Could managing water levels of Lunan Water at the outlet to Balgavies Loch help conserve Chapel Mires from eutrophication and loss of biodiversity?

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Photo courtesy of D.Vinten

1. Introduction

In the upper reaches of the Lunan Water, Angus, Scotland is a chain of wetlands and Lochs which have a high conservation value, surrounded by intensive mixed arable farmland. Water levels in this area at times generate flooding problems for local residents, farmers, roads, and recreational and fishing interests. Downstream there is a good deal of abstraction for irrigation of potatoes and horticulture with the result that the Lunan Water has been downgraded because of the ecological impact of low flows (SEPA). The presence of these three pressures on the water environment (ecological conservation, flood risk and low flow risk) has led to a proposal to intervene more actively in the management of the Lunan Water at the outlet to Balgavies Loch, where historic structures to control flows (a mill lade, weir and watermill) have been restored.

Currently the water level management of this area is principally according to riparian owner interests, and it has been proposed (Vinten et al.,2015; 2017) that installation of a tilting weir with greater range of base level and flows than is currently possible, might provide more flexibility of management across the various interests. We have considered the potential impact of such intervention on upstream and downstream flooding, and on low flows, elsewhere (Vinten et al., 2017, 2018), but our purpose here is to explore in more detail the interaction between Balgavies loch water levels and levels in the Lunan Water downstream, with the hydro-ecology of the wetland area known as Chapel Mires adjacent to the Lunan Water just downstream of this Loch. The N and P content of the waters leaving Balgavies Loch vary strongly through the year and our hypothesis is that it may be possible to reduce the ingress of such eutrophying waters into the Chapel Mires by management of an additional new weir with great capacity for water level control (or by improved management of the existing structures). This could help to reduce the spread within these wetlands of nutrient-loving, competitive species such as Canary grass (*Phalaris arundinaceae)* and Burr Reed (*Sparginium eructum),* and protect the more biodiverse and oligotropic *Carex* rich areas from degradation.

To assess the potential of such management change to achieve this, we have carried out intensive monitoring of water levels, water chemistry and wetland plant communities in the area in April-July 2017 and also during 2015, alongside more routine monitoring over the last 10 years, with the following objectives:

2. Objectives

A To improve our understanding of the relative contributions of Lunan Water and other sources (eg rainfall, shallow flows from adjacent land, groundwater, road runoff) to the flux of water and nutrients into Chapel Mires;

B. To draft a National Vegetation Classification (NVC) (http://jncc.defra.gov.uk/page-4259) map of chapel mires area and update quadrat-based species lists for quadrats;

C. To use this information to identify risks and opportunities for conservation of the wetland biodiversity in Chapel Mires, especially with regard to water management.

3. Site description

Figure 1 shows the distribution of some of the main non-agricultural land cover classes and surface waters in the upper Lunan Water catchment. Rescobie and Balgavies lochs, covering 1.78 km^2, support over 60 species of breeding birds and with their surrounds form a Site of Special Scientific Interest (SSSI).

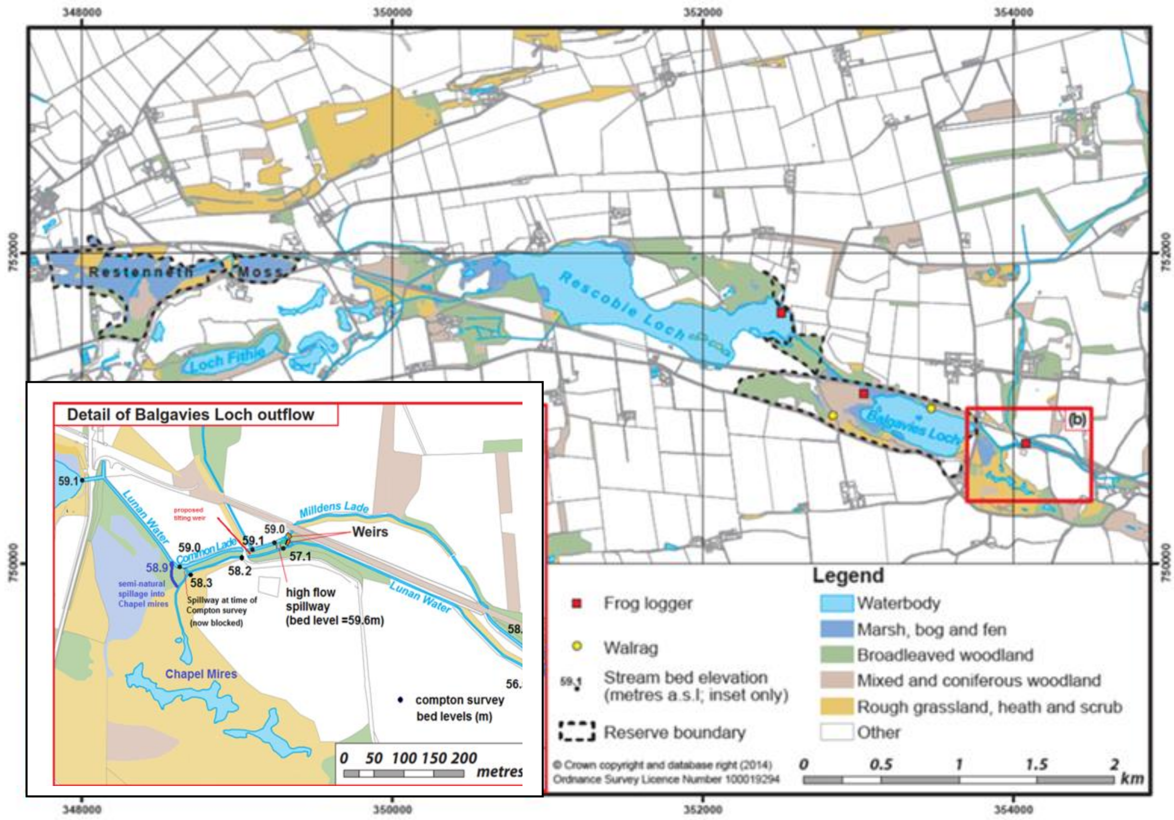

Figure 1. Overview of the upper Lunan Water catchment showing the main non-agricultural areas (MASTERMAP coverage) and positions of water level recorders in the current study (3 automated sites installed in 2014 and long term manual min-max-mean water level recording stations orWALRAGs). The inset shows detail of the Milldens weir and associated lades on the area downstream of the outlet to Balgavies Loch.

There are a number of aquatic species such as *Menyanthes trifoliata* (Bogbean) and *Utricularia australis* (Bladderwort) that occur in shallow water and any significant change in water levels are likely to affect them. In the area south of the Lunan Water (Chapel Mires) there is a complex mosaic of open water, willow scrub and sedge-dominated fen vegetation including National Vegetation Classification classes M9 (*Carex rostrata-Calliergon mire*), M27 (*Filipendula ulmaria –Angelica sylvetris* mire), S28 (*Phalaris* swamp), S9 (*Carex rostrata* swamp) and S27a(*Carex rostrata–Equisetum fluviatile* sub-community) occupying the lower lying areas. This has led to this area also being included in the Rescobie and Balgavies SSSI. The nationally scarce *Cicuta virosa* (Cowbane) and *Lysimachia thyrsiflora* (Tufted Loosestrife), could be threatened by changes in water levels or the input of nutrients. Note that the land cover classification shown in Figure 1 has insufficient discrimination to show the detail of the wetland mosaic, which is needed for informed water management of the area.

Positions of water level recorders in the current study are shown. These comprise 3 automated sites installed in 2014 (at Rescobie Loch, Balgavies Loch and above the existing Milldens weir gates which are shown in Figure 2) monitoring at 15 minute intervals and a long term manual min-max-mean water level recording stations or WALRAGs) which monitored at fortnightly intervals from 2003. Also shown in the inset of Figure 1 is the detail of the water courses in the region downstream of Balgavies Loch, where the existing and proposed water level control structures are located. The hydraulic arrangements downstream of Balgavies Loch are a complex system originally designed to bring water to two water mills located at Milldens, via two lades, one of which (the North Lade) has been restored to use along with its water mill (in 1980-82), the other (the South Lade) having been completely removed (within living memory, but some decades ago). A farmer in the catchment (John Compton of West Mains of Turin, now deceased) carried out a survey of the bed levels in the region downstream of Balgavies Loch in the 1980's. These are summarised in Figure 1 insert (after updating to metric units and rounding to the nearest 0.1m). Some of the flow in the common lade discharges through a semi-natural spillage zone into Chapel Mires. This rectangular gap (in the soft sediment wall of the lade) has a width of about 2.9m and a bed level of approximately 58.9m.

Figure 2. Existing weir gates controlling flow from the common lade into Milldens Lade (left) or returning to the Lunan Water (right).

4. Methods

4.1 Estimation of mixing of water from Lunan Water with Chapel Mires

Estimation of the current contribution of the water flowing from Balgavies Loch along the common lade into the Chapel Mires is a key objective for this project. To make this estimation we have employed end-member mixing analysis (EMMA) methods similar to those outlined by Christopherson and Hooper (1992) and Hooper (2016):

(1) a dataset was obtained of the concentrations of a number of conservative solute in samples of sources of water into the wetlands (eg river water, rainwater, road runoff, superficial and deep groundwater) and also at points within the chapel mires wetland open water bodies.

(2) The main solutes were measured to aid understanding of the mixing and the biogeochemical processes occurring in the system. The full list of determinands was as follows:

Al As B Ca Cu Fe K Mg Mn Na Ni Pb
Si Sr Zn Cl- SO42-S TOC F H^2 O^{18} pH EC NH_4-N NO_3-N
Total N Org N PO4-P Tot-P Org-P DOC Alkalinity

(3) The data were standardized into a correlation matrix such that solutes with greater variation do not exert more influence on the model than those with lesser variation and exploratory principal-components analysis (PCA) was performed on the correlation matrix using various combinations of solutes.

(4) A model was selected that accounts for the greatest amount of variability with two principal components, implying a three end-member model;

(5) The concentrations of the end members were standardized and projected into the U space defined by the PCA of the non-end member samples, by multiplying the standardized values by the matrix of eigenvectors;

(6) The extent to which the end members bounded the wetland open water observations was examined in U space;

(7) The goodness-of-fit of solute concentrations predicted by the EMMA was compared with the concentrations measured in the wetlands through least-squares linear regression.

(8) The above procedure could be carried out using an Excel worksheet supplied by Hooper (2016) in conjunction with PCA using Genstat 17.

Table 1 shows the field sampling programme from which the Principal Component and EMMA dataset was drawn.

4.2 Vegetation survey of Chapel Mires

A rapid identification of National Vegetation Classification (NVC) classes over the site, supported by survey with an RTK-GPS and aerial photographs, was carried out over 2 days in June 2017. The information obtained was used to construct a map of the area showing NVC classes for the non-open water areas. Two quadrats were installed in 2015 and species identification was done in May and July, with the expert support of T. Louizou a local conservation botanist, 2015 and again in June 2017. Quadrat Q1, NVC class 27a (*Carex rostrata*) was at 354103 750403; quadrat Q2, NVC class 27a was at 35395 735040. A pre-existing quadrat site was identified and sampled during June 2017, quadrat Q3, NVC class W3/S28 (*Carex/Phalaris arundinacea* boundary) at 35395 735040.

Site	Type	Dates	No. of samples	Easting	Northing	Sample letter code
Potential end members						
Lunan Water d/s of Loch	Loch/river	Sep 16- Dec 17	11	353789	750883	BAL
Balgavies Burn	Burn	Sep 16-Dec 17	11	354454	751184*	BB
Rainfall	Rainfall	Apr 12-June 17	15	various		Rain
Woodland Pond	Pond	May-Jun 2017	3	354227	750437	Wood
Roadside gully pot S. of Chapel Mires	Road runoff	2017	2	353711	750401	GP
Mixed samples						
Quadrat small wetland west	Wetland	Sep16-Oct 17	13	353953	750420	Q2
Quadrat small wetland east	Wetland	Jan-Oct 2017	11	354103	750403	Q1
Small wetland	Wetland	May-Jun 2017	4	354138	750382	C
Small wetland	Wetland	May-Jun 2017	4	354065	750384	E
Small wetland	Wetland	May-Jun 2017	4	354000	750386	G
Small wetland	Wetland	May-Jun 2017	1	353939	750420	I
Pond 1 – repeat sampling site	Pond	Sep16-Oct 17	13	354115	750456	Qx
Pond 1	Pond	May-Jun 2017	4	354059	750466	M
Pond 1	Pond	May-Jun 2017	3	354081	750504	P
Pond 1	Pond	Apr-Jun 2017	3	354013	750527	S
Pond 2	Pond	May-Jun 2017	4	353884	750519	K
Pond 2	Pond	May-Jun 2017	3	353826	750556	U

*This is the sampling point. Balgavies Burn enters the Lunan Water Common lade at: 354029 750774.

Table 1. Water samples for End Member Mixing Analysis at Chapel Mires.

5. Results and discussion

5.1 Mapping of NVC categories, quadrat species lists and their implications

A detailed draft map of the National Vegetation Classification habitat codes for the Chapel Mires area is shown in Figure 3. The key thing to note in respect of water management options is the presence of competitive, nutrient and sediment tolerant species such as Canary Grass (*Phalaris arundinacea*), Burr Reed (*Sparganium erectum*) and Common Reed (*Phragmites australis*), which show possible evidence of spreading from the northern area close to the river into the more biodiverse sedge-rich southern areas. Quadrat species lists for 3 sites sampled in this project are supplied in Table 2. Other quadrat sampling data can be found in Vinten et al. (2017).

The quadrats show the presence of rare species such as *Lysimachia thrysifolia* in the NVC S27a areas but not in the northern quadrat (Q3) located at the edge of the *Phalaris* dominated area. *Lysimachia thyrsifolia* is on the GB Red List as critically endangered and IUCN as Least Concern. It would likely be affected by any N-enrichment or by encroaching woodland as it requires high light levels.

We used community-weighted Ellenberg values (Ellenberg et al., 1991) to compare N and moisture (water levels) in each of the quadrats. The vegetation composition of Q1 indicates a more or less infertile site with low levels of nitrogen; The quadrat Q3 is in an area of intermediate fertility/nitrogen levels and Q2 is intermediate to these two. The vegetation at Q1 and Q2 is characteristic of permanently wet sites while Q3 suggests damp but not wet soils. The vegetation data is showing no evidence of any change in nutrients or water level between 2015 and 2017.

The NVC communities probably most as risk of change are S27a which requires high water and nutrient levels. M9 is the habitat most limited in its distribution at a national scale. It would be important to maintain a high water table in this area to prevent succession to woodland.

Holaday et al (2015) noted that *Carex stricta* "appears to be adapted to tolerate low nitrogen availability but cannot respond as rapidly and extensively as *Phalaris arundinacea* when nitrogen supply is high". Werner and Zedler (2002) noted that sedimentation reduces micro-topography of *Carex* tussocks making them vulnerable to invasion *by Phalaris*. However it should also be noted (*O'Hare, pers.comm*) that these species are a normal part of the assemblage in mesotrophic systems and may not be progressing in their extent. The small areas of *Phalaris* in the central part of the area have been accurately mapped with the RTK-GPS system, so we can return in future to assess whether these areas are extending.

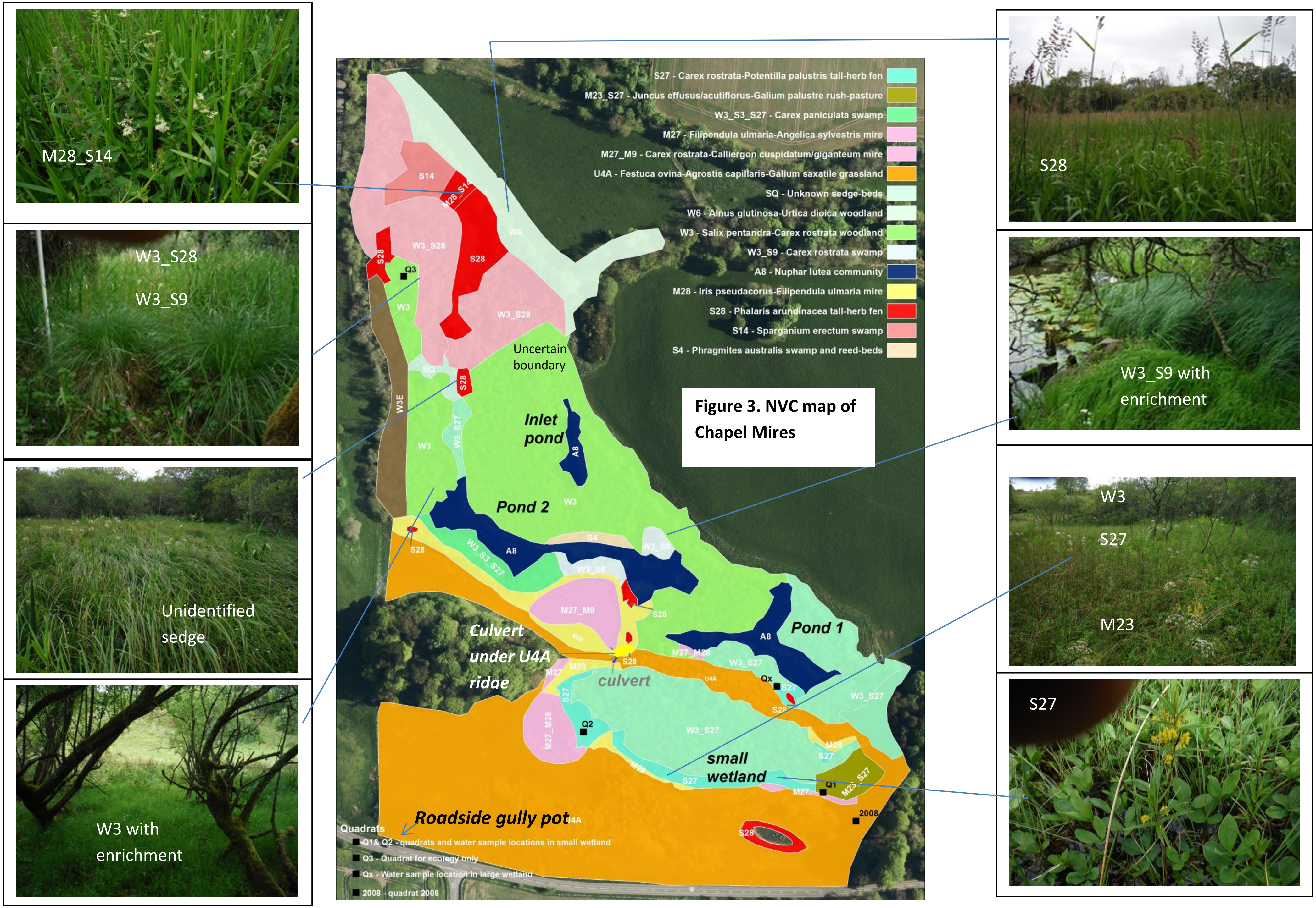

Figure 3. NVC map of Chapel Mires

QUADRATS	May- 15			Jul-15			Jun-17		
Quadrat	Quadrat Q1 S27a East Carex rostrata 354103 750403	Quadrat Q2 S27a West Carex rostrata 35395 735040	Quadrat Q3 W3/S28 P.arundinacea 353813 750739	Quadrat Q1 S27a East Carex rostrata 354103 750403	Quadrat Q2 S27a West Carex rostrata 35395 735040	Quadrat Q3 W3/S28 P.arundinacea 353813 750739	Quadrat Q1 S27a East Carex rostrata 354103 750403	Quadrat Q2 S27a West Carex rostrata 35395 735040	Quadrat Q3 W3/S28 P.arundinacea 353813 750739
Agrostis stolonifera	<1						0		
Carex disticha				<1			1		
Carex pedunculata			1			1			2
Carex rostrata	<1	5		<1	20		1	8	
Carex sp.	<1								
Juncus articulatus	1	<1		<1	1		3	2	
Phalaris arundinacea			40			50			50
Sparganium sp.			<1			2			<1
Angelica sylvestris						<1			
Caltha palustris			+						0
Chrysosplenium oppositifolium			<1			<1			0
Cicuta virosa	3	<1		15	2		1	1	
Comarum palustre	<1	<1		3	<1		<1	<1	
Epilobium ciliatum		4	<1		4	<1		4	<1
Epilobium palustre	2	4			10		2	0	
Filipendula ulmaria			15			35			15
Galium palustre		3	3			1		8	3
Iris pseudacorus	4	25	<1	5	40		10	30	<1
Lemna minor	3	1		1	<1		<1	<1	
Lysimachia thyrsiflora	20			20	1		30		
Menyanthes trifoliata	25	5		48	10		40	5	
Myosotis sp.		<1	2					<1	2
Myosotis scorpioides		1	<1		1	1		2	<1

Myrica gale	<1			1			<1		
Potamogeton polygonifolius	8			10			3		
Urtica dioca			<1			1			<1
Equisetum arvense?						<1			<1
Equisetum fluviatile	<1	<1	<1	<1	2		3	<1	0
Brachythecium rutabulum			?						
Calliergon cordifolium		30	?					40	1
Calliergonella cuspidata		<1						<1	
Hypnum cupressiforme			?						?
Utricularia sp.	<1			<1			0		
Alnus glutinosa			+						<1
Salix cinerea		+			2			2	

Table 2. Species lists and percentage cover for 4x4m quadrats Q1 and Q2 (see Figure 1) taken in Chapel Mires in 2015 and 2017. Species scored as <1 = present but at less than 1% cover, 0 = had been present but could not be found, + = present outside boundaries of quadrat, ? = identification uncertain, species may be present.

5.2 Principal component analysis and end member mixing analysis

A number of potential solutes for mixing analysis were considered for suitability for EMMA. We settled on Ca, Mg, Na, Si, F and K as these showed differences across potential end members, are likely to behave conservatively under changing redox, and do not duplicate. The potential end members that we considered initially were outflow from the Balgavies Loch, Balgavies Burn, rainfall, presumed groundwater-fed woodland ponds located topographic depressions in adjacent woodland to the south east of Chapel Mires, and a roadside gully pot to the south of the area (the Chapel Mires area is bounded to the south and west by roads contaminated runoff (containing high NaCl) would be important). The first two principal components explained 96.02 % of the variation across all data (Figure 4).

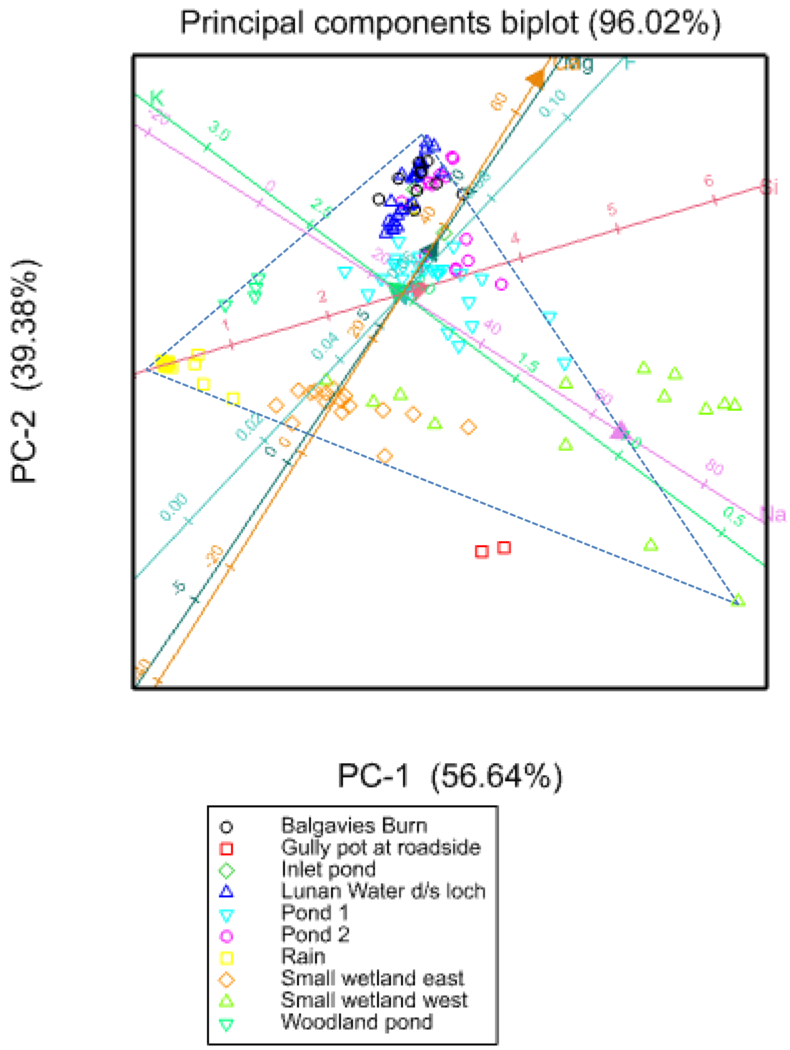

Figure4. PCA showing the distribution of water quality across Chapel Mires and potential end members using solutes Ca, Mg, Si, K, Na ad F. Also shown are the end members (Rainfall, Lunan Water d/s of Balgavies Loch, and an extreme value of small wetland west, assumed to represent road contaminated runoff from the south) which were used for End Member Mixing Analysis.

We see that Balgavies Loch outflow and rainfall form two useful apices for EMMA. There is clearly a contribution from Na rich water contaminated by the road, but neither the gully pot or woodland pond candidates form a clear third apex for the Na rich water. It is possible that runoff from the south is not well represented by our sampling. We considered the point in the extreme bottom right of figure 5 as a potential end member representing runoff from the south of the site into the western part of the small wetland. We have therefore carried out exploratory end member mixing analysis using this sample point as the third end member, together with the outermost values of the rainfall and Balgavies Loch outflow samples to form the apices of a triangle. This enables us to estimate proportions of water coming from the Lunan water d/s of Balgavies Loch, rainfall and runoff from the south. Figure 5 shows results of these calculations. Note those points in the wetland which show no contribution from the Lunan Water are in the NVC S27a area to the south of the culvert which offers protection from incoming water to the north when water levels are low (see Figure 3). Pond 2 has the highest proportion of loch water while pond 1 is intermediate. Neither of these vary greatly through the year, but the proportion of Lunan Water end member in the western part of the small wetland certainly does, with evidence that at high water levels (>59.5m), there is more transfer of water from the north.

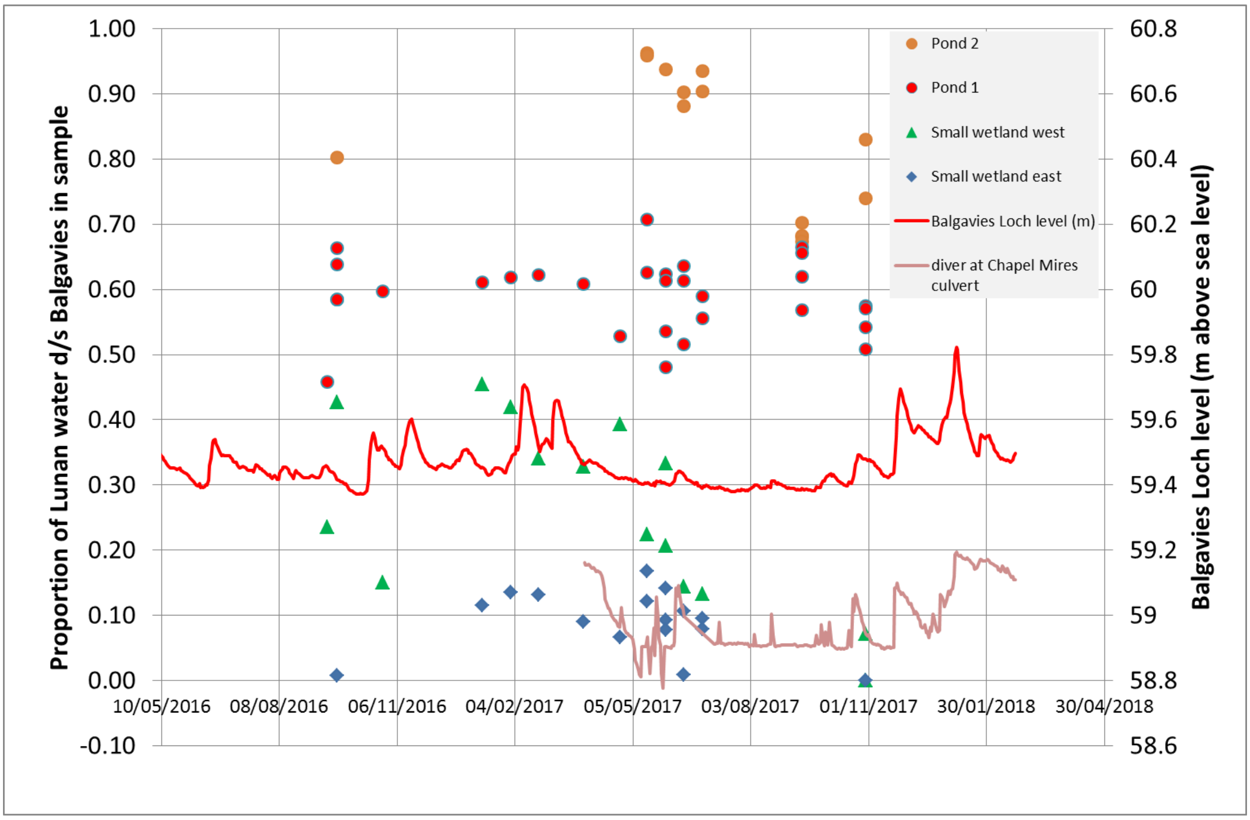

Figure 5. Estimation of the contribution of the Lunan water d/s of Balgavies to the composition of samples in Chapel Mires wetland. Also shown is the Balgavies Loch water level, and the water level in the diver located in a dipwell at the culvert between the small wetland and the ponds in Chapel Mires.

5.3 Controls on water levels in the southern part of chapel mires

The water levels observed at the culvert between the ponds and the small wetland in the southern part of Chapel Mires from June 2017 to January 2018 are shown in figure 6. Results are plotted against water levels in Balgavies Loch for a series of events. These results show that changes in water level in Chapel Mires occur without change in Loch levels and show little hysteresis, suggesting groundwater control and/or input from the southern end member. The clockwise hysteresis loops widens for Sep/Oct/Nov perhaps reflecting filling of ponds 1 and 2 providing a barrier from the North, slowing drainage of surface runoff from the south through the small wetland. In the Dec 2017 –Jan 2018 event, a totally difference response occurs, with long lasting hysteresis and an anticlockwise loop. This probably reflects the point at which direct filling of the small wetland from the north occurred, corresponding to a Loch water level of around 59.7m. This level might serve as a useful guide for when control of water entering Chapel Mires from the North would prove directly beneficial to reducing nutrient loads, although lower water levels are relevant to nutrient loading of the two ponds.

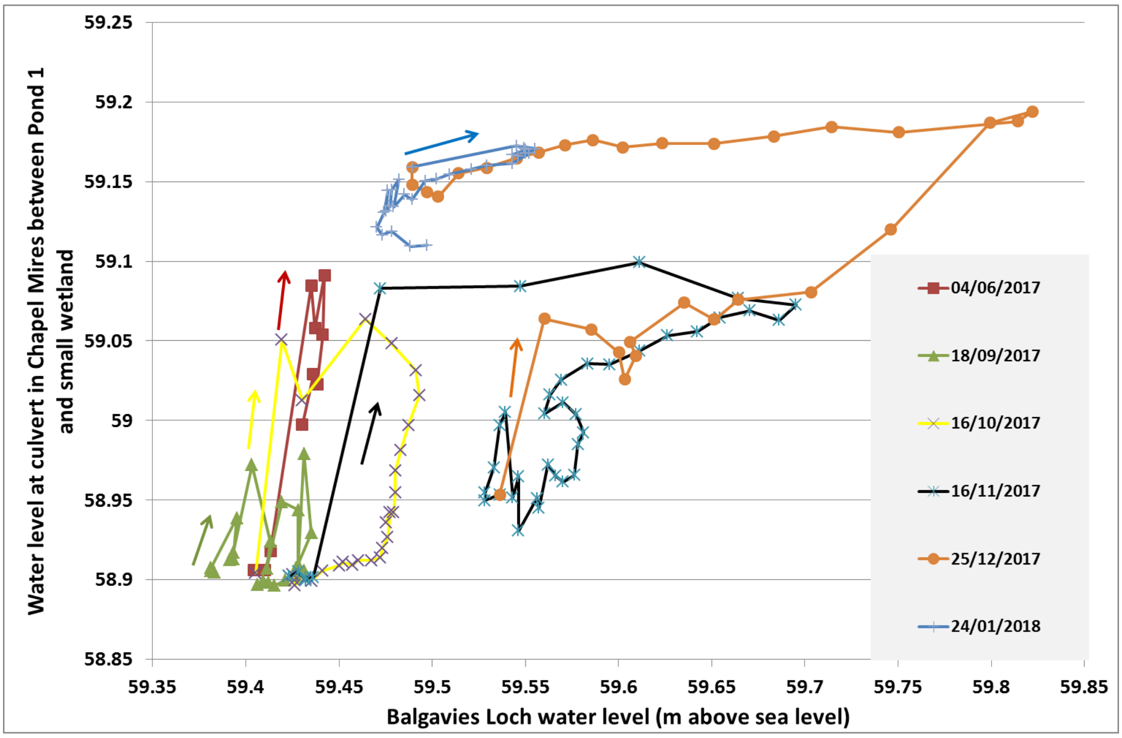

Figure 6. Plot of water levels at culvert between Chapel Mires ponds and small wetland for events from June 2017-Jan 2018. Levels are compared with observations in Balgavies Loch.

6. Conclusions

The analysis of water sample data from Chapel Mires has shown that there is mixing of the Lunan water d/s of Balgavies Loch with other, less enriched sources such as rainfall, road runoff and oligotrophic groundwater. This varies across the site, with less Loch water in the southern, species-rich NVC S7a Carex wetlands than in ponds 1 and 2 in the centre of the area. The southern area is partially protected at low water levels by a culvert (see figure 3), but not at high water levels (Loch levels >59.7m). A rule base could be developed, using annual pattern of P loads from the Loch, as described by May and Vinten (2018). Information from this report can now also be brought together with a hydrological/hydraulic model of the system, to identify how to manage flows with an artificial tilting weir (see Vinten et al., 2018).

7. Acknowledgements

We thank Mr James Osborne of Balmedies Farm /Estate for permitting us access to Chapel Mires to collect water samples, carry out vegetation survey, and for useful discussions with him about the practical and governance issues associated with the scheme.

We thank Peter McPhail of SNH for helping with identification of NVC classes on site during June 2017.

We also thank Scottish Government for the funds to carry out the Payments for Ecosystem Services – Lessons research project, of which this “Water for All” project forms an important part. This project was part of Work Package 1.4.3.

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