**Restoring hydrological regimes for rich-fen habitats on the Anglesey & Llŷn Fens Special Areas of Conservation, North-west Wales**.
(extract from Proceedings of Technical LIFE Project Workshop).

Peter S. Jones, Justin Hanson, Janine Guest & Rhoswen Leonard

## Introduction

Restoring appropriate hydrological regimes is often an important component of fen restoration. Definition of what constitutes a favourable hydrological regime for a particular wetland feature is an important first but sometimes difficult step in this process. For example, hydrological conditions characterised for wetland plant communities of conservation value at a particular site may not necessarily be optimal for that community. Furthermore, there may be significant variation between sites or even locations within a site in terms of the hydrological conditions associated with a particular plant community, habitat or feature of conservation interest (see Low *et al*., this volume). Nevertheless, in recent years several important initiatives have sought to provide guidance on the hydrological conditions associated with particular target fen habitats (e.g. Wheeler *et al*., 2009; 2010). One of the aims of these projects has been to help hydrologists and ecologists understand how specific hydrological impacts in or adjacent to a site might be expected to affect specific wetland features of conservation interest. A further important aim is to introduce a more rigorous approach to planning and implementing restoration measures to restore hydrological regimes associated with particular wetland types where drainage or other impacts have resulted in adverse or at least sub-optimal hydrological conditions (notwithstanding the caveats above!). There has also been a drive to improve understanding of the hydrological processes that influence fens, with a view to ensuring that restoration achieves appropriate outcomes (e.g. Grootjans & van Diggelen, 1995; Grootjans *et al*., 2005).

Actions to restore hydrological regimes consistent with rich-fen formed an important part of the Anglesey & Llŷn Fens LIFE project. This section reviews the main measures employed and some interim results for key case examples. The chapter by Leonard *et al*. (this volume) describes the special case of Cae Gwyn which represents a particularly spectacular example of restoring groundwater influence and raising water levels.

## Overview of main categories of hydrological restoration

The importance of restoring calcareous groundwater influence was recognised as being at least as important as restoring or retaining wet conditions during the early years of the conservation management of the wetlands considered here (see Ratcliffe, this volume; Gilman & Newson, 1982; Gilman 1994). Considerable restoration effort was devoted to both issues from the 1980s onwards at Cors Erddreiniog in particular, despite the then Nature Conservancy Council's tenuous hold (and rather limited powers) over the sites. Early pioneering work by Les Colley achieved notable improvements in the hydrology of areas of fen affected by drainage (Gilman, 1994) and extended to infilling some marginal so-called 'foot-slope' drains along the eastern edge of Cors Erddreiniog. These measures undoubtedly served to extend the influence of calcareous seepage whilst also preventing further drainage and wastage of adjacent peats. Extensive bunding and programmes were also undertaken, together with the installation of a major sluice on the main outflow of Cors Erddreiniog in the early 1990s. The sheer extent and severity of hydrological modification at Cors Erddreiniog and most of the other project sites was such that significant scope for further restoration remained at the beginning of the *LIFE* project.

Detailed review of all the potential project sites was undertaken during the formulation of the *LIFE* project to identify locations where hydrological intervention was needed. This process confirmed the requirement for two primary categories of intervention, namely raising water levels, and restoring groundwater pathways (Table 1) with a third category (modifying drainage systems to reduce flooding and extend groundwater influence) identified as the project progressed .

**Table 1**. Summary of main categories of hydrological restoration and key examples across the Anglesey & Llŷn Fens *LIFE* project area. * = featuring as case studies in this chapter.

| ***Hydrological restoration category*** | ***Key examples*** |
|---|---|
| Restoring groundwater influence through reconnection of spring-heads and other groundwater supply pathways. | Cors Bodeilio (Fly Orchid Spring)*<br>Cors Erddreiniog (Nant Isaf springs & Cae Gwyn)<br>Cors Geirch (Mathan Uchaf springs)*<br>Cors Geirch, Cors Ceidio* |
| Raising / stabilising water levels. | Cors Cefn Uwrch ditch blocking and bunding *<br>Cors Erddreiniog ditch blocking west of Cae Gwyn<br>Cors y Farl main ditch weir* |
| Modifying drainage systems to reduce the depth and duration of flooding and extend groundwater influence | Cors Bodeilio compartments 3 & 4*<br>Cors Erddreiniog<br>Cors Hirdre main ditch project* |

Low *et al*. (this volume) describe the main methodological approaches used to define the specific requirements for hydrological restoration.

**Table 2**. Key criteria employed in the selection and design of hydrological restoration project elements for the Anglesey & Llŷn Fens LIFE project.

| ***Key criteria for design of hydrological restoration projects*** | ***Approach / solutions*** |
|---|---|
| Hydrological restoration must not cause undesirable effects on neighbouring land. | Land purchase if effects are likely.<br>Negotiation / land management agreements<br>Prevention of effects through scheme design – e.g. topographic survey. |
| Hydrological projects should ideally deliver wider ecosystem benefits as well as specific benefits for the Annex I features and associated fen features. | Location of peat deposits likely to be affected by hydrological restoration measures, with associated benefits for C storage and potential sequestration. Topographic information to indicate likely benefits in terms of water storage and runoff attenuation. |
| Hydrological restoration should be designed to work with the hydroecological 'grain' of the project sites. | Development of conceptual model of current hydrological processes and comparison with perceived hydrological supporting conditions of target habitats, with particular reference to the Wetland Framework approach of Wheeler *et al*. (2009). |
| Restoration should be sustainable in the long-term with a minimum of maintenance. | Preference for 'low-tech' solutions using site-won peat with simple gravity-fed overflows etc. |

## Case study 1. Modifying drainage systems to reduce the depth and duration of flooding: Cors Bodeilio (Anglesey Fens SAC) case-study.

An overview of Cors Bodeilio is provided in the relevant conference excursion account. Three extended rectangular and more or less flat compartments occupy much of the south-eastern part of the site, extending some 0.5 km from the SE edge of the site to the axial drain (Figure 1). All three compartments were once drained by

means of longitudinal ditches feeding into the main axial ditch, but these had become largely ineffective due to peat infill and sedimentation, with one being infilled deliberately to limit drainage. Lack of drainage here is suspected to have contributed to dereliction and the spread/consolidation of dense stands of *Juncus subnodulosus* and *Phragmites australis* at the expense of areas of alkaline fen (both M13 and M9).

In coarse hydroecological terms the main expanse of fen is probably best described as rheo-topogenous, exhibiting characteristics of both WetMec 8 (groundwater-fed bottoms with aquitard) and 16 (groundwater flushed bottoms). The thin deposit of residual peat is only *c*. 0.4 – 0.6 m deep over a stiff silty clay which probably restricts groundwater seepage to the edges. The target regime in this case was to maximise the influence of water percolating from the site margins, whilst limiting the depth and duration of flooding. Re-excavation of the longitudinal ditch between compartments 3 and 4 was undertaken to try and achieve this. The ditch was excavated to *c*. 0.5 m depth using a staggered system such that the ditch alternates either side of the low boundary bank between the two compartments – thus achieving a degree of drainage for both compartments without having to excavate two parallel drains with attendant issues of spoil disposal. The ditch passes through three peat cuttings created by the LIFE project, partly to address peat softening caused by repeated Pistenbully tracking when compartment CB4 was mown in 2010. A 360 degree 12 Tonne excavator fitted with wide tracks was used for this work, with ditch arisings being spread on alternating sides of the raised bank separating the two compartments.


**Figure 1.** Oblique aerial photograph of Cors Bodeilio taken in October 2011 and looking SE down the long-axis of compartments 3 and 4. The newly opened ditch line (yellow line – diagrammatic only and not exact form) replaces two earlier largely infilled features (dashed white lines) and drains NW into the main axial ditch (blue line) which flows from R to L in this image. Hydrological and rainfall data for location D1 are presented in Figure 2 and Table 3.

The mire level falls by only *c*. 0.4 m along the 500 m long axis of compartment CB3. The pale line on the LH side of this image is the boardwalk.

Re-excavation of the ditch resulted in an drop in water level at station D1 in the centre of the compartment (some 52 m away from the ditch line – see Figure 2) of 2 cm between 20 and 21/1/12 despite 2.4 mm of rainfall on the 21st, and thereafter water levels deeper than 14 cm do not occur again during the following month despite a series of significant rainfall events. Comparison of monthly mean water levels before and after the ditch was re-opened indicate it has achieved a mean drop of a few cm (Table 3) and there is evidence from hourly data-logger measurements of water level that water level spikes induced by rainfall are of shorter duration, though the overall duration of flooding has probably not been affected significantly (further statistical analyses of these data are underway).

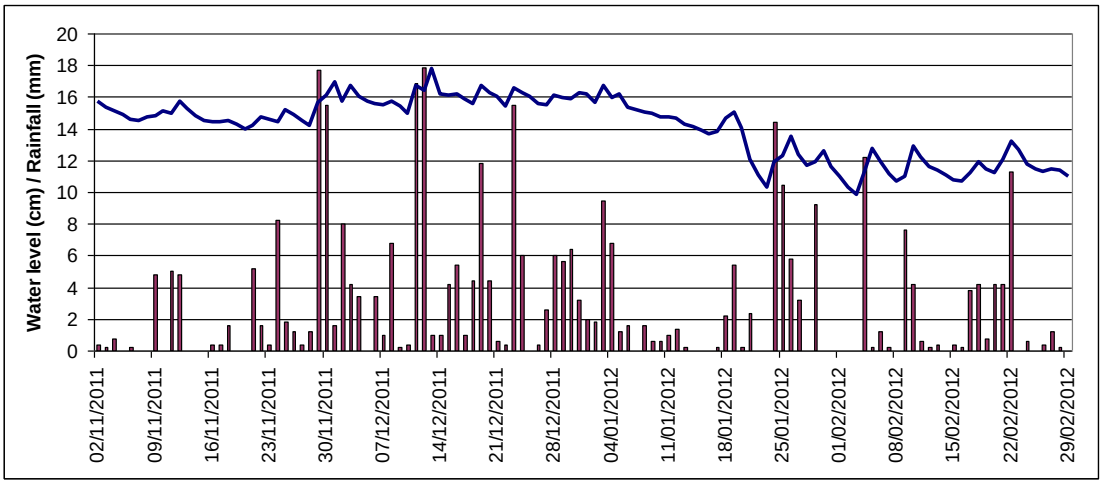



**Figure 2.** Average daily water levels (cm relative to peat surface, mean of 24 hourly measurements) and daily rainfall totals (mm) for station D1 at Cors Bodeilio between 2 November 2011 and 29 February 2012. Work to re-open the ditch between compartments CB 3 and 4 began on 18/1/12.

| | Feb 2009 | Feb 2010 | Feb 2011 | Feb 2012 | Feb 2013 | Feb 2014 |
|---|---|---|---|---|---|---|
| Average water level (cm) | 11.3 | 12.4 | 14.04 | 11.5 | 10.4 | 11.3 |
| Rainfall (mm) | 16 | 42.4 | 124.6 | 58.4 | 65.3 | 139.8 |

**Table 3**. Comparison of mean February water levels (above ground) at Cors Bodeilio dipwell D1 based on hourly measurements for months before (2009-2011) and after (2012-2014) re-opening of a nearby ditch. Note the difference in levels before and after ditch re-opening for months with broadly comparable rainfall totals, notably 2010, 2012 and 2011, 2014.

The rather modest effect of drain re-opening probably reflects the shallowness of the ditch and the very gentle hydrological gradient of 0.08% along the long axis of the compartment and 0.01% across its width. In hindsight, sections of the ditch could have been excavated to a greater depth (though this would have created even more spoil, with attendant problems of disposal) to further reduce the depth and duration of flooding, with a system of simple sluices employed to avoid significant seasonal dewatering of adjacent peats. A significant associated benefit of this project has been the appearance of substantial new populations of *Potamogeton coloratus* and Charophytes in the ditch (Figure 3).

Opening up overgrown or silted ditches to prevent flooding of *Schoenus nigricans* vegetation formed part of the 1995-1998 Belgian LIFE project for calcareous mires

(Raeymaekers, 2000). There is scope for extending the approach to other locations on the project sites.

**Figure 3**. Drainage ditch between compartments CB3 and CB4 at Cors Bodeilio NNR. Photo taken in March 2014, two years after the ditch was re-opened. Note dense patches of *Chara* in the foreground and surrounding flooding.

**Case Study 2. Raising/stabilising water levels: installation of a control structure on the main site drain at Cors y Farl (Anglesey Fens SAC).**

Cors y Farl (SH 490778) occupies a shallow basin on Carboniferous Limestone and supports a large central stand of *Cladium* swamp and fen (Figure ) with a narrow fringe of more open rich-fen including *Carex rostrata* – *Calliergon* spp. mire (M9), *Schoenus* dominated mire (M13) and a swampy form of *Juncus subnodulosus* fen meadow supporting a range of M9 species (Birch, 2008). The extent of wet *Cladium* swamp at Cors y Farl is unusual amongst the fens series (Figure 4).

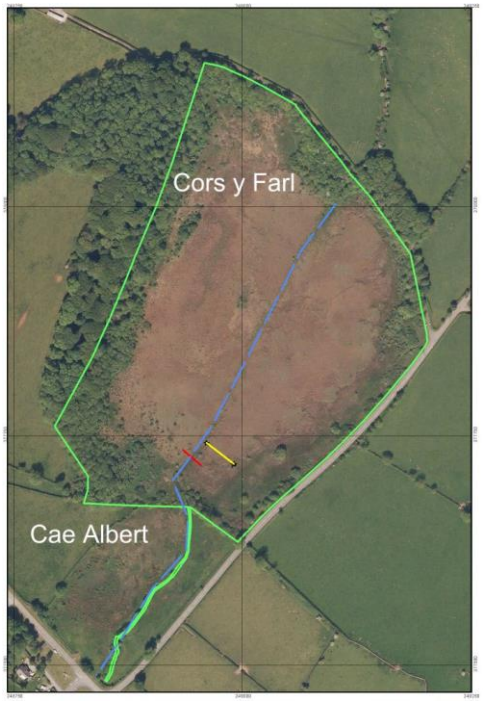



**Figure 4**. Aerial photograph of Cors y Farl (Anglesey) showing the SSSI boundary (green line), the axial ditch (blue dotted line), the levelled transect referred to in the text (yellow line) and the weir and stock-bridge (red line). Fine black lines are OS 250 m grid lines. An annex to the site (Cae Albert) was restored through scrub removal, mowing and grazing by LIFE project Konik ponies, which revealed important stands of alkaline fen.

The stratigraphy of the site (based on Huggins, 2008; Wheeler & Shaw, 2009) consists of a relatively shallow (30 – 70 cm) surface layer of sloppy peat and rhizomes over deposits of marl alternating with bands of silt/clay to at least 500 cm depth. Groundwater supply appears focused around the site margins as generally intermittent seepages, with more localised areas of sustained seepage and springs. Much of the topogenous basin is referred to the seepage percolation basin WetMech (#13) of Wheeler *et al*. (2009), with marginal groundwater flow seeping through the rather transmissive surface peats. The wetness of the basin may be related more to constraints on water outflow (including via the largely occluded axial drain) than the magnitude of groundwater inputs. The straightness of the axial drain indicates it was canalised in the past, though the mire may have spawned a natural headwater stream. Limited water chemistry data for the site indicates a low concentration of nitrate (<0.2 mg/l) and substantial amounts of calcium (137 mg/l) in the drain at the (upgradient) NE corner of the site at or close to its apparent origin, possibly indicating groundwater influence. Similar results (but with higher pH and calcium) were obtained for marginal springs (Farr *et al*., 2012).

The *LIFE* project assessment for this site was that water levels in the main drain should be maintained at a high level to sustain wet *Cladium* swamp, but with a slight hydrological gradient down towards the drain from the site margins. Water quality data indicated there were no significant enrichment issues related to the drain water chemistry, thus ruling out the need to maintain an open drain to prevent overspill of potentially enriched water (see for comparison the case study for Cors Hirdre). The ability to adjust drain levels was considered important to enable access for mowing or grazing for at least the peripheral stands of *Cladium*, and also to encourage a more significant hydrological gradient from edge to axis (a levelling survey indicated a more or less flat water table profile over a 40 m transect out from the main drain). The option chosen for Cors y Farl was to replace an existing but leaking timber sluice with a cheap adjustable design installed in conjunction with a stock-bridge to encourage pony access to the western side of the fen (Figure 5). The 1.2 m wide sluice consists of two metal open-sided box sections into which 15 cm high hardwood (alder) planks can be dropped, thus allowing fairly sensitive manipulation of drain levels. Manipulation of drain levels can now be undertaken in association with water level monitoring across the fen to determine an optimum long-term level for the main drain.

**Figure 5.** The main drain sluice at Cors y Farl installed by LIFE contractors A.J. Butler and Matt Sutton in spring 2013. Alder weir boards are visible stacked on the boardwalk ditch crossing beside the stock-bridge.

**Case study 3. Raising/stabilising water levels: installation of peat dams and bunds at Cors Cefn Uwrch (Anglesey Fens SAC.**

Cors Cefn Uwrch is a valley-head fen located immediately to the SSE of Cors Erddreiniog. A canalised ditch runs down the long-axis of the site and numerous side drains feed into this at c. 90 degree angles: some at least of these ditches may have been dug to aid peat removal (see Justin & Hanson in Proceedings of Technical Workshop). A further feature of the drainage of this site is a fen-margin drain along its western edge. The vegetation of the western side of the fen includes large areas of degraded *Molinia* dominated vegetation (see Figure 5 of Birch *et al*., in Proceedings of Technical Workshop) over a very dark highly humified peat with low summer-time water levels. In its pre-restoration state, the site was probably referable to the drained ombrotrophic WetMech (#4b) of Wheeler *et al*. (2009).

Purchase of part of the western section of the site through LIFE project funding in early 2013 enabled a hydrological restoration project. The purchase included a sizable grassland strip to act as a buffer against fertiliser and other land-spreading applications on the neighbouring agricultural fields. The restoration method chosen in this case was to use peat dams at intervals of *c.* 20 m in each of the lateral drains (Figure 6), with dams being constructed into a pre-excavated notch recessed into the peat either side of the drain to act as a 'key' for the dam (Figure 7). Peat for each dam was obtained by excavating shallow (c. 0.4 m deep) adjacent scrapes which could be reached without the 360 degree excavator changing position: these scrapes will provide small patches of bare peat for early successional vegetation and some may hold water for much of the year. Each scrape had to be dug deep enough to obtain well humified peat lacking a substantial root content to ensure the material was suitable for dam construction. Each dam was completed *c*. 0.2 m above the surrounding ground surface to allow for settlement (Figure 8). This will also prevent any issues associated with overtopping, with any overflow passing around the dams instead. This is unlikely to be a very significant issue because no individual ditch acts to impound a large volume of water. In addition to blocking all the major ditches in this section of fen, shallow bunds are also being trialled to try and rewet shallow peat-cuttings which occur widely on the site.

Vegetation was removed from selected ditch sections between dams to create linear open water pools, but with sections of *Cladium* swamp within the ditch lines avoided (Figures 9 & 10). All operations required the use of a 360 degree tracked excavator – in this case a specialised 12 tonne machine fitted with 1.2 m wide tracks (Figure 11). Table 4 provides an analysis of the main advantages and disadvantages of the approaches employed, and Table 5 provides a comparison of water levels in blocked and unblocked ditches.

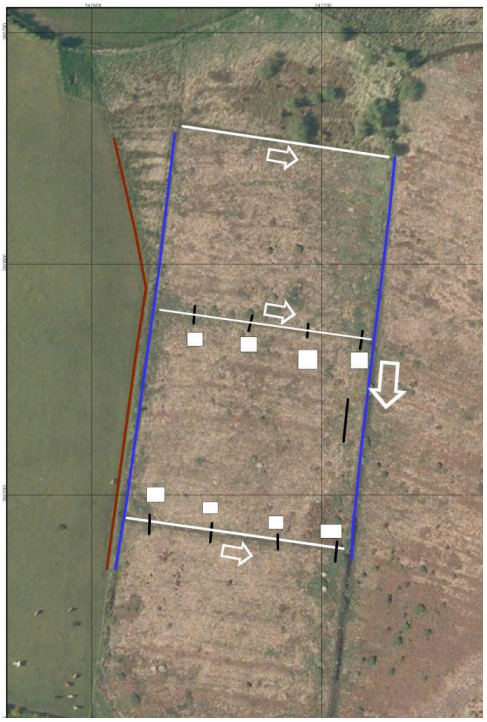


**Figure 6**. Part of the Cors Cefn Uwrch fen subject to installation of peat dams. White lines indicate lateral ditches feeding into the main axial drain (blue line) with peat dams shown in black and scrape areas as white circles. The fen-margin drain (also shown in blue) lies just inside the original fenceline (part of which is shown here in brown). Purchase of the western side of the fen included a substantial grassland buffer. Fine black lines are OS 250 m grid lines. Dams are only shown for two of the ditches for clarity – see also Figure 8.

**Figure 7**. Excavation of a notch in a ditch line running left to right. The notch is recessed into solid peat either side of the drain to act as a 'key' for the peat dam.

**Figure 8**. Completed peat dam perpendicular to the left to right axis of the drain. Note the thickness (left to right in this image) of the dam.

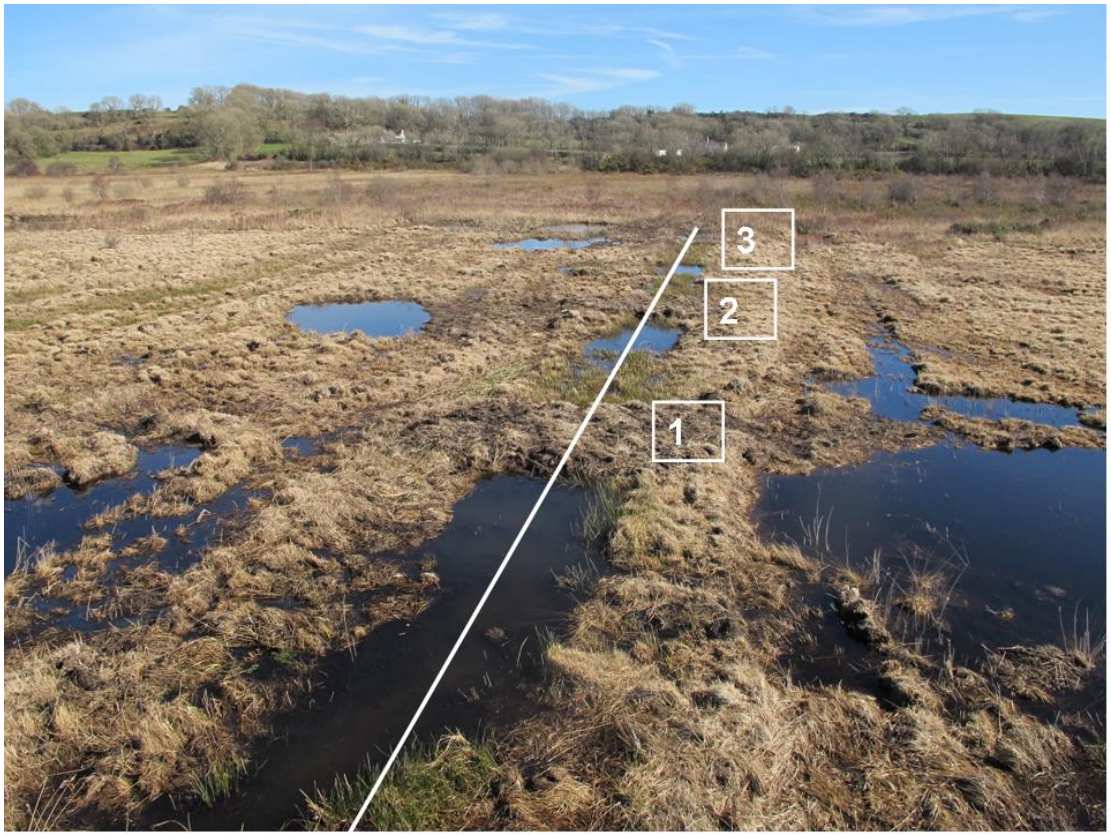



**Figure 9**. Mast photograph from an elevation of *c*. 5.5 m above ground level looking down one of the blocked ditch sections at Cors Cefn Uwrch. Three dams are visible, with the

original line of the ditch indicated with a white line and flooded peat pits either side. Image is looking ESE

**Table 4.** Summary of issues relating to choice of method for blocking ditches at Cors Cefn Uwrch.

| *Option* | *Advantages* | *Disadvantages* |
|---|---|---|
| Peat dams | Uses local material derived from site. Additional benefit in this particular context is the creation of open seasonally flooded peat scrapes for early successional / open water species. | Vulnerable to trampling damage from grazing animals. Peat dams can leak, though this has hopefully been minimised by creating dams at least 1 m thick. Leaves relatively deep flooded sections of ditch which may act as a methane source. |
| Installation of synthetic dams | Can be installed by hand, requires minimum of machinery/equipment. Eliminates need to excavate peat for dam construction. | Cost. Requires use of synthetic material with a carbon cost associated with manufacture and transport. |
| Complete infill of ditches | Reduces risk of leakage still further and avoids risk of entrapment if grazing animals in flooded ditch sections. | Would require a substantial volume of peat to the extent that a parallel ditch-like feature could be created. Complete infill eliminates open-water habitat. |

**Table 5.** Comparison of water levels (cm, relative to adjacent peat surface) in unblocked and dammed ditches at Cors Cefn Uwrch for a single measurement date in March 2014. The difference between median values is significant (*U* test, p = 0.0285).

| **Management (n)** | **Average** | **SD** | **Max.** | **Min.** |
|---|---|---|---|---|
| Blocked (4) | -2.9 | 3.8 | 2 | -8.2 |
| Un-blocked (4) | -18.3 | 7.9 | -11 | -26.5 |

**Figure 10.** Section of ditch between dams subject to ‘de-weeding’ to create open water.


**Figure 11.** 360 degree Hitachi excavator fitted with 1.2 m wide tracks. This or similar machines were used at Cors Cefn Uwrch, Mathan Uchaf, Cors Bodeilio and Cae Gwyn for peat stripping and hydrological restoration projects.

**Case study 4. Restoring groundwater supply: fly orchid spring at Cors Boldeilio NNR (Anglesey Fens SAC).**

Fly Orchid Spring represents the most potent visible source of groundwater at Cors Bodeilio. Spring flow only occurs during high water table levels, with an average discharge of 0.82 l/s (70.8 $m^3$/day, n=95) with a range to-date of 0.003 (7 May 2013) to 2.82 l/s (19 November 2009). The spring water is calcareous (120 – 140 mg/l of calcium) and although displaying comparatively elevated N there is little evidence to-date of enrichment downgradient of it.

Discharge from the spring irrigates one of the best areas of M13 alkaline fen in the fens series and up until the LIFE project was intercepted by a side ditch of the main axial drain downgradient of the M13 (Figure 12). The side ditch prevented groundwater discharge from fly orchid spring reaching an area of *Cladio-Molinietum* vegetation with areas of alkaline and calcareous fen. Restoring groundwater flow to this area was an obvious option, but complete infill of the ditch could not be undertaken because of the need to maintain free drainage for neighbouring farmland. For this reason the option chosen was to bury a 450 mm diameter bypass pipe along the 145 m length of ditch section A-B shown in Figure 12 and then carefully backfill the void to encourage diffuse groundwater flow across it.

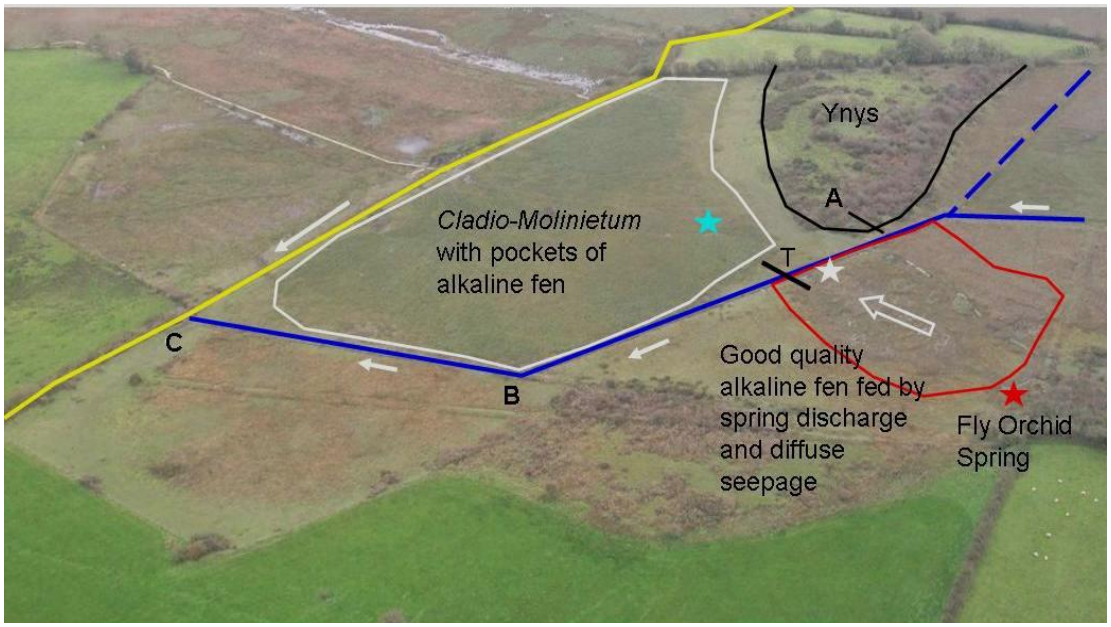



**Figure 12**. Oblique aerial photograph of fly orchid spring restoration area looking SE from approximate NGR SH 500778. The ditch described in this case study is shown as a solid blue line with flow direction indicated with white arrows. This ditch connects with the main axial drain (yellow) at point C. The bypass pipe installed during this project runs between points A and B. Fly orchid spring is marked with a red star and the former point of focussed discharge to the drain as a white star, with the open white arrow denoting one of the key flow routes. The blue star E of the Ynys marks a point where a groundwater upwelling was noted in the winter of 2012/13. The dashed blue line marks a minor non-flowing drain which separates an area of alkaline fen at the base of the Ynys (left) from calcareous fen to the right. The red boundary line denotes the main area of good quality alkaline fen (mainly M13) influenced by fly orchid spring.

Installation of the bypass pipe had the immediate effect of allowing spring water to spread out over the area down-gradient of the former ditchline. Hourly measurements of water level for a well in this area shows higher and more stable water levels compared to the pre-intervention period (see Technical Report 2), but with the two sets of results separated by periods of significant water table drawdown during the comparatively dry summer of 2013 when flow from fly orchid spring ceased. Although based on limited data, concentrations of calcium in groundwater downgradient of the former ditch line also appear to have increased since the ditch was infilled (Table 6).

A benefit of the bypass pipe option chosen here is that the inlet of the pipe could be fitted with an adjustable 90 degree bend to raise levels in the upstream ditch network, thus countering seasonal water table drawdown in the ditch and adjacent peats (see Table 7 and Technical Report 2) whilst also providing overspill into the pipe. Topographic survey confirmed that overbanking of the ditch system would serve to prevent any flooding of neighbouring agricultural land (Figure 13)

**Table 6**. Calcium concentrations (mg/l) determined for each of the six dipwells (D1-6) straddling the ditch downgradient of fly orchid spring for two dates before (26/4/13 and 2/5/13) and two dates after (18/6/13 and 20/9/13) measures to restore groundwater flow across the drain alignment. Data for wells D4-D6 also include in brackets Ca concentration as a percentage of the mean concentration in the three wells upgradient of the drain. Installation of the bypass pipe and infill of the former ditchline was completed by 10th. May 2013.

| | *Upgradient of ditch, Ca mg/l* | | | | *Downgradient of ditch, Ca mg/l (% upgradient mean)* | | |
|---|---|---|---|---|---|---|---|
| Location | D.1 | D.2 | D.3 | Drain | D.4 | D.5 | D.6 |
| 26/4/13 | 117.4 | 118.2 | 124.9 | 119.2 | 77.3 (64.3) | 93.1 (120.3) | 37.4 (40.2) |
| 2/5/13 | 165.4 | 123.2 | 152.5 | 121.2 | 135.6 (92.2) | 147.5 (108.7) | 67.2 (45.8) |
| 18/6/13 | 132.3 | 133.5 | 125.9 | | 164.5 (125.8) | 154.9 (94.1) | 119.4 (77.1) |
| 20/9/13 | 149.9 | 89.1 | 116.2 | | 150.1 (126.8) | 115.5 (76.9) | 91.2 (78.9) |

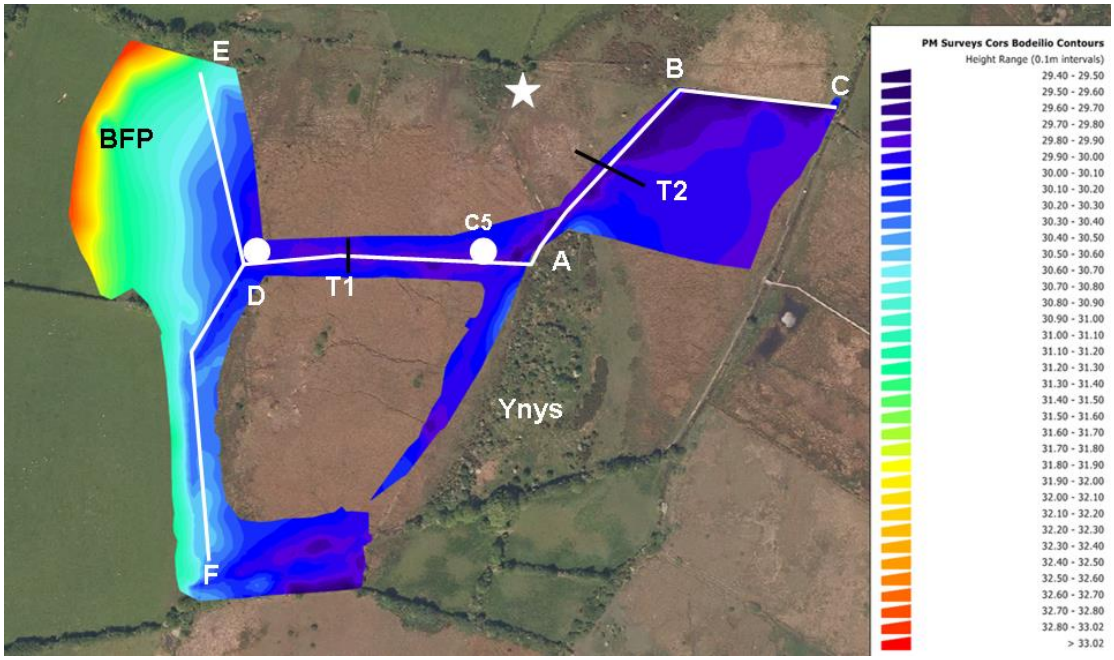



**Figure 13**. Topographic survey plot of part of Cors Bodeilio showing areas of land delimited by 0.1 m elevation aOD contours. The white star marks Fly Orchid Spring and the white line indicates part of the ditch network. Section A-B is the bypass pipe, with water levels from A-D raised according to the level of the bypass pipe U bend. T1 and T2 indicate dipwell transects across the ditches; white circles denote ditch stage measurement points. The plot indicates scope for over-banking of ditches within the fen sufficient to prevent any nuisance flooding of the higher agricultural land to the west. See also Figure 2.2.

An unfortunate consequence of infilling ditch section A-B has been the loss of open running water in a ditch section fringed with open clumps of *Schoenus*, with consequent impacts on invertebrate communities and the calcareous ditch flora. This will be mitigated to an extent by a planned after-LIFE project to create shallow scalloped ledges in the canalised up-stream section of ditch shown in Figure 15 of the Cors Bodeilio excursion account (see Workshop Proceedings).

**Table 7.** Water level data for measurement point c5 in ditch section A-D at Cors Bodeilio – see Figure 13. for location. Water levels are in cm relative to the measurement datum at 29.701 maOD. The two water level measurements for January and June 2014 lie beyond the range recorded since 2007 for the respective half-year periods, indicating a significant rise in ditch levels post restoration (May 2013). The June 2014 measurement was after a dry period of xx days.

| | Average | N | Max | Min | Post-restoration |
|---|---|---|---|---|---|
| April – Sept | -1.4 | 9 | 1.5 | -4 | 14 (26/6/14) |
| Oct - Mar | 6.9 | 6 | 20.8 | 1.9 | 32.5 (16/1/14) |

**Case study 5. Restoring groundwater supply: issues presented by peat wastage adjacent to drains – the example of the south drain feature at Cors Erddreiniog (Anglesey Fens SAC).**

Cors Erddreiniog is the largest of the project sites within the Anglesey Fens SAC and has been heavily influenced by canalised drainage. One such drain (the South Drain) runs into Llyn yr Wyth Eidion, the primary example at this site of the Annex I open water habitat 'Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp. H3140'. The age of this drain is unclear: it seems to be absent from the tithe apportionment map of 1846 for Llaneugrad parish (Gilman & Newson, 1979), and yet it appears to exist on earlier tithe and estate maps dating from 1840 and 1777 respectively (Bath, 1986). The drain carries flow from a minor NW-SE valley head at Bodgynda which receives water from Nant Newydd Quarry: this feature originally flowed S through Cors Cefn Uwrch but a channel of unknown age was cut through the confining ridge to the south of the main fen basin ridge to route it into the South Drain. Under natural conditions the primary terrestrial hydrological inputs to the lake would be groundwater as both diffuse seepage and in channels from the more prominent spring-heads.

The South Drain may have been cut along the line of a natural smaller precursor, though the presence of deep peat on both sides of it just S of the lake may indicate otherwise. Flow in the South Drain is significant (c. 10-15 l/s during typical winter flows) and this is reflected in substantial lake outflow via a canalised drain (Figure 14) which ultimately connects with the main axial drain. The South Drain carries an episodically high suspended solids load and palaeolimnological evidence for the lake (ref) indicates declining water quality. Coupled with these observations is the degraded quality of fen vegetation to the west of the drain (and thus cut-off from any obvious groundwater influence from the limestone), which is dominated by *Molinia caerulea* with *Myrica* and *Phragmites* (M25), compared with the more ostensibly groundwater influenced vegetation to the east which includes M22 and pockets of M9 and M13 (Figure 14). The *Molinia* dominated vegetation west of the drain appears to have changed little despite higher water levels and reduced summer drawdown achieved through raising the level of the lake outflow and blocking ditches in the fen peat SW of the lake in *c*. 1983/84 (Gilman, 1994 – Figs 5 & 19). This highlights the importance of also restoring groundwater supply to this area.

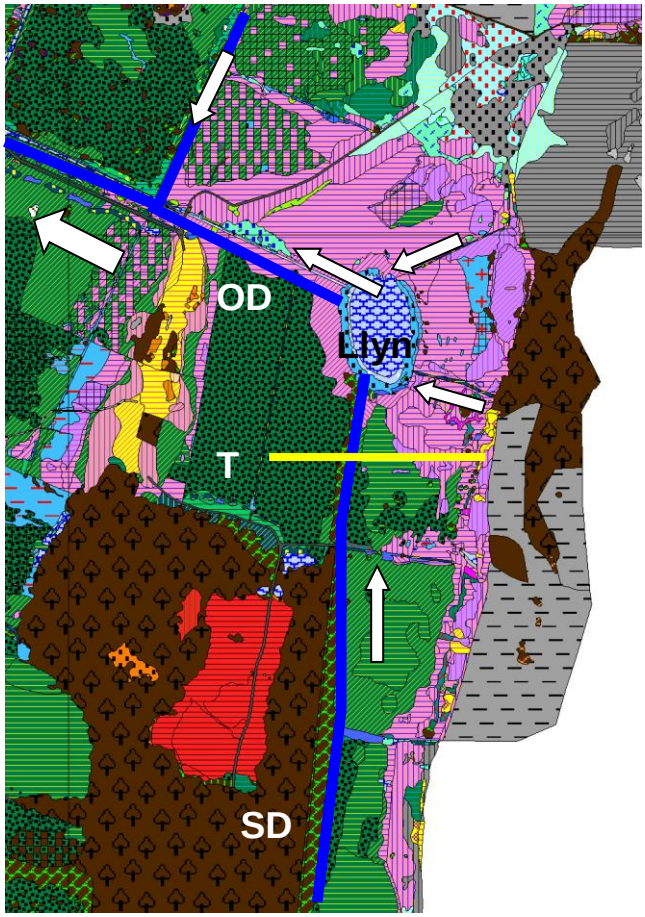



**Figure 14**. Plant community map of the central-eastern section of Cors Erddreiniog showing Llyn yr Wyth Eidion, the inflowing South Drain (SD), the SE-NW flowing outflow drain (OD), the two predominantly groundwater fed drains to the east of the lake and the topographic survey transect (T – yellow line). White block arrows denote directions of flow. This map is an extract of the full-site plant community map reproduced as Figure 2a in Birch *et al*., this volume. The topography survey line (T) passes from west (left) to east (right) through a very species-poor form of M25 with *Phragmites* and *Myrica* west of the drain, a thin bank of M25 mire east of the drain, M13 *Schoenus* mire and then *Juncus subnodulosus* fen ,meadow (M22). Dipwell 3 of the Institute of Hydrology study (Gilman & Newson, 1982) was located just S of the OD lettering in the area of degraded *Molinia* dominated fen and showed a significant response to hydrological restoration in the 1980s..

Diverting the South Drain and then infilling its channel would deliver two major benefits. Firstly it would restore groundwater supply as the dominant terrestrial hydrological input to the lake, thus reducing the overall flux of water through the lake and also the suspended sediment and nutrient load. Secondly, it would restore a degree of groundwater influence west of the current ditch line. The first stage in assessing the feasibility of such a scheme was to establish a topographic transect line across the South Drain (shown in Figure 14).

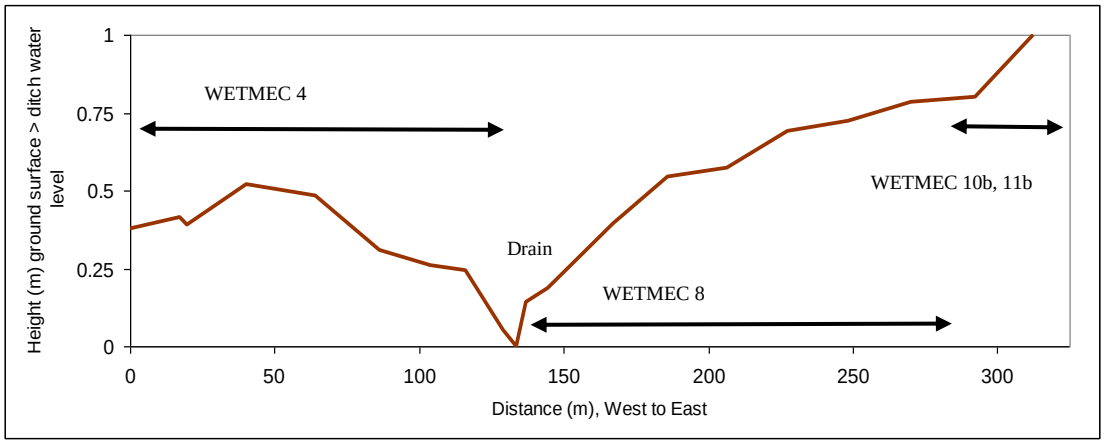



**Figure 15**. Plot of ground level relative to water level in the South Drain at 138 m on the west to east transect line indicated in yellow on Figure 14. Water levels closely follow ground level.

The plot (Figure 15) shows significant wastage of peat either side of the South Drain and wastage associated with a minor drain which runs parallel to the South Drain in the middle of the peat body at 0 m (this had already been blocked some years ago). This has left the peat body to the west of the South Drain with a markedly domed profile (as observed originally by Meade & Blackstock, 1988), indicating much of it is probably now referable to WetMech 4. The slope east of the drain receives groundwater seepage from the eastern limestone slope and there is some groundwater upwelling in the centre of this peat block. These results indicate that ditch infilling would not achieve any significant additional influence for groundwater unless a substantial volume of peat was placed in the valley of the ditch line, though infilling the ditch would at least limit ongoing wastage of adjacent peat. One possible source for peat infill could come from re-profiling the crown of the peat dome to the west of the drain. Another major factor determining the feasibility of this project is the availability of an alternative route for the South Drain. The drain would originally have flowed south to join the axial drain of Cors Cefn Uwrch and this remains the best option and is currently being reviewed through the Mawndir Mon project (see Cowley, this volume) as part of the after-*LIFE* programme.

This case study illustrates some of the potential benefits of restoring a more naturally functioning hydrological regime, the value of simple topographic survey, and the important influence of drainage induced peat wastage in certain situations.

**Case study 6. Addressing drainage, peat enrichment and modifications to groundwater supply at Cors Ceidio, Cors Geirch**.

Cors Ceidio is a narrow strip of fen at the northern tip of Cors Geirch (Llyn Fens SAC; Figure 16). The site supports some of the deepest peat deposits within the SAC (up to 230 cm were recorded by Shaw & Wheeler, 1991) but it has been heavily modified as a result of several factors, including deepening and straightening of the Afon Geirch, drainage at the margin of the peat body, and a fire *c*. 25 years ago which resulted in combustion/modification of some areas of peat and subsequent peat enrichment. These impacts are reflected in significant humification of the peat (Figure 17), marked changes in surface profile adjacent to the river (Figure 18) and significant modification of the vegetation, with *Holco-Juncetum* mesotrophic grassland (MG10c), *Typha latifolia* swamp (S12), *Rubus fruticosus* underscrub (W24) and patches of *Chamerion angustifolium* (OV27) present in place of more typical topogenous fen (Figure 19).


**Figure 16**. Location of Cors Ceidio (bordered in black) in relation to the rest of Cors Geirch (brown shading).

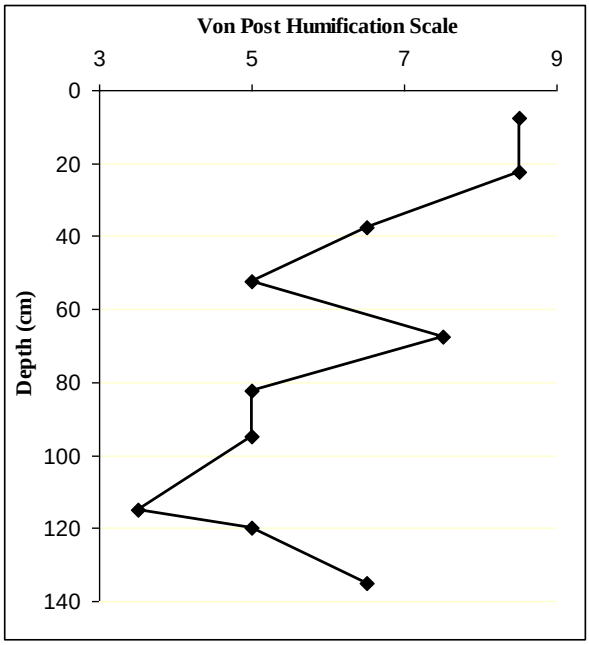
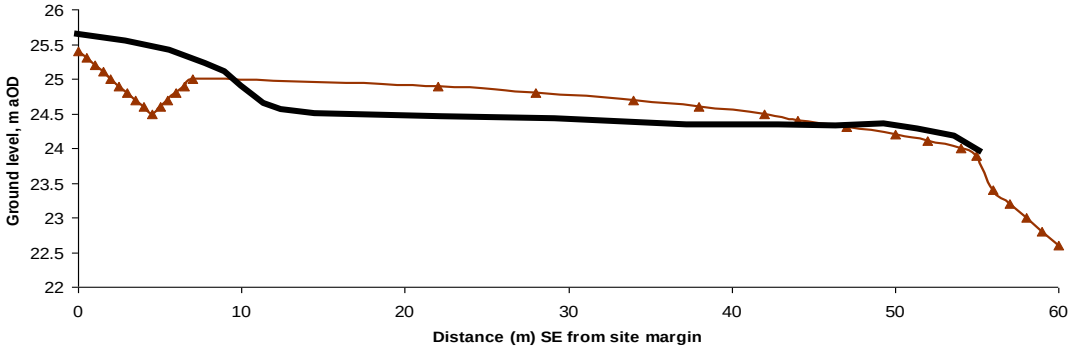



**Figure 17**. Changes in humification with depth recorded at Cors Ceidio dipwell DW3 (SH30650.38080). Humification is assessed qualitatively using the Von Post scale (see Rydin & Jeglum, 2006), with the degree of decomposition increasing up the scale. Scores between integers represent the mid-point of ranges of humification recorded during field examination of samples from particular depth bands. Von Post scores of 8-9 (recorded here in the uppermost 30 cm of the peat profile) represent very strongly or almost completely decomposed peat; this is likely to reflect the drainage history of the site.



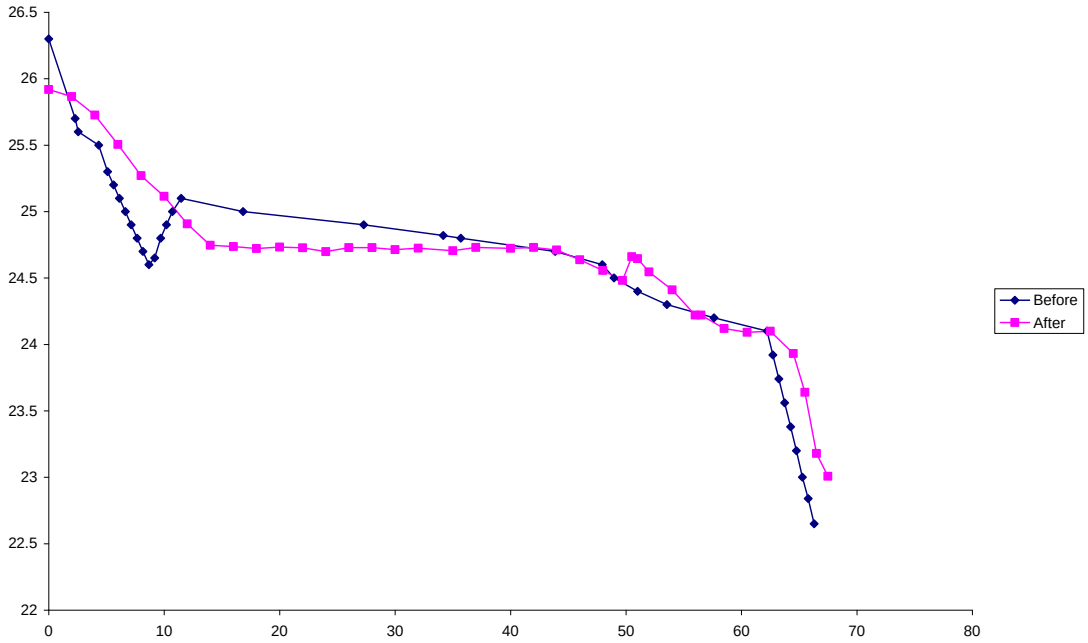



**Figure 18**. Upper: Ground level profile (m above OD) along section T0 (NW) to T1 (SE) of Figure B. The brown line and points are extracted from a topographic survey of the site undertaken by Digital Mapping Surveys under contract to the *LIFE* project. Dipwell DW3 shown in Figure C is at c. 30 m on this plot. The black line shows the approximate form of the peat re-profilling, with peat removal from the RH area and infill of the site margin ditch on the left and more limited deposition over part of the wastage slope adjacent to the river at 60 m. Note the sharp drop in surface profile down to the bed of the Afon Geirch from 55 – 60 m, with a less marked break of slope visible at *c*. 43 m. The lower plot shows the post restoration profile based on field measurements.

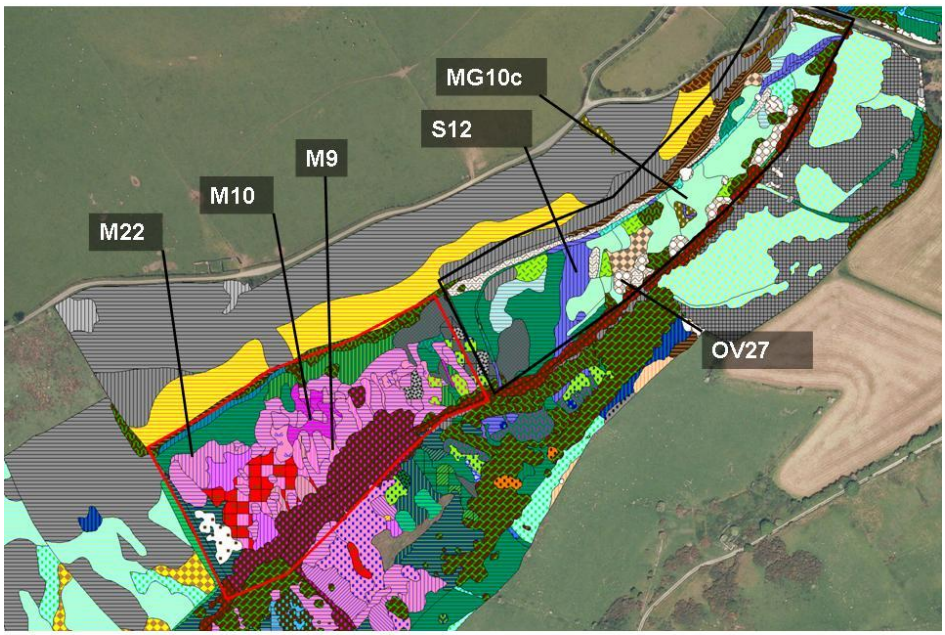



**Figure 19**. Plant community map of the N tip of Cors Geirch, showing the more heavily modified vegetation of Cors Ceidio outlined in black and rich-fen vegetation in peat cuttings to the SW outlined in red. Key plant communities are identified. The centre of image is at c. SH 305380 and spans *c*. 800 m from left to right. Mapping undertaken by the CCW/NRW Lowland Peatland Survey of Wales project – see Birch *et al* (this volume).

Cors Ceidio is flanked to the NW by a slope which forms part of the series of fluvioglacial terraces bordering the site. This landform forms part of a large kame-morraine complex, with fine sand the dominant component (National Assembly for Wales, 2003). A stratigraphic sequence revealed in a now infilled nearby quarry cutting into this landform at SH 302379 revealed >15 m thickness of coarse gravels, sands and diamicts (Edge, 1990) and several seepage zones are visible at the base of the slope at the margin of the fen, particularly above former ditch alignment D-C and continuing to the WSW (Figure 20). This seepage was formerly intercepted by ditches cut along parts of the 'upslope' fen margin – particularly section D-C. Ditch section A-B was dug in the early 1990s in an attempt to irrigate the upslope (NW) margin of the fen peat body through diversion of the Afon Geirch, but this had the inevitable but unwanted effect of intercepting seepage entering the fen from the drift slope to the west. Weirs were previously installed along both ditch sections C-D and A-B to try and limit seasonal drawdown of water levels, but interception of seepage would still have occurred and automated hourly monitoring of water levels down-gradient of section C-D shows water levels significantly below ground surface for much of the year and thus outside the range normally associated with either target Annex I habitat (Figure 21).

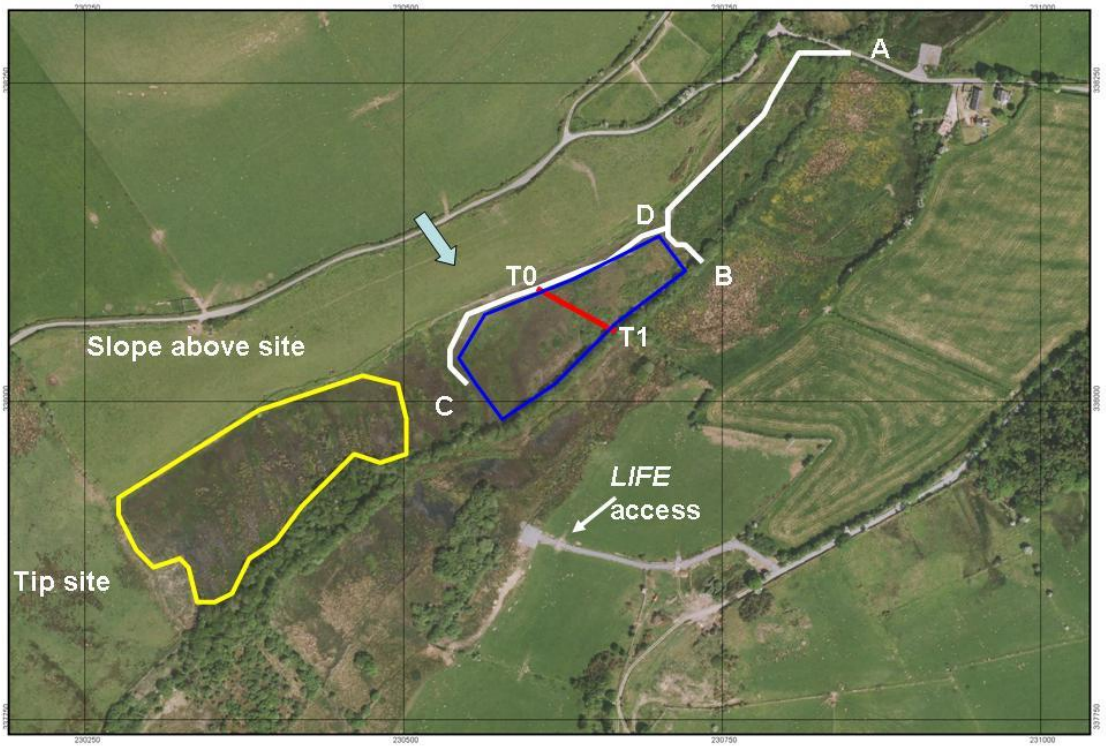



**Figure 20**. 2013 aerial image of part of Cors Ceidio (Cors Geirch) showing ditch sections A-B and C-D in white, the dipwell and topographic survey transect of Fig. C in red (from T0 to T1) and the outline of the peat scrape area in blue. The Afon Geirch is visible as a line of willow and alder trees running as a curving line from NE to SW. The area outlined in yellow denotes the area of peat cuttings which support rich-fen vegetation, including alkaline fen. The blue block area shows the location of Figure G. This figure shows the new *LIFE* track created to allow access to the E margin of the fen and land acquired through the *LIFE* project at Allt Goch Fine black lines denote 250 m grid lines of the British National Grid. Centre of image is at c. SH3065.3810.

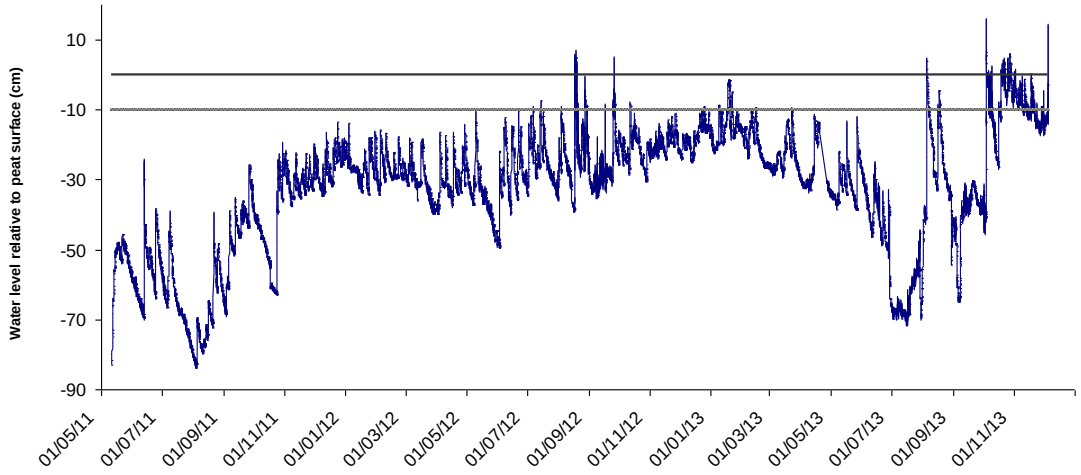



**Figure 21**. Hourly records of water table level at dipwell DW3, Cors Ceidio, prior to restoration measures in January-February 2014. Ground level is shown at 0 cm as a solid line. The post-restoration surface which is 10 cm lower than the original ground surface at this location is shown as a dotted line. Well DW3 is located mid-way along transect To-T1 of Figure E.

Old peat cuttings are a prominent feature of the block of fen immediately to the SW of Cors Ceidio and these support areas of alkaline fen (M10 and M9) and *Juncus subnodulosus* fen (M22 – see Figure D), as well as the largest population of the nationally rare *Eriophorum gracile* at the site. This indicated an important potential role for peat cutting in the restoration of the more heavily modified sections of Cors Ceidio.

Restoration measures were implemented in the last quarter of the final year of the *LIFE* project (January 2014) and the key elements employed are summarised in Table 8.

**Table 8**. Summary of primary restoration elements employed at Cors Ceidio, Cors Geirch.

| **Restoration measure** | **Rationale** |
|---|---|
| Infill ditch section C-D (see Fig. E). | • Eliminates drainage effect of marginal ditch.<br>• Enables partial/complete restoration of groundwater supply pathway from marginal fluvio-glacial deposits. |
| Removal of surface peat down-gradient of marginal ditch section C-D and the Afon Geirch. | • Removes eutrophic vegetation, surface enriched and humified peat<br>• Lowers ground-surface closer to the water table.<br>• Profile of cut reduces slope towards river. |
| Restore Afon Geirch to original course | • Removes influence of potentially enriched river water on fen peat.<br>• Restores original valley axis course, albeit canalised. |

The primary restoration element concerned the removal of a tapering wedge of peat from the area marked in blue on Figure 20, with the depth of cut decreasing from the upslope margin of the site towards the river. This profile was guided by a detailed topographic survey of the site (Digital Mapping Services, 2013) which yielded height contours at 0.1 m height intervals and was designed to reduce the slope of the restored peat surface towards the river.

The same specialist low ground pressure excavator employed at Mathan Uchaf (see D.V. Jones *et al*, this volume) was used for this project, together with relatively light-weight tracked dumpers to move peat (Figure 22). Excavated peat was deposited in

three main areas, (i) as infill for the ditch at the upslope edge of the fen beneath the kame-moraine slope (Figures 23 and 24), (ii) to replace peat lost to oxidative wastage on both sides of the deepened and canalised river, and (iii) to create a floating road across a highly modified part of the peat body on the E side of the Afon Geirch, thereby enabling access to the restored site from a track installed leading down to the eastern margin of the fen.

The amount of peat stripped at Cors Coedio was inevitably constrained by the availability of on-site locations for its disposal at this narrow valley-head location. A greater depth of peat would ideally have been removed (corings along the dipwell transect indicate over 1 metre of peat) and over a larger area, but this would have necessitated expensive disposal off-site. Peat fertility at Cors Ceidio was noted as relatively high by Shaw & Wheeler (1991) and it is unlikely that the depth of peat removed will have been sufficient to expose more oligotrophic (nor, with reference to Fig 17 less humified) deposits. The presence of patches of seepage at the interface between the peat stripped area and the peat infill along the alignment of the upslope drain is encouraging (Figure 25), though their seasonal persistence is unclear. An 18 m deep borehole drilled into the same drift unit to the E failed to yield water (National Assembly for Wales, 2003), but any groundwater unit might be quite heterogeneous, with seepage faces supported by sometimes only small and localised groundwater units. Patches of *Callitriche* sp. on oozing seeps issuing from the ditch infill may relate more to mineralisation of disturbed peat then inherently poor groundwater quality and the slope above the fen is included in the SAC and subject to a management agreement to limit nutrient applications.

The modest depth of peat removed coupled with the uncertain yield and seasonal persistence of the upslope seepages could mean that the newly exposed peat surface remains too dry to sustain rich-fen: further peat stripping is a future option. Restoration of the highly modified river channel is an obvious priority. It remains over-deepened and canalised and the Water Level Management Plan so far implemented on the ground only across some of the peripheral drains at Mathan Uchaf should be extended more widely to support the development of a more natural morphology, wider bands of riparian vegetation and reduced hydraulic gradients within the adjacent peat bodies.

**Figure 22**. Peat stripping work in progress at Cors Ceidio in February 2014 as seen from the lane at the top of the slope to the NW of the site (see Fig. E for location). The three flooded oblong areas are deeper excavations designed to mimic historic peat cuttings which remain a short distance to the right (SW) of this image. The new access track to the opposite (E) side of the fen is seen to the right in the distance.

**Figure 23 a & b.** Photographic comparison of part of Cors Ceidio looking WNW from the dipwell transect marked as line T0 to T1 on Figure E. Figure left (19 April 2013) shows the situation pre-restoration with the rising drift slope in the distance, ditch-line C-D filled with dead *Typha* stems and wells DWP3 and DW3 to the left and right respectively of *LIFE* Project Officer Rhoswen Leonard. Figure right (28 May 2014) shows the same scene post peat stripping. Note the increased height of exposed well liner resulting from removal of c. 10 cm of peat at this location, and the inflled ditch at the edge of the peat body, with excavated peat piled as a sloping surface up to the fenceline.

**Figure 24**. Before (L, April 2013) and after ( R, May 2014) views of part of the restoration area at Cors Ceidio showing the upslope ditch prior to restoration and the restored profile with peat infill of the ditch.

**Figure 25**. View looking upslope from the edge of Cors Ceidio showing peat exposed by peat stripping, a band of seepage with a natural iron film, and the wedge of now revegetated deposited peat used to infill the drain.

**Case Study 7. Measures to restore groundwater influence at Mathan Uchaf, Cors Geirch (Llyn Fens SAC).**

A detailed description of this project is provided by D.V. Jones *et al* (see workshop proceedings). The main elements include restoration of groundwater influence through a combination of peat stripping and ditch infilling, coupled with installation of a major constructed wetlands system to reduce the nitrogen load of enriched spring inflows. This account summarises the main hydrological restoration elements of the project.

The main feature of the site is an extended rectangular area of topogenous peat aligned NW-SE and flanked to the SW by the Afon Geirch and (formerly) to the NE by a footslope ditch at the base of a rising slope which supports a series of spring

discharges. Monitoring of water levels in the topogenous peatland prior to restoration revealed a fairly dynamic water table regime, with periods of deep flooding and substantially sub-surface water levels (Figure 26), neither of which would be typical of M13 alkaline fen (Wheeler *et al*., 2010). However, the presence of this feature elsewhere in the same compartment (see Figure 9 of Birch *et al*., see Proceedings of Workshop) suggested that Mathan Uchaf might present good restoration opportunities. The pre-restoration ground-surface profile was unusual in that the expected mire margin – mire axis slope was absent (Figure 27); instead a shallow trough was evident with a long upwardly sloping gradient to a prominent bank which is presumed to have originated through dredging and canalisation of the river. Peat re-profiling would ideally have yielded a gentle gradient all the way to the river from the mire margin, with removal or at least lowering of the river bank then enabling an interface with a narrow strip of seasonally inundated riparian fen: this remains as an opportunity for the future.

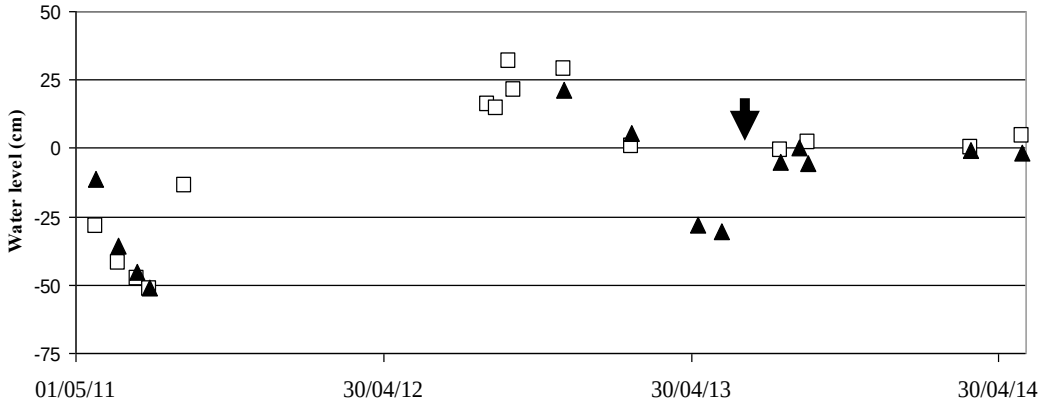



**Figure 26.** Plot of water levels relative to peat surface recorded before and after restoration of spring inflows at Mathan Uchaf (Cors Geirch, Llyn Fens SAC) on 17 July 2013 (see arrow mark). Data are shown for dipwells 2 (triangles) and 3 (open squares) – see Figure M3 for locations.

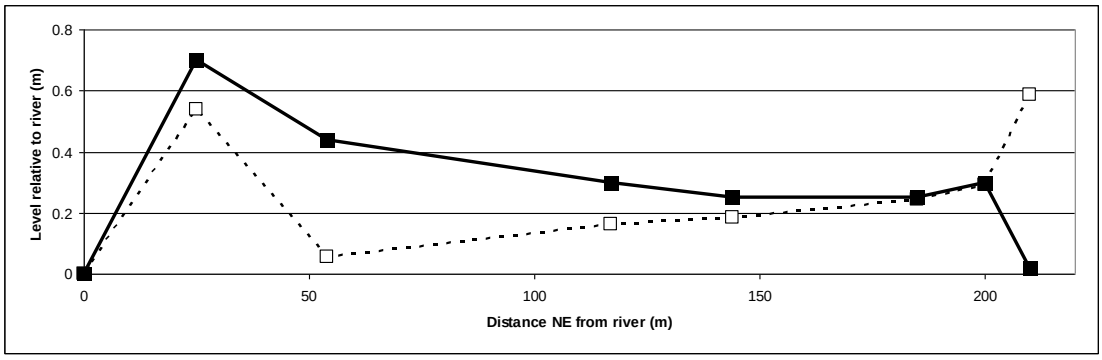



**Figure 27.** Topographic profiles along the NE to SW alignment shown in Figure M3 at Mathan Uchaf (Cors Geirch) before (solid line and squares) and after (dotted line and open squares) restoration. Levels are shown relative to river level (0 m) with the levels at 210 m representing the original footslope drain water level and the subsequent water level within the constructed wetland. Pre-restoration elevation data are derived from DMS (2013) – post restoration levels were obtained through a laser level survey in March 2014.

Peat stripping was designed to create a profile which greatly expands the influence of seepage water entering the site from the outflow of the constructed wetland installed over the top of the infilled footslope drain (see D.V. Jones *et al*., this volume). The continuation at a right angle of the peat stripped area as a profiled cutting running from NW to SE (Figure 28) prevents deep flooding where the cutting abuts the river bank and, in effect, increases the overall length of the artificial seepage feature. An

overflow at the SE tip of the peat cutting carries excess water to the remaining open section of the footslope drain close to the hard-standing area visible in Figure M3. The overall gradient achieved prevents deep ponding of water (Figure 29), with variable inverts for the constructed wetland outflows allowing some control over irrigation of the surface (see Figure 16b of D.V. Jones, Proceedings of Technical Workshop). Water levels at dipwells D2 and D3 now show a limited range above and below the peat surface, although the data-run post restoration is limited.

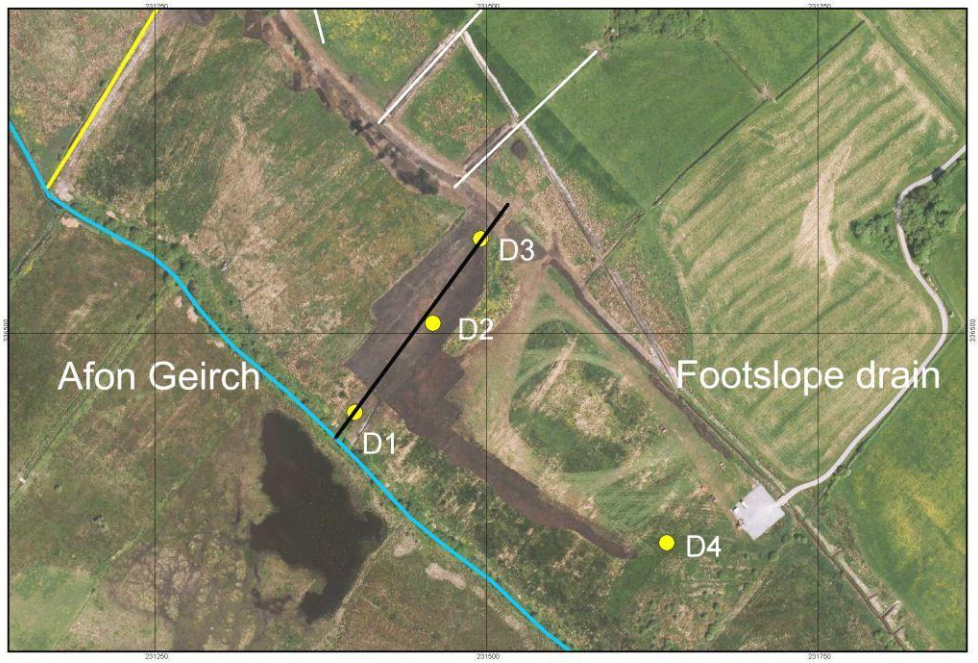



**Figure 28**. 2013 aerial view of Mathan Uchaf (Cors Geirch) showing the peat re-profiling and spring water diversion work in progress. Exposed peat is clearly visible, though the full extent of this is not yet apparent in this image, nor the constructed wetlands which will overlap the former footslope ditch. The dipwell transect D3 to D1 and the Afon Geirch is shown – see Figure M2. The NE tip of the transect is coincident with the constructed wetland system installed shortly after this photograph was taken. Grid lines are at 250 m intervals. The square hard-standing and access track built with LIFE funding are shown to the right of the image. Centre of image is at SH 314364.

**Figure 29a**. Dipwell D2 and the peat stripped area at Mathan Uchaf shortly after its completion in June 2013 but before irrigation of the surface with outflow from the constructed wetlands.

**Figure 29b**. The same scene as Figure M4a in March 2014 with outflow from the constructed wetland in the distance flowing towards the observer as a shallow sheet of water.

The Mathan Uchaf project work may also realise some flood management benefits for communities downstream of Cors Geirch. This is because spring outflow which was formerly wholly intercepted by the footslope drain is now routed through a much longer pathway subject to plant uptake and (once revegetated) a degree of retention prior to its ultimate discharge back into the axial drainage system. Quantitative monitoring of any such effect was unfortunately beyond the scope of this *LIFE* project.

**Conclusions**

An obvious priority for the future is to continue water level monitoring both of sites subject to hydrological restoration but also more widely on the rich-fen series. In terms of the latter, the paucity of baseline hydrological information for key examples of the two Annex I habitats hampered the definition of intervention measures during the *LIFE* project and presents particular difficulties when assessing the impact of land management and development proposals within the site catchments. The importance of collecting baseline hydrological data for key wetland plant communities is included under recommendation #1 of Wheeler *et al*. (2009) and has been identified as a high priority 'basic and applied research need' in the context of wetland impact assessment (Acreman & Miller, 2004). This work can be undertaken on a highly cost-effective basis by conservation science and wardening staff based close to the project sites.

Despite the significant gains achieved during this LIFE project, scope remains for further hydrological restoration measures across the project sites. For example, most sites bear canalised and historically over-deepened axial drains which would be ideal candidates for restoration to achieve a more natural morphology, even in cases where raising water levels is not currently feasible or desirable: the Geirch and Erddreiniog systems present major future opportunities in this regard. There is also significant scope for modifying hydrological inputs from the site catchments to reduce both sediment and nutrient loads: constructed wetlands represent an important and now proven technique in this area. The after-*LIFE* plan will document key priorities.

Ensuring appropriate hydrological management of the site catchments is a priority for the future, both in terms of water quantity (namely securing optimal groundwater and surface water supply to the wetlands) and also quality. Climate change and land-use may increase the pressure on groundwater resources in both project areas and the cumulative impact of current pressures (including unlicensed abstractions) is poorly known. The comparatively limited storage and small area (28 $km^2$) of the Anglesey Limestone (Robins & McKenzie, 2005) highlights its potential vulnerability whilst also suggesting that some form of groundwater protection zone scheme could be quite tightly focussed to secure environmental benefits at an ecosystem scale: the same principles apply to the Llŷn fens.

**Acknowledgements**

Dyfed Jones was the lead project officer for the Mathan Uchaf and Cors Ceidio projects and saw both projects through to successful completion. We thank the following ground-works contractors: G.H. James (particularly Gwilym and Dewi Jones and Huw Salt) at Mathan Uchaf, Cors Cefn Uwrch, Cors Hirdre and Cors Ceidio; Mulcair Limited at Cae Gwyn and Bodeilio case study#1; and Gwyn Roberts & Sons for the Fly Orchid spring groundwater reconnection project at Bodeilio. We thank *LIFE* project officer Llion Jones for his invaluable contribution across all these projects. We thank Mike West for his role in developing the staggered ditch alignment described in case study #1 at Cors Bodeilio, and Bethan Jones for dipwell monitoring. It is a pleasure to acknowledge the work of Les Colley in undertaking all the early pioneering hydrological repair work at Cors Erddreiniog, supported by John

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**References**

Acreman, M.C. & Miller, F.M. (2004). *Impact Assessment of Wetlands: Focus on Hydrological and Hydrogeological Issues. Phase I report*. Environment Agency Research & Development Report W6-091/TR1, EA, Bristol, UK.

Bath, J.C. (1986). *Cors Erddreiniog: a palaeoecological study*. M.Sc. Thesis, University College of North Wales, Bangor.

Birch, K.S. (2008). *Lowland Peatland Survey Site Report for SH 47/11P Cors y Farl*. Countryside Council for Wales, Bangor.

Edge, M.J. (1990). Cors Geirch – Maesoglan. In: *The Quaternary of North Wales: Field Guide*. Eds. K.Addison, M.J. Edge & R. Watkin. Quaternary Research Association, Coventry. pp. 48-49.

Digital Mapping Services (2013). *Topographic Survey of Cors Ceidio, Cors Geirch*. DMS reference 3653, Digital Mapping Services Ltd, Mochdre, North Wales.

Farr, G., Breen, R., Jones, P.S., Guest, J. & Leonard, R.M. (2008). *Hydroecological Site Walkover Report for Cors y Farl.* Environment Agency Wales, Cardiff.

Gilman, K. (1994). *Hydrology and Wetland Conservation*. Wiley.

Gilman, K. & Newson, M.D. (1979). The Anglesey Wetlands Study: First Annual Report of Progress. Institute of Hydrology Report to NCC.

Gilman, K. & Newson, M.D. (1982). *The Anglesey Wetlands Study*. Institute of Hydrology Report to NCC.

Grootjans, A.P. & van Diggelen, R. (1995). Assessing the Restoration Prospects of Degraded Fens. In (Eds.) Wheeler, B.D., Shaw, S.C., Fojt, W.J. & Roberston, R.A. Restoration of Temperate Wetlands. John Wiley & Sons. pp. 73-90.

Grootjans, A.P., Janakova, M., Madaras, M., Seffer, J., Stanova, V., Ripka, J. & Wolejko, L. (2005). *Ecohydrological research as a base for restoration of calcareous fens in the Slovak Republic*. University of Groningen/DAPHNE, Institute of Applied Ecology, Bratislava. 92 pp.

Huggins, T.S. (2008). *The Late-Pleistocene, Late Glacial and Holocene Palaeoecological Records of Hydroseral Development in Rich-fen Plant Communities, Anglesey, North Wales*. Ph.D. Thesis, Department of Geography, University of Birmingham.

McBride, A., Diack, I., Hamill, B., Jones, P.S., Schutten, J., Skinner, A. & Street, M. (Eds.) (2011). *The Fen Management Handbook*. Scottish Natural Heritage, Perth.

Meade R. & Blackstock, T.H. (1988). The impact of drainage on the distribution of rich-fen plant communities in two Anglesey basins. *Wetlands* **8**, 159-177

Raeymaekers, G. (2000). *Conserving Mires in the European Union: Actions co-financed by LIFE-Nature*. European Communities, 2000.

Robins, N.S. & McKenzie, A.A. (2005). Groundwater occurrence and the distribution of wells and springs in Precambrian and Palaeozoic rocks, NW Anglesey. *Quarterly Journal of Engineering Geology and Hydrogeology* **38**, 83 – 88.

Rydin, H. & Jeglum, J. (2006). *The Biology of Peatlands*. Oxford University Press.

Shaw, S.C. & Wheeler, B.D. (1992). *Potential for the Restoration of a Wetland Reclaimed for Agriculture*. Sheffield University Report to CCW North-west Region, Countryside Council for Wales, Bangor. 39 pp plus appendices.

Wheeler, B.D. & Shaw, S.C. (2009). *Ecohydrological site accounts for Wales: Cors y Farl*. Appendix H of Wheeler et al. (2009).

Wheeler, B.D, Shaw, S.C. & Tanner, K. (2009). *AWetland Framework for Impact Assessment at Statutory Sites in England and Wales*. Environment Agency Science Report SC030232/SR1. 748 pp.

Wheeler, B.D., Shaw, S.C., Whiteman, M.W. & Brooks, A.W. (2010). *Protecting the plant communities and rare species of fen and mire wetland systems: Ecohydrological guidelines for lowland wetland plant communities fens and mire update* (March 2010). Environment Agency, Bristol, UK. 148 pp.