short period. This will have reduced water the average water retention time of the loch significantly compared to a more 'normal' year.

Nutrient concentrations within the Lunan system

When combined, the longer time series of data for Rescobie and Balgavies revealed some intra-annual patterns in the data series created. The data for Rescobie showed a series of summer peaks and winter troughs in the concentrations of P fractions, and the opposite in nitrate concentrations (Figure 8). The data also showed that P concentrations in the loch had fallen since about 2011, while nitrate concentrations had risen in these later years.

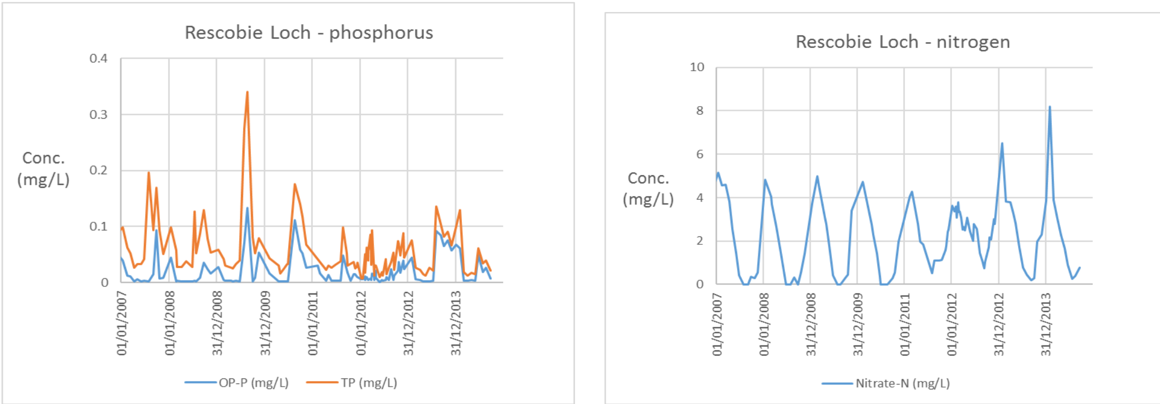

Figure 10 Long term variation in phosphorus (left) and nitrate (right) concentrations at Rescobie Loch, 2007-2014

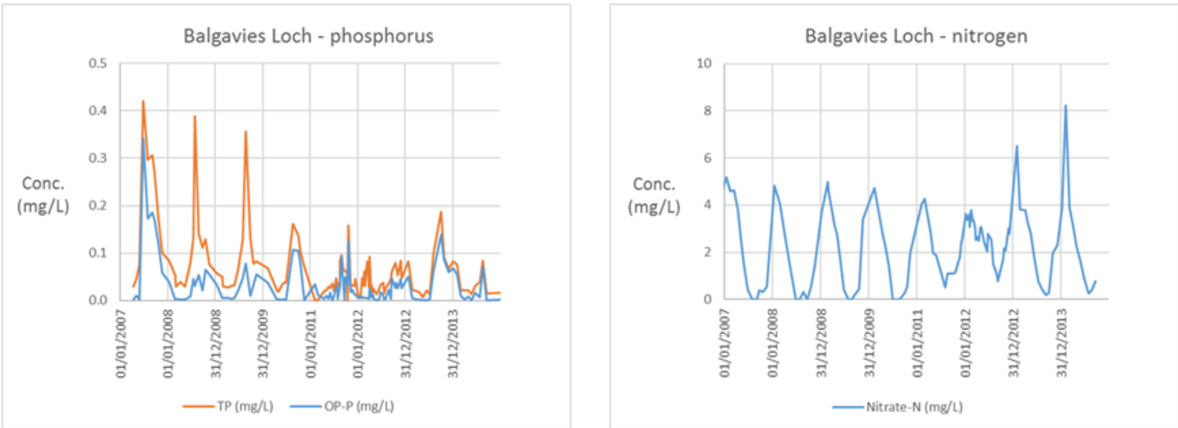

Figure 9 Long term variation in phosphorus (left) and nitrate (right) concentrations at Balgavies Loch, 2007-2014.

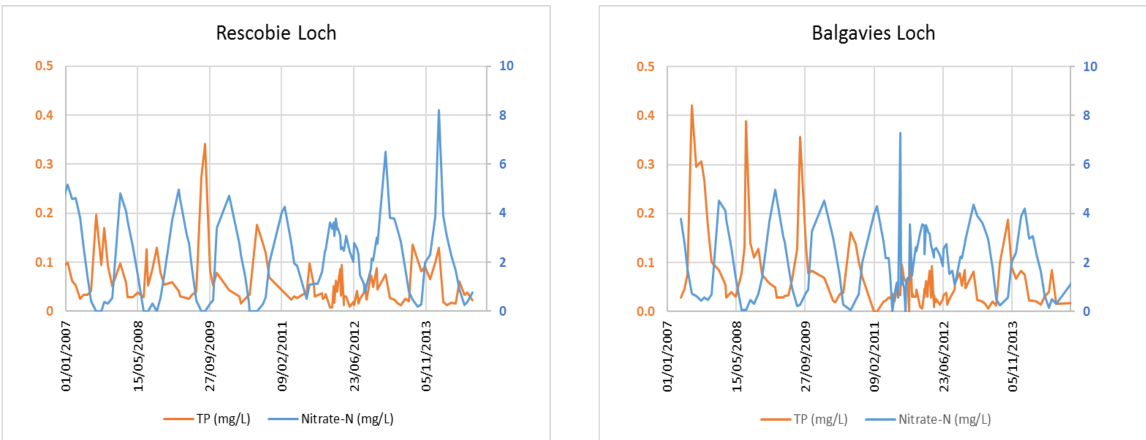

Figure 8 Temporal changes in total phosphorus (TP) and nitrate-n concentrations in Rescobie and Balgavies Lochs, showing an inverse relationship over time.

The pattern of change at Balgavies Loch was similar to that observed in Rescobie (Figure 9), except in 2007 and 2008 when P levels were much higher in Balgavies than Rescobie. The reason for this is unclear.

When P and N concentration data for Rescobie, and those for Balgavies, were combined on the same graph, an inverse relationship between the concentrations of these two nutrients can be seen more clearly (Figure 10). This strongly suggests that both of these lochs are experiencing N limitation accompanied by P release from the sediments in the summer and early autumn, a typical pattern associated with summer deoxygenation of the water column.

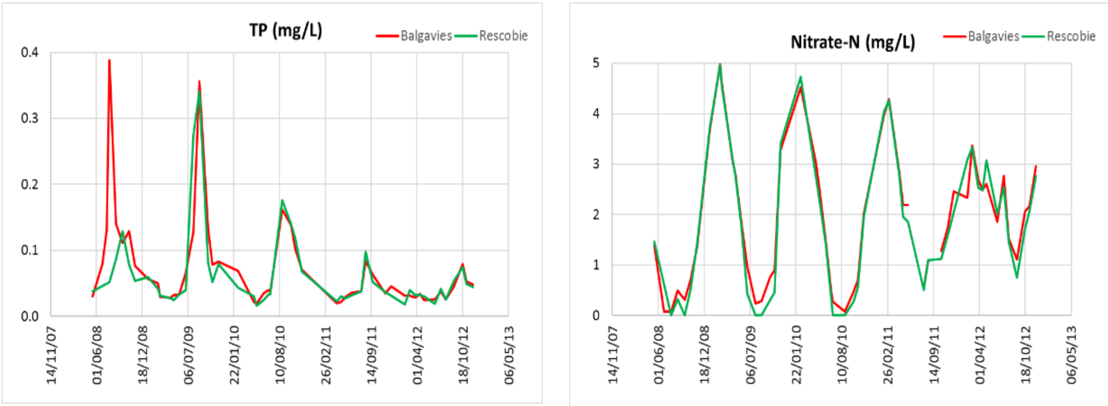

Figure 11 Relationship between total phosphorus (TP) and nitrate-N concentrations in Rescobie and Balgavies Lochs, 2007-2014.

However, closer inspection of the data showed that the data from Balgavies Loch follows that from Rescobie almost exactly (Fig 11). This indicates that almost all of the nutrient processing in this system occurs in the upper loch (Rescobie), and that the water quality of the lower loch (Balgavies) generally reflects that of the water that is discharged into it from the upstream loch (Rescobie).

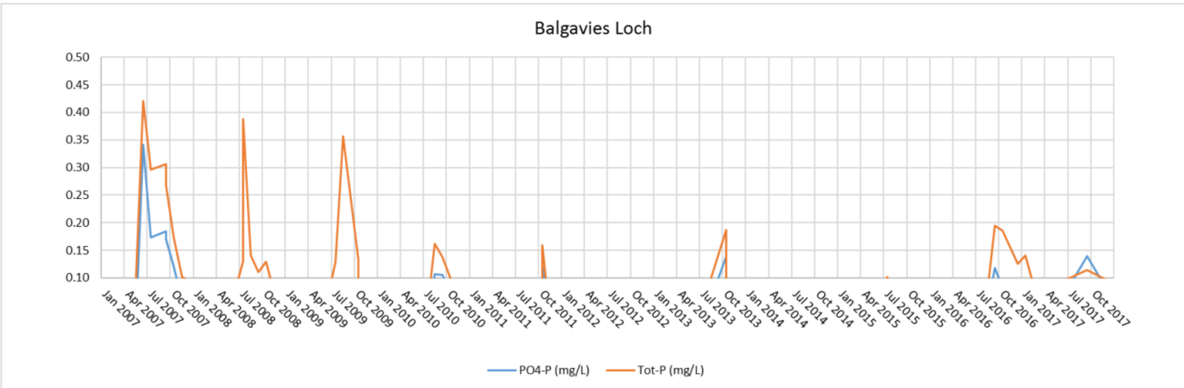

Figure 12 Timing of phosphorus (P) concentrations in Balgavies Loch that are above 0.1 mg/L, suggesting phosphorus release from the sediments.

This is not surprising, given that the water retention time of Balgavies Loch is only 15 days and the fact that it has travelled only a short distance (0.5 km) between the two lochs. In addition, the main inflow and outflow of this loch are relatively close together, which will also affect the water retention time.

Sudden, high P concentrations in loch water are usually associated with a release of P (as PO_4-P) from loch sediments under anoxic conditions. Such events are characterised by a peak in TP, mainly caused by a sudden increase in PO_4-P, and usually occur is late summer/autumn. **Error! Reference source not found.** shows that peaks of high TP concentrations (> 0.1 mg/L) mostly occur between August and September, suggesting that flow diversion over this period would be likely to reduce the influx of water with high P concentrations into the wetland.

Estimating the amount (load) of phosphorus discharged from Balgavies Loch

The amount of P that was being discharged from Balgavies Loch was estimated from each P concentration measured and the associated rate of water discharge from the outflow. Sufficient data to perform this calculation were available for 2014-2016, only, and there were few data for the winter months (October to March). However, the data were sufficient to show the temporal pattern of P discharge from the loch.

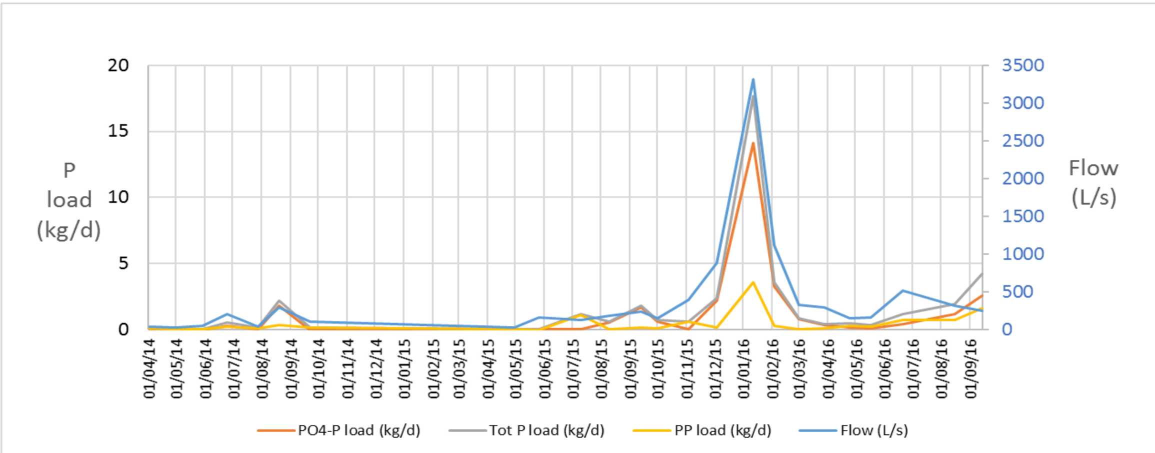

Figure 13 Temporal changes in load of different phosphorus (P) fractions exported from Balgavies Loch, 2014-2016

In addition, it was possible to derive good relationships between flow and both dissolved (PO_4-P) and total P loads for the outflow. These are shown in Figure 14.

From this relationship, it was possible to identify a flow threshold beyond which P inputs to Chapel Mires would be high unless the P-laden water were diverted away from this waterbody. A discharge rate of about 500 L/s is suggested. This corresponds to a loch level of about 59.5 masl.

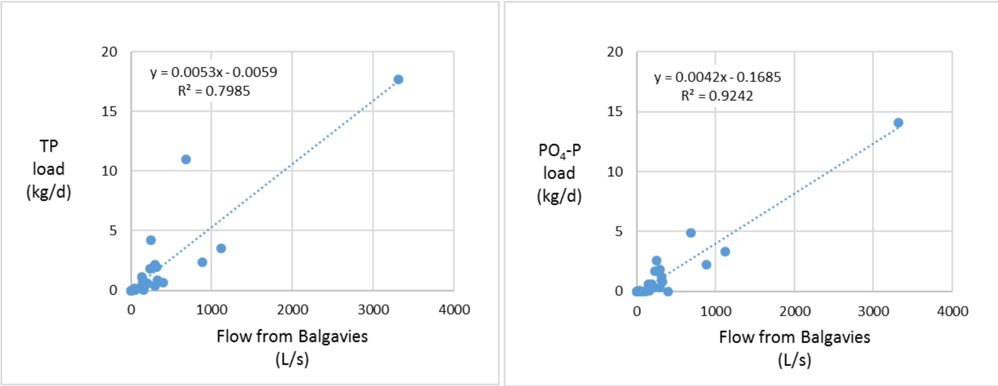

Figure 14 Relationships between flow and TP load (left) and PO_4-P load (right) in the outflow from Balgavies Loch, 2014-2017.

Conclusions

To divert water with high P concentrations away from Chapel Mires, flow diversion needs to take place

(1) between August and October, as these are the months when releases of P from the sediments are most likely to occur, and
(2) when large winter storm events which lead to poor retention of catchment sediment bby the lochs.

To reduce the delivery of high P loads to Chapel Mires, the outflowing water from Balgavies Loch needs to be diverted away from the wetland when the loch level is high. Based on end member mixing analysis (Vinten et al., 2018), Balgavies loch levels above 59.5masl (*P(exceedance)* =22%) lead to potential contamination of vulnerable Carex rich wetland (NVC S27a) with river water coming from the Loch.

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