PROSIECT LIFE+ CORSYDD MÔN A LLŶN
ANGLESEY AND LLŶN FENS LIFE+ PROJECT
LIFE 07 NAT UK 000948

RESTORATION OF A KEY GROUNDWATER SUPPLY PATHWAY AND RELATED HYDROLOGICAL RESTORATION WORK AT CORS BODEILIO NATIONAL NATURE RESERVE

(*LIFE* project actions A5, C10, C11, C13, E.4, E.4.03)

Final Report of the Anglesey & Llyn Fens LIFE Project: Technical Report No. 2.

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Authors	**Peter Jones, Justin Hanson, Rhoswen Leonard and Janine Guest**
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LIFE is the EU's financial instrument supporting environmental and nature conservation projects throughout the EU, as well as in some candidate, acceding and neighbouring countries. Since 1992, LIFE has co-financed some 2,750 projects, contributing approximately €1.35 billion to the protection of the environment.

LIFE+ Nature aims to:
Fund the implementation of the objectives of the EU Birds' Directive 79/409/EEC and the EU Habitats' Directive 92/43/EEC including the Natura 2000 network of sites and focuses on sustainable long-term investments in Natura 2000 sites.

Project title:
Restoring alkaline fen and calcareous fen within the Corsydd Mon and Llyn (Anglesey and Llyn Fens) SACs in Wales.

Project Objectives:
The objective of this project is to bring 751 ha of fen within the Corsydd Mon/Anglesey Fens SAC and Corsydd Llyn/Lleyn Fens SAC into favourable or recovering condition through measures aimed at tackling the factors adversely affecting their condition and by delivering more sympathetic management.

Distribution List (* electronic only)

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Cover photo: Cleaning the ditch below fly orchid spring prior to installing a bypass pipe to prevent loss of groundwater down the ditch line, 7 May 2013. Photo taken from close to SW end of ditch looking NE.

CONTENTS

CRYNODEB

Mae Cors Bodeilio (CGC SH 501774) yn ryw 54 ha o faint, ac ynghyd â Chors Erddreiniog a Chors Goch yn un o dri safle mwy cyfres ffeniau mwnol Môn. Mae'r safle yn rhan letaf blaen dyffryn Nodwydd, ac yn cynnwys mannau gwastad, gweddol eang o fawnogydd topogenaidd / rheo-topogenaidd[1], gyda ffeniau dŵr wyneb (gan gynnwys rhai o'r enghreifftiau gorau o gynefin ffen alcalïaidd o fewn yr ACA), tir pori corsiog a ffeniau hesg ar yr ymylon.

Mae rhwydwaith draenio dŵr wyneb eang ym Modeilio, sydd â rhai elfennau ohoni'n derbyn dŵr wyneb sy'n llifo i mewn i ymylon y safle. Y ffynhonnell dwr daear gryfaf yw'r hon a elwir y darddell tegeirian pryf, sydd, pan lifo, yn gollwng tua 71m^3 o ddŵr daear calchaidd y dydd i ffen alcalïaidd o ansawdd da (M13). Cyfyngwyd cylch dylanwad y dŵr daear hwn, gynt, gan ddraen, a ddaliai llawer, onid y cyfan, o ddŵr y darddell tegeirian pryf, a hefyd y dŵr a oferai o glwt o M13 yn nesaf ati. Y ddraen hon, hefyd, fu prif gludwr dŵr o'r caeau amaethyddol i'r gorllewin o'r safle. Penderfynwyd bod adfer dylanwad naturiol llawn y darddell tegeirian pryf ar ddŵr daear ymhlith blaenoriaethau cyntaf y prosiect LIFE, ond byddai'n rhaid cyflawni hynny heb effeithio er gwaeth ar ddraeniad o dir cyfagos.

Cynhaliwyd dadansoddiad dewisiadau manwl, ar sail archwiliadau eang ar y safle. Dewiswyd cynllun a olygai claddu pibell ddargyfeirio a fyddai'n caniatáu i ddŵr barhau i ddraenio o dir cyfagos, ac yn caniatáu, hefyd, i ddŵr wyneb lifo'n ddilyffethair ar draws llwybr blaenorol y draen. Mae offer rheoli a osodwyd ar fewnfa'r bibell ddargyfeirio yn awr yn caniatáu rheoli lefelau'r draen a lefelau dŵr cyfagos yn y mawn ledled rhannau o gell orllewinol y ffen (CB1). Gwnaed yr holl waith ar y safle yn gynnar ym Mai 2013, yn dilyn asesiad er mwyn sicrhau na therfid ar adar sy'n magu. Roedd y gwaith cysylltiedig yn cynnwys agor pedair ffos fawn er mwyn darparu mawn yn ddeunydd llanw, gosod argaeau dalennau plastig lle'r oedd dyfroedd daear yn dod ynghyd i lifo allan o'r mawn, a gosod yr un math o argae yn rhan arall o'r ffos, lle bernid na fyddai ei llenwi'n llwyr yn ddymunol.

Mae arolygu hydrolegol ar y prosiect wedi cadarnhau bod dylanwad dŵr dar wedi'i ehangu yn dilyn llenwi'r ffos, gyda lefelau dŵr uwch a mwy sefydlog yn ystod y cyfnodau pan fo'r darddell yn llifo. Mae yna bellach orlifo tir ar hyd ac islaw'r draen flaenorol, a gwelwyd ymlediad cyflym rhawn yr ebol yno yn ystod 2013 a 2014. Mae arolygu hefyd wedi cadarnhau nad yw gwaith amaethyddol cyfagos wedi'i dioddef unrhyw ddrwgeffeithiau hydrolegol.

Bernir bod y prosiect a ddisgrifir yn yr adroddiad hwn yn un o lwyddiannau allweddol elfen adfer hydrolegol prosiect LIFE Ffeniau Môn a Llŷn.

[1] Wynebau topogenaidd gyda symudiad dŵr ochrol sylweddol (hidliad) – Wheeler *et al* (2009).

SUMMARY

Cors Bodeilio (NGR SH 501774) extends over an area of approximately 54 ha and with Cors Erddreiniog and Cors Goch is one of the three larger sites of the Anglesey rich-fen series. The site occupies the broadest part of the valley-head of the Afon Nodwydd, and comprises fairly extensive flat areas of topogenous / rheo-topogenous[2] peatland fringed by soligenous fen (including some of the best examples of alkaline fen habitat within the SAC), marshy grassland and reed-fen.

There is an extensive surface drainage network at Bodeilio, some elements of which intercept marginal groundwater income to the site. The most potent point-source of groundwater is referred to as fly orchid spring, and when flowing discharges a daily average of 71 m^3 of calcareous groundwater over an area of high quality alkaline fen (M13). The areal influence of this groundwater was formerly limited by a drain which captured much if not all of the spring discharge from fly orchid spring and also seepage from the area of M13 adjacent to it. This drain was also the primary conduit for drainage water from the agricultural fields to the west of the site. Restoration of the full natural extent of groundwater influence from fly orchid spring was identified as an early priority for the LIFE project, but this would have to be achieved without compromising drainage from neighbouring land.

A detailed options analysis was undertaken, based on extensive site investigations. The chosen option involved installation of a buried bypass pipe allowing continued drainage from neighbouring land whilst also allow unhindered surface groundwater flow across the former course of the drain. A control structure fitted to the bypass pipe intake also now allows control of drain levels and adjacent water levels in the peat body across parts of the western fen compartment (CB1). All site works were undertaken in early May 2013 following an assessment to ensure lack of disturbance to breeding birds. Associated works included excavation of four peat cuttings to provide a source of peat-infill, installation of plastic piling dams in areas of focussed groundwater outflow from the peat body and installation of the same dam type in another part of the ditch section where complete infill was considered undesirable.

Hydrological monitoring of the project has confirmed the extended influence of groundwater following infill of the ditch, with a higher and more stable water level regime during periods of spring discharge. Areas of flooding now occur along and down-gradient of the former drain, with rapid colonisation by stoneworts noted during 2013 and 2014. Monitoring has also confirmed the lack of any adverse hydrological effects for neighbouring agricultural operations.

The project described in this report is regarded as one of the critical successes of the hydrological restoration component of the Anglesey & Llyn Fens *LIFE* project.

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[2] Topogenous surfaces with significant lateral water movement (percolation) – Wheeler *et al* (2009).

1. INTRODUCTION

Cors Bodeilio (NGR SH 501774) extends over an area of approximately 54 ha and with Cors Erddreiniog and Cors Goch is one of the three larger sites of the Anglesey rich-fen series. The site occupies the broadest part of the valley-head of the Afon Nodwydd, and comprises fairly extensive flat areas of topogenous / rheo-topogenous[3] peatland fringed by soligenous fen (including some of the best examples of alkaline fen habitat within the SAC), marshy grassland and reed-fen. A key feature of the site is the relative shallowness of the peat profile (typically 0.4 – 0.7 m, Jones *et al*. in-prep.), with extensive peat-cutting in the past thought to be an important influence. The peat is underlain by stiff grey clay which is likely to focus calcareous groundwater supply to the site margins where the low conductivity basin infill thins out (SWS, 2010). An important consequence of this scenario is that surface drainage has the potential to intercept groundwater discharge and its distribution onto the site, thus depriving areas of the fen surface from calcareous seepage.

This report describes work undertaken during the Anglesey & Llyn Fens LIFE project to address a critical drainage feature that intercepted one of the key groundwater supply routes at the site. The report utilises a significant amount of data collected during an ongoing CCW/NRW study of the hydrology of Cors Bodeilio (Jones, in-prep.) which has run in parallel with the *LIFE* project. Also included are data collected as part of a related joint CCW/Environment Agency Wales project which used Cors Bodeilio as a test site for developing techniques to investigate groundwater quality and quantity impacts on SAC sites under the Water Framework Directive (WMC, 2008; SWS, 2010).

2. CONCEPTUAL UNDERSTANDING OF SITE HYDROLOGY AND HYDROECOLOGY

Carboniferous Limestone flanks and underlies much of the site except along parts of the south-east boundary where the geology is dominated by schistose rocks of the Pre-Cambrian Gwna Melange, together with a thin wedge of Ordovician geology. Significant amounts of calcareous groundwater (Ca concentrations typically 130 mg/l or more – see Table 2) arise from a fluvioglacial sand and gravel unit mapped to the east and north-east of the site (BGS, 1980) which at least locally[4] appears to be in direct hydrological contact with the limestone (WMC, 2008). Groundwater associated with the Pre-Cambrian geology also appears to support calcium concentrations of the order of 70 mg/l (WMC, 2007). Two limestone 'Ynys' (the Welsh name for island) features outcrop through the peat along the approximate mid-line of the site and may provide localised sources of groundwater. The largest of these features flanks the project area described in this report (Figure 1) and part of its outline in shown in Figure 2.

The hydrology of Cors Bodeilio is strongly influenced by a series of ditches (Figure 1). The main axial ditch (the Afon Nodwydd) is likely to be the modified successor of an original feature which would have drained the shallow valley-head of which Cors Bodeilio forms a part. Ditches feeding into this canalised and probably over-

[3] Topogenous surfaces with significant lateral water movement (percolation) – Wheeler *et al* (2009).

[4] WMC (2008, p. 16) states that for borehole BD2 at Cors Bodeilio, "the sand and gravel is likely to be in hydraulic continuity with the underlying limestone".

deepened feature are also generally linear and are presumed to originate from previous attempts to improve the drainage of the basin, though some may also represent highly modified successors of natural drainage features. The ditches in the western part of the fen (site management compartment CB1) comprise a fairly intensive network of drains which will have modified the influence of marginal groundwater seepage. Ditch section A-C is clearly identifiable on the 1889 Ordnance Survey Map, but whether this feature succeeded an original stream course is unknown.

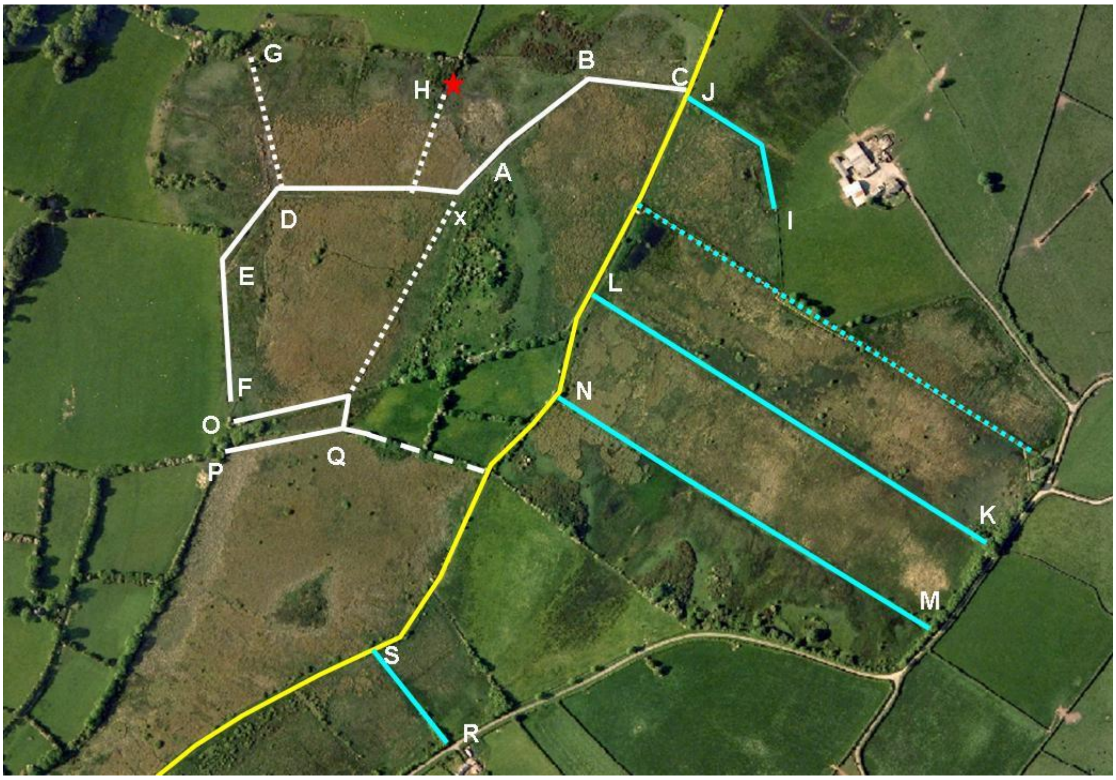


Figure 1. Map of selected elements of the drainage network at Cors Bodeilio. Drains marked with dotted lines had already been subject to some restoration work prior to the LIFE project. The yellow line marks the canalised course of part of the Afon Nodwydd. Ditches to the NW of the river are coloured white, those to the SE blue. Ditch sections are described with letter codes. This report describes work to restore favourable hydrological regimes in the ditch network between points D and C. The red star marks the location of fly orchid spring. Work to modify the influence of ditch section K-L is described in the proceedings of the *LIFE* project conference. The main Ynys feature extends SSW from point A. North is at the top of the image. Left to right distance is approximately 1200 m in this image.

Springs and seepage zones occur at several locations around the periphery of Cors Bodeilio and also bordering the Ynys ridges. The most striking of these is fly orchid spring which is believed to be a key discharge point for the minor sand and gravel aquifer. Discharge from fly orchid spring irrigates a particularly species-rich and good quality area of alkaline fen referable to the M13 *Schoenus nigricans* mire community, but the potential extent of its influence is truncated by ditch section A to B (Figure 2) which until the project described here, served to completely intercept all seepage draining SE from fly orchid spring. The distribution of plant communities reflects this (Figure 3) with alkaline fen represented by the M13 community up-gradient (W & NW) of ditch section A-B and modified calcareous fen referable to the *Cladio-Molinietum* community (albeit with patches of M13) down-gradient of it to the SE. It is reasonable to assume that alkaline fen grading into calcareous fen with significant *Caricion davallianae* elements would be much more prominent SE of the ditch-line under the un-impaired influence of groundwater seepage. This was recognised at a conceptual level at the time of preparation of this LIFE project bid and restoring a groundwater flow pathway at this location was identified as a key priority of the project.

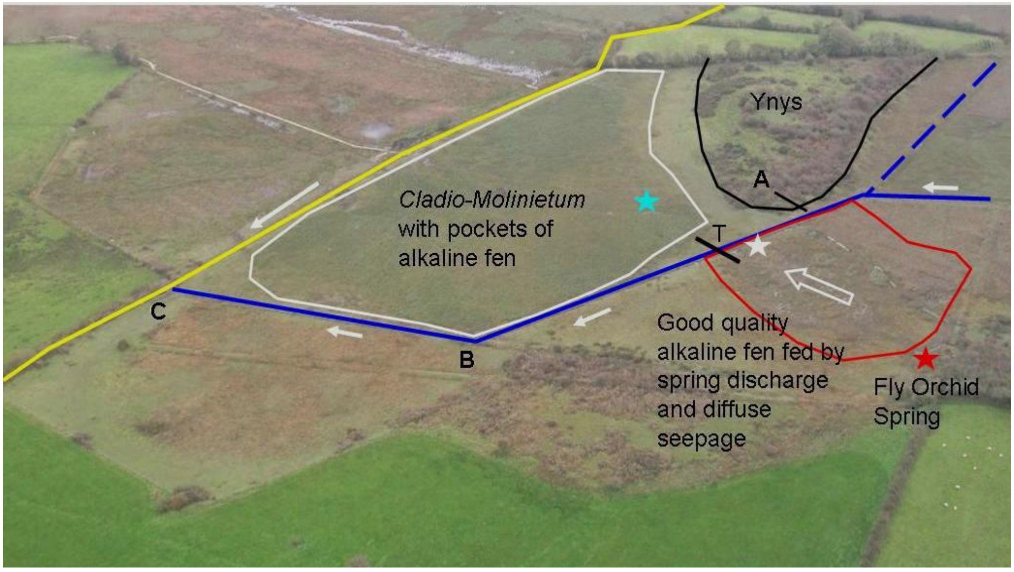


Figure 2. Oblique aerial photograph of fly orchid spring and some of the restoration area covered by this report, looking SE from approximate NGR SH 500778. The ditch covered by this project is shown as a solid blue line with flow direction indicated with white arrows. This ditch connects with the main 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, but with some areas of *Cladium*) influenced by fly orchid spring. The black line marked 'T' is dipwell transect T2. Aerial photo taken 22 October 2011 from a helicopter owned and piloted by Mr Jeremy Taylor of Tracked Dumpers UK Ltd: original image no. IMG_5649.

3. INVESTIGATIONS TO DEFINE RESTORATION WORK

A range of investigations were undertaken to determine both the desirability and feasibility of creating a wider zone of influence for groundwater discharge from the Fly Orchid Spring area.

3.1. Fly Orchid Spring flow regime and chemistry

Gauging of flows from fly orchid spring has been undertaken since February 2009 in order to quantify its hydrological significance as a source of groundwater supply. Gauging has been undertaken using the bucket and stopwatch technique (Brassington, 1988), with flows being collected from the end of a 110 mm plastic pipe set into a crude dam formed from the local sandy clay a few metres downstream of the spring-head where it cuts through an old cloddiau (Figure 4).

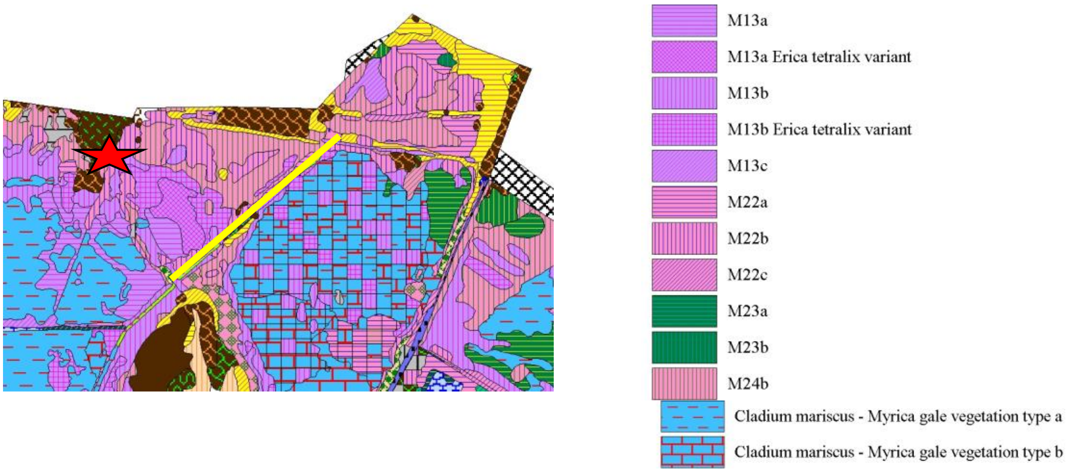


Figure 3. Extract of Phase 2 (NVC) map of Cors Bodeilio (Jones *et al*. in prep. 2015) showing fly orchid spring (red star), the area of M13 down-gradient of it, ditch section A-B (yellow line) and *Cladio-Molinietum* (Wheeler, 1980) dominated vegetation to the SE of the ditch A-B. M24 flanks the M13 to the N and NE, reflecting greatly reduced groundwater discharge in this area. The legend is selective and does not include all plant communities mapped. This vegetation map prepared by Alex Turner and others is one of the outputs of the current CCW/NRW Lowland Peatland Survey of Wales project (Bosanquet *et al.,* 2013). North is to the top of the figure.

Most of the data presented in Figure 5 are means of between 3 and 5 measurements, with care taken on each occasion to ensure lack of leakage through the dam. It proved possible with practice to achieve repeatable results.

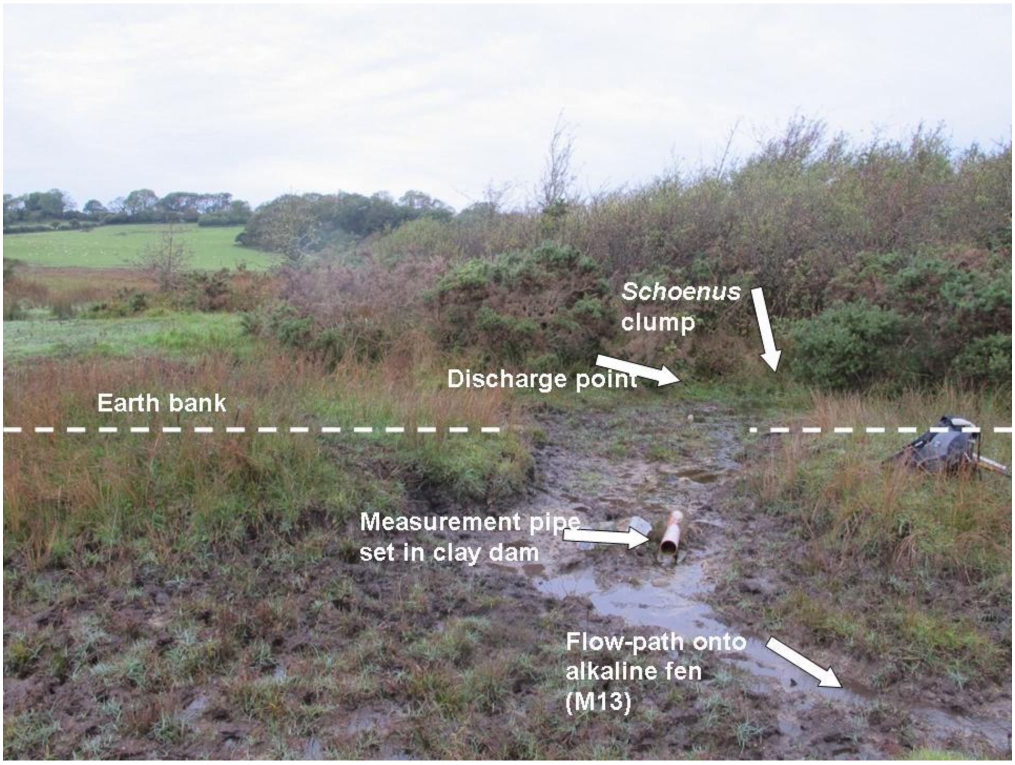


Figure 4. Flow gauging at Fly Orchid Spring, 18 October 2013, looking W from just below discharge point. Note heavy poaching by ponies in the foreground. A few *Schoenus* clumps occur at the discharge point and well above the main expanse of M13 vegetation (behind the photographer).

The spring displays a seasonal flow regime (Figure 5) which typically extends from autumn to spring, but with periods of summer-time flow during sustained wet weather (e.g. August 2012). Average discharge over the period of flow measurements (n = 95) was 0.82 l/s (70.8 m^3/day) with a range of 0.003 (7 May 2013) to 2.82 l/s (19 November 2009).

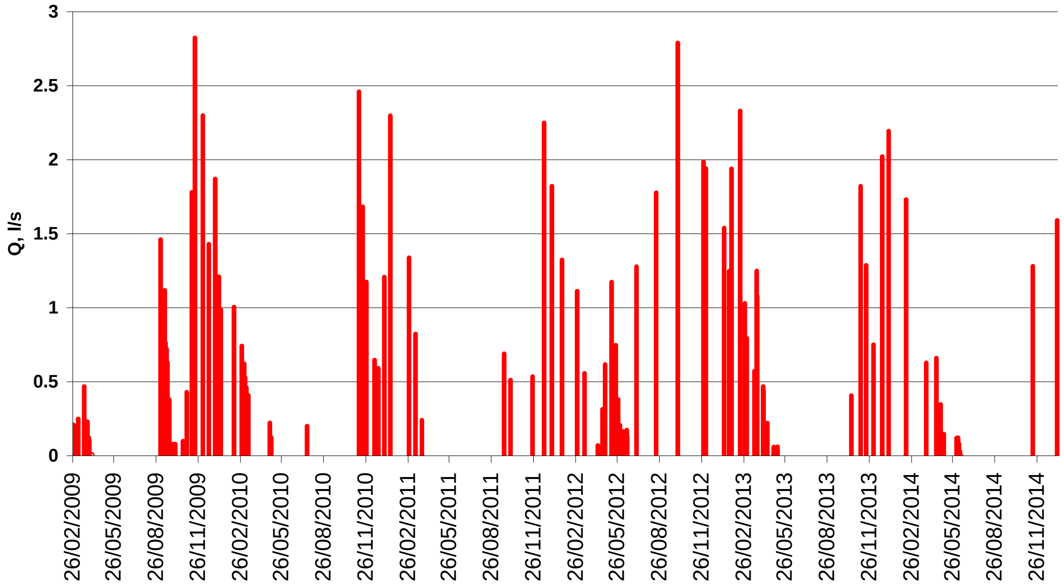


Figure 5. Mean estimates of discharge from Fly Orchid Spring, February 2009 to January 2015.

Discharge from the fly orchid spring alkaline fen area into ditch section A-B used to occur at a number of points, with a particular focus at the location marked with a white star on Figure 6. Discharge to the ditch at this location was noted on a number of occasions when fly orchid spring had ceased to flow, suggesting both a wider pattern of groundwater outflow below the spring-head. Discharge from this point was measured in November 2010 using a series of wooden planks to focus outflow to a single measurement point. Significant care was taken to prevent leakage and ensure capture of as much flow as possible. Measurements were timed for a period with only modest antecedent rainfall to try and maximise the groundwater as opposed to surface runoff contribution. The results (Table 1) indicate a flow gain of about 28% additional to that from fly orchid spring. Further diffuse and low volume seepage was noted elsewhere along the NW (up-gradient) side of the ditch face of A-B. These observations suggest a significant additional seepage component to that of fly orchid spring alone.

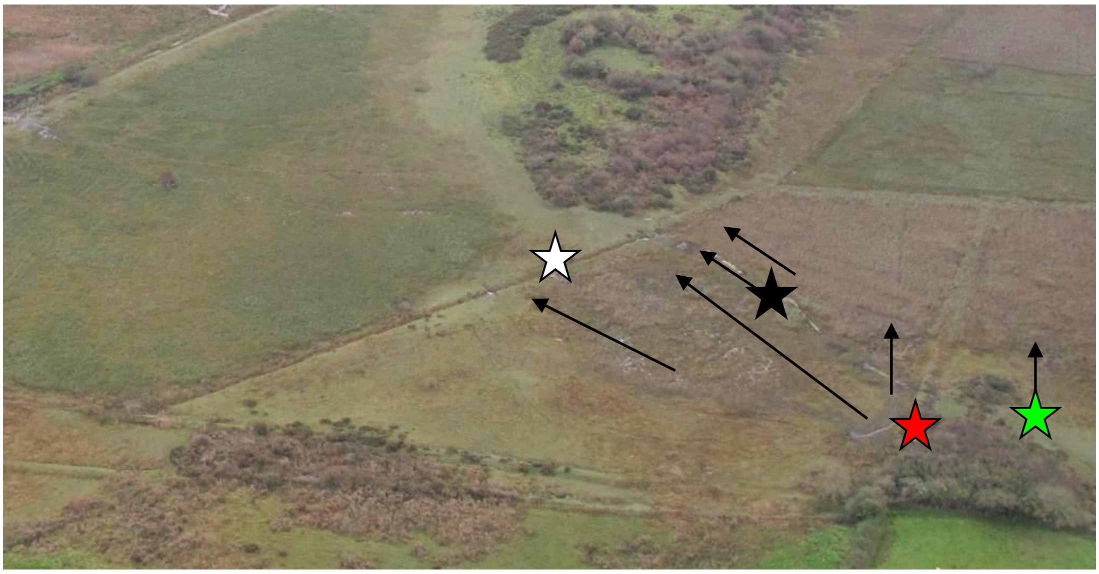


Figure 6. Cropped section of Figure 2 showing fly orchid spring (red star), the point of focussed outflow to ditch section A-B (white star), another putative groundwater discharge point close to the small boardwalk section (black star) and a seasonal discharge point close to dipwell 15 which oozes fine sand when running strongly (green star). Black arrows denote general direction of seepage.

Table 1. Comparison of discharge estimates from fly orchid spring and the collective discharge from the spring and the area of M13 down-gradient of it into drain A-B on 27 November 2010. These two measurement points are marked with a red and white star respectively in Figures 2 and 6. Rainfall totals have been extracted from the hourly rainfall record for Cors Bodeilio provided by the ARG100 rain gauge in the meteorological enclosure in compartment CB3.

Location	*NGR (SH)*	*Q (cm³/s)*	*N*	*SD (cm³/s)*
Fly orchid spring discharge	50020.77720	1175	5	56.6
Discharge to drain section A-B	50080.77650	1509	5	65.9
Antecedent rainfall (mm)	27 November, 00:00 – 12:00	26 November 00:00 – 24:00	25 November 00:00 – 24:00	24 November 00:00 – 24:00
	0.2	1	0.8	0.2

The quality of water discharging from fly orchid spring has been assessed as part of investigations to determine the extent to which groundwater supply to the site may be enriched with inorganic nitrogen (SWS, 2010): calcium concentrations have also been determined on a number of occasions (Table 2). The calcium data indicate amounts consistent with calcareous rich-fen (Shotyk, 1988; Wheeler, 1980b; Wassen *et al*., 1996) and more specifically M13 *Schoenus* fen (Wheeler & Proctor, 2000; Wheeler & Shaw, 2010) and confirm the general desirability of ensuring this water influences the surface chemistry of parts of the site strongly affected by drainage (namely the area SE of drain section A-B), and thus potentially losses of calcium due to rainfall leaching. However, the nitrogen data (Figure 7) indicate amounts of nitrate-N periodically in excess of the proposed trigger level for UK assessments of water quality impacts on calcareous rich-fens (4.5 mg/l, UKTAG, 2012) – though a limit of 2 mg/l (as used in Figure 7) would be more precautionary.

Table 2. Concentrations of calcium and nitrate-N recorded at Fly Orchid Spring. Data expressed as both milliequivalents / mgl^{-1}. Data for 2007 are from Banks *et al*. (2008), all other data from SWS (2010).

	3 Dec 2007	*21/4/2008*	*19/8/2008*	*1/2/2010*
Calcium meq/mg/l	6.64 / 133	6 / 120	7 / 140	6.9 / 138

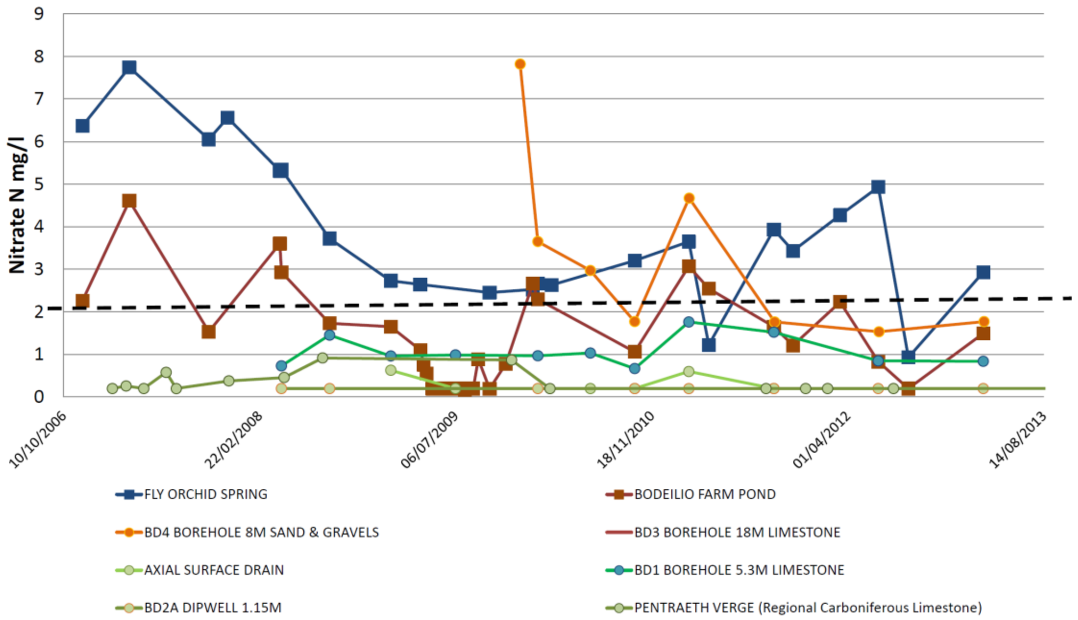


Figure 7. Water quality monitoring at Cors Bodeilio, Anglesey – after Farr *et al* (2015 – in prep. - data source: Natural Resources Wales). The suggested threshold value of 2mg/l N is shown with a horizontal dashed line.

The characteristics of the fly orchid spring location preclude use of a constructed wetland option for dealing with elevated N in discharge water. Given that the spring already influences some of the best quality alkaline fen at the site, it seems reasonable to extend this influence whilst also working towards improvements in its N chemistry through measures targeted at the surrounding fields/wider catchment.

3.2. Topographic and water level gradient survey

Detailed topographic survey was undertaken for two primary applications, the first being to determine the likely distribution of ground- and surface water following reconnection of the seepage pathway. The second requirement was to assess the wider-scale effects of raising water levels at point A on water levels elsewhere within and adjoining the western fen (compartment CB1) should this be pursued either as one of the options for restoring a groundwater seepage pathway, or as an additional restoration measure to yield higher water levels in ditch section A-D.

An initial appraisal of ground and water-level gradients across ditch section A-B was undertaken in 2011 using a levelled transect (*LIFE* project transect number T2) of 6 dipwell tubes installed across the ditch alignment and terminating at each end with existing CCW wells no. 5 (NW end of transect and located in the fly orchid spring area of M13) and 4 (SE end of transect located in *Cladio-Molinietum* vegetation) (Tables 3a and 3b). The results (Figure 8) indicate a hydrological gradient from left to right such that even the dipwell closest to the ditch on the up-gradient (WNW) side (transect dipwell 3 at 56.18 m) supports water levels higher than on the SE side, thus demonstrating potential for restoring a seepage gradient across the ditch line. The ground level data indicate the presence of spoil banks on both sides of the ditch (more so on the WNW bank), suggesting a significant mineral soil content. This confirmed that ditch infilling would need to be accompanied by some re-profiling to encourage an even spread of seepage water.

Tables 3a and 3b. Details of the peat water table and ditch water level monitoring network relevant to the restoration work at fly orchid spring. * original coordinates before drain works. i.d. indicates measurements based on internal diameter of wells. The data-loggers in wells T2.3 and T2.6 were removed on 7 May 2013 at the commencement of site works.

Table 3a. *Dipwell No.*	*Peat (P) or Ditch (D)*	*Easting (SH)**	*Northing (SH)**	*Date of installation / re-installation*	*Liner diameter (i.d) mm)*	*Liner length (cm)*	*Diver Serial No.*
5	P	50054	77706	7/11/06			
T2.1	P	50090	77674	18/1/11	33	58	
T2.2	P	50093	77672	18/1/11	33	40	
T2.3	P	50098	77669	18/1/11	34	74.7	H5691
Ditch	D	50104	77668	18/1/11	Steel pin	NA	
T2.4	P	50104	77664	18/1/11	33	59.5	
T2.5	P	50110	77660	18/1/11	33	60.2	
T2.6	P	50114	77658	18/1/11	34	100.5	H8561
4	P	50178	77630	26/10/06	50	67	
21	P	50197	77613	26/4/07	31	100+	
14	P	50220	77600	21/2/07	Peat hole	NA	
U bend	D	50060	77629	24/6/13	39	100.5	H0366
Confluence	D	49844	77607	24/6/13	34	65.5	H0447

Table 3b. *Dipwell No*	*Original distance along transect (m)*	*Distance along transect, 7/1/14 (m)*	*TOC height original survey*	*TOC height – 7/1/14 re-survey*	*Difference (cm)*
T2.1 (NW)	0	0	30.128	30.135	0.7
T2.2	4.13	4.14	30.18	30.167	-1.3
T2.3*	9.18	9.27	30.331	30.236	-9.5
Drain	14.14	Buried	29.445		
T2.4*	15.23	18.28	30.095	30.05	-4.5
T2.5*	24.7	23.43	30.04	30.135	9.5
T2.6 (SE)	29.1	29.1	30.048	30.061	1.3

A wider programme of topographic survey was undertaken via a contract to PM Surveys Limited in February 2012 – see Annex 3 for the contract specification. This survey yielded 1229 points of known height referred to ten figure NGR coordinates throughout the active ditch network of the western fen (compartment CB1) and at some distance lateral to the drains at selected locations. Part of the focus of this survey was over the block of fen ESE of drain A-B (Figures 9 & 10) to provide topographic information additional to that of the simple single transect investigation described above. The survey results (Figure 10) indicated significant potential for the spread of seepage water east of the ditch but with a likely tendency for flow across the distal (NE) portion of A-B to track NE roughly parallel to the original course of the ditch.

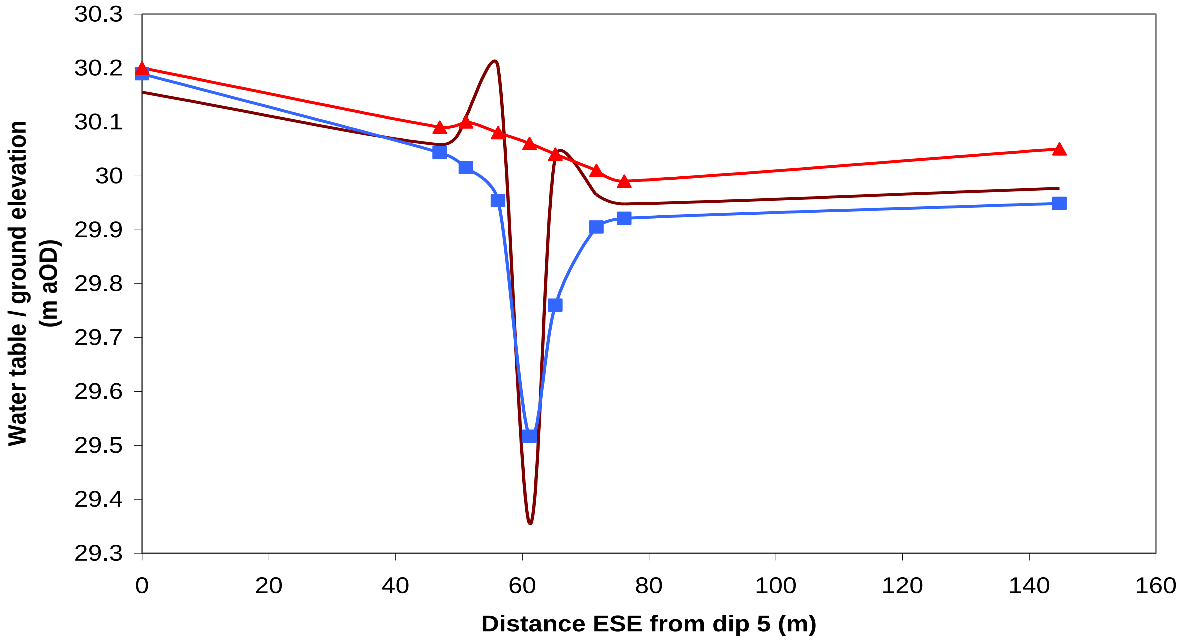
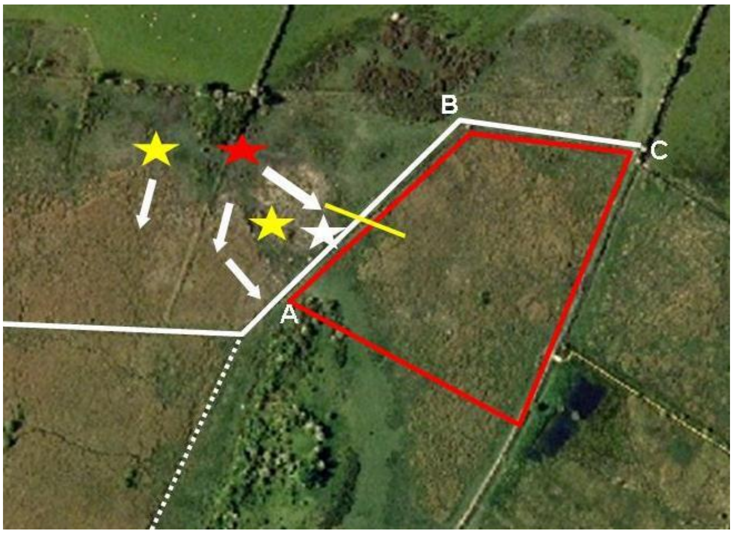


Figure 8. Variation in ground (brown) and water table level (blue, 24/11/11; red, 24/12/13)) for a 145 m levelled transect running WNW to ESE between dipwell 5 (SH 50053.77703) and dipwell 4 (SH 50178.77630). Ditch section A-B is crossed at c. 60 m. The blue and red plots show the respective water table profiles before and after infill of ditch section A-B; the brown line shows the original pre-restoration ground profile. See Figures 2 and 18 for transect location.

Figure 9. Approximate outline in red of area down-gradient of fly orchid spring (red star) subject to the detailed topographic survey shown in Figure 10. The white star marks the former point of focussed spring and seepage water discharge into ditch section A-B (white line). The yellow line marks the approximate alignment of the dipwell monitoring transect, with dipwell T2.1 at its NW end and T2.6 at the SE tip. Yellow stars indicate other springs/upwellings; white arrows denote spring flow pathways. Image extends from 100 m grid line 499 (L) to 503 (R). Image centre *c*. SH 5011.7768.



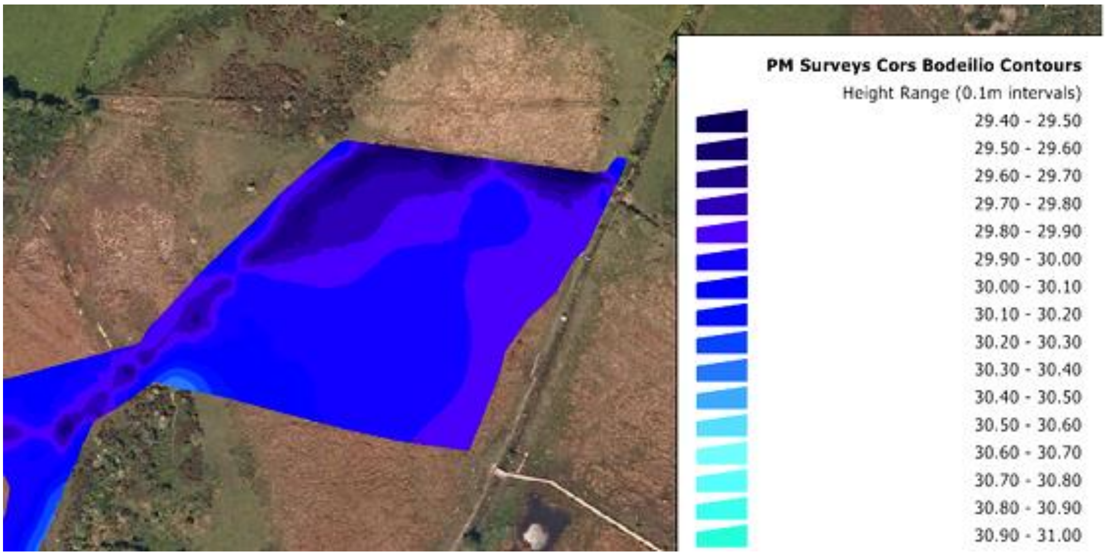


Figure 10. Topographic survey plot for the area ESE of drain section A-B and showing the results of the PM Surveys Ltd survey as colour-coded 0.1 m height intervals.

The topographic survey indicates a relatively gentle water level gradient in the ditch network upstream of point A towards point D (Figure 11), with a *c*. 25 cm height difference in ditch water level elevations between A and D. Ground surface either side of section A-D is typically between 10 and 20 cm higher than ditch water levels at the time of survey, indicating that any significant sustained rise in water levels would register as flooding either side of ditch section A-D before affecting the much higher ground to the west of the site under third party ownership (Figure 11). The topographic survey was also able to demonstrate that the elevation of the outflow point from a feature referred to as Bodeilio Farm Pond (Figure 11) is much higher than the general water level elevation across the fen, thus ruling out any risk of water levels 'backing-up' to a point where drainage out from the pond could be impeded.

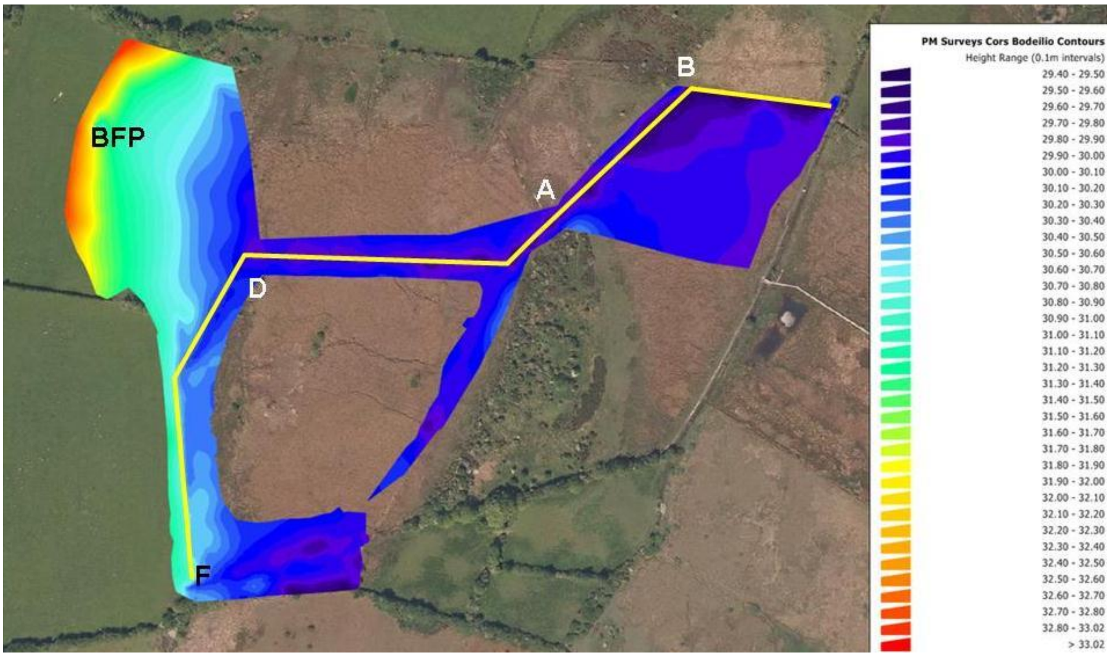


Figure 11. Topographic survey plot for the ditch network and surrounding peat surface in the western part of Cors Bodeilio NNR. Levels are shown as colour-coded 0.1 m height intervals. The yellow line with letter-coded points shows parts of the drainage network. Bodeilio Farm Pond is indicated as BFP.

Particular attention was given to examination of ditch water levels and adjacent upslope ground levels along ditch section D-E-F (Figures 1 and 12, Table 4) based on the PM Surveys topographic survey. The survey results indicate a height difference of between 45 and 57 cm, with ditch water levels at point E lying 41 cm above the water level at point A. Given the relationship between peat surface and ditch water level elevations between point A and D, these observations rule out any possible nuisance flooding to neighbouring land resulting from water level changes at point A. As Figure 12 shows, surface ponding of water along the field boundary close to ditch E-F occurs already during very wet periods.

A buried field drain emerges from beneath the field and opens into the ditch network at point E. The invert of the drain was determined as 30.11 m aOD and water levels in the ditch were determined as some 6 cm higher than this during the PM Surveys Assessment – i.e. the end of the field drain pipe was already subject to periodic flooding prior to the restoration work described in this report. Observation suggests that the field drain is no longer effective even when water levels in the ditch are lower than the drainage pipe invert.

Monitoring of water levels in the ditch network between points A and D has been undertaken to test the conclusions of the topographic assessment – see section 5.

Figure 12. Boundary fence between ditch D-E and adjoining agricultural land to the west – looking S. Photo taken at peak winter time water levels after heavy rain caused surface runoff from the field into the fen. Photo taken January 2008. The T4 boundary ditch datum point is just out of sight to the L.

Table 4. Comparison of water levels in ditch 1 and ground levels along the alignment of the adjoining fenceline between points E and F (see Figure 2.1). All data based on PM surveys drawing PMS-12006 (8 February 2012).

Water level in ditch (mAOD)	*Ground level along adjoining fenceline (mAOD)*	*Height difference (m)*
30.17	30.73	0.56
30.31	30.76	0.45
30.27	30.84	0.57
30.34	30.88	0.54
Range		0.45 – 0.57
Average		0.53

4. OPTIONS ANALYSIS AND DEFINITION OF TARGET OUTCOMES

4.1. Options analysis.

A range of options were considered for achieving renewed groundwater influence to the south-east of drain section A-B – these are summarised in Table 5. All options were informed by two primary criteria, namely (i) the objective of securing a groundwater seepage pathway across drain section A-B, thereby accomplishing an element of the site works package needed to deliver favourable conservation status for both SAC habitat features, and (ii) maintenance of drainage freeboard for agricultural land owned by a third party to the west of the fen (though see section 3.2 above for discussion of the actual risk of flooding to neighbouring land). The latter criterion relates to NRW's duty to ensure its activities do not result in unacceptable consequences for neighbouring agricultural land and clearly has a major bearing on the reputation of NRW and the *LIFE* project.

All five options in Table 5 were considered, with a combination of options 1 and 2 being proposed by one of the contractors asked to tender for the groundworks. Options 1,2 and 5 were rejected at an early stage for the reasons given in the final column of the table, with options 3 and 4 considered further. Option 4 was considered to pose a number of risks, chief among these being the potential for significant interception of groundwater supply to some of the western parts of the fen, even though ditch section E-F would probably only have required relatively shallow deepening to reverse its current S-N flow. Option 3 was selected as offering the best ultimate combination of restoration outcome and upstream water level control, this decision being influenced to a degree by the use of pipe bypass systems in an analogous context some years ago at Cors Geirch (Rhyd y Clafdy section). Option 3 was chosen on the basis that impacts on invertebrate and botanical assemblages could be mitigated to a degree through a combination of deweeding sections of ditch A-D, and by creating shallow peaty ledges or possibly additional off-line ditch sections peripheral to the main ditch profile of A-D. These measures are now planned for the after-*LIFE* phase.

Table 5. Summary of options analysis used to inform final choice and design of groundwater supply reconnection project at fly orchid spring. See Figure 1 for location codes.

Option	*Advantages*	*Disadvantages*
1. Raise water levels in ditch section A-B but do not completely infill. Engineer irrigation scrapes leading off raised level of section A-B into fen SE of ditch.	Retains ditch A-B and associated invertebrate and botanical interest (though some of this may have been 'flooded-out'.	Raises water levels upstream in A-D-E network. Even if levels were maintained bank-full, the drain would still act to intercept groundwater from fly orchid spring. Periodic over-banking of drain may have occurred, with potential for enrichment (NRW has limited control over land management practices on land west of the fen).
2. Cut a new route ESE for the ditch from point A to the main drain, cutting past NE tip of Ynys.	Enables ongoing drainage of A-D-E network. Enables complete infill of ditch sections A-B and D-C.	Potentially intercepts seepage influence from main Ynys feature to fen SE of drain A-B (a groundwater upwelling was noted close to the position of the proposed new ditch – see Fig. 2). Would involve cutting a new ditch in peat – an option generally ruled out for the *LIFE* project.

Option	*Advantages*	*Disadvantages*
3. Install bypass pipe in ditch section A-B with adjustable invert level for intake.	Enables creation of a surface profile across ditch A-B conducive to re-supply of groundwater to SE fen. Enables raising of water levels in section A-D but with benefit that a large pipe intake can accommodate flood flows. Adjustable invert means that water levels in ditch section A-D can be lowered to pre-restoration level without affecting groundwater supply SE from fly orchid spring.	Installation of a synthetic pipe represents an un-natural engineered approach. Pipe will result in an inevitable maintenance requirement. Complete infill of ditch section A-B results in loss of local invertebrate/botanical assemblage. Pipe outlet level dictates limit to extent to which water levels can be raised in ditch B-C.
4. Completely infill ditch section A-B, modify ditch network from D-F to connect with point O, thus enabling drainage of western fen to an upstream location on the Afon Nodwydd.	Enables complete infill of ditch sections A-B and B-C and raising of water levels in A-D system. Offers a potential means of removing enriched runoff from fields to the west of the fen.	Reduced groundwater flushing of ditch section D-A. Would require deepening of ditch section E-F with possible risk of groundwater interception and reduction / loss of groundwater supply to calcareous and alkaline fen (a groundwater 'high' point is known to occur just E of section E-F – see Annex 7. Extra flow routed through section O-Q might comprise groundwater supply which is suspected to contribute significantly to the botanical quality of this ditch. Engineering an alternative route to point P might have interrupted groundwater supplies to O-Q.
5. Do nothing - leave drainage network unchanged.	Acknowledges long-standing character of drainage network and the biodiversity value of the invertebrate and botanical assemblages of ditch section A-B. Existing drainage regime for neighbouring land retained.	Fails to contribute to delivery of Favourable Conservation Status for the two primary SAC features. Missed opportunity to undertake radical restoration project within lifetime of *LIFE* project.

4.2. Definition of project

Following the selection of option 3 as the main element of this project, a series of complementary projects were also defined. These are defined fully in the ground-works specification (Annex 2) but the key elements are summarised in Table 6.

Table 6. Summary of the main elements of the fly orchid spring groundwater pathway restoration project at Cors Bodeilio NNR. See Figures 2.1, 3.5 and 3.7 for locations.

Project element (LIFE actions)	*Target outcomes*	*Key restoration elements*
1. Complete infill of section A-B, bypass flow enabled with buried pipe. (C10, C11).	Restore groundwater pathway across former ditch line. Encourage expansion / redevelopment of alkaline fen.	Excavate ditch section to create uniform profile for pipe. Install pipe. Backfill with ditch arisings and extra peat sourced from new peat cuttings nearby (see below).
2. Raise water levels in up-stream ditch section A-D-E. (C10, C11).	Encourage deeper year-round column of calcareous water suitable for a range of Charophytes and vascular macrophytes. Reduce adjacent water table draw-down and peat wastage.	Install flexible inlet at start of bypass pipe intake such that upstream water levels can be raised but overflow maintained.
3. Raise water levels in downstream ditch section B-C. (C10, C11).	Encourage deeper year-round column of calcareous water. Reduce adjacent water table draw-down and peat wastage.	Install dams
4. Raise/stabilise water levels in the peat body down-gradient of fly orchid spring adjacent to the main drain and ditch section B-C.	Raise and stabilise water levels in the peat body. Prevent erosion of peat into the main drain.	Install peat dams at key locations where surface outflow to main dry from peat body has been observed. Re-profile/infill erosion gulleys at edge of peat body.
5. Create peat cuttings.	Restore early successional elements of both Annex I habitats. Provide peat for infill of ditch section A-B.	Excavate 4 peat cuttings. Transport material and use in elements 1 and 4.

5. PROJECT IMPLEMENTATION

The contract for all site ground-works was let to Gwyn Roberts & Sons Construction of Bala (North Wales) and work commenced on 7 May 2013. This followed a survey for presence of ground-nesting birds undertaken by Les Colley of NRW across all parts of the project area; this confirmed the absence of any nesting territories. The project was managed by RML with support from JH, PSJ, JG and LJ.

<u>5.1. Infill of ditch section A-B and raising of water levels in ditch sections A-D-E (elements 1 & 2)</u>.

Cleaning of ditch section A-B was completed on 7 May 2013 (Figure 13 and report cover image) and pipe installation by 10 May 2013 (Figure 14). Significant wastage of the original spoil banks meant that most of the infill surrounding the pipe was sourced from four nearby peat cuttings (see section 5.4).

Figure 13. Cleaning of ditch section A-B to create a graded bed for the bypass pipe. Sections of bypass pipe can be seen in the distance tied onto a steel cage mounted on a tracked dumper. Image taken 7 May 2013, looking NE from close to point A. Original image number IMG_8085.

Figure 14. Infill of ditch section A-B and burial of the bypass pipe at Cors Bodeilio NNR, 8 May 2013. The peat infill visible in the distance was sourced from peat cutting areas in compartment CB1NE. Photo looking SW with Ynys on left. Original file number IMG_8110.

Ditch cleaning was preceded by an operation to strip *Schoenus* turfs from the ditch flanks; these were placed to one-side ready for reinstatement. The pipe sections used are 6 m sections of 450 mm diameter twin-wall high-density polyethylene pipe[5] and a total of 145 m was installed. The post-installation fall in level from inlet to outlet is 25.5 cm (0.17%). The pipe is fitted with two rectangular inspection hatches and with an adjustable 90 degree bend fitted over the end of the pipe intake (Figure 15, 16). Under high water level (typically winter-time) conditions, the outflow of the pipe is almost or completely submerged as a result of measures to raise water levels in ditch section B-C. Both the pipe inlet and outlet were finished with surrounding stone headwalls constructed as dry-stone features from limestone dug up during the initial ditch cleaning (Figure 15). An option to locate transverse impermeable seals along the former ditch line was considered but ultimately rejected as un-necessary: leakage of water along the former ditch course does not appear to be significant. Measures to positively anchor the pipe in the excavated ditch profile were discussed on-site with the contractor but ultimately rejected as un-necessary. However, during the summer of 2014 a section of pipe close to point A 'floated' to a point where it actually broke through the peat covering in a few places. Remediation works will need to be undertaken during the after-LIFE phase.

The infilled ditch surface was finished slightly proud of surrounding ground level to allow for settlement, with *Schoenus* turfs bedded in at locations close to their original position along the ditch axis. Care was taken to ensure material was replaced in the correct stratigraphic order. Ponding of water on the upslope side of the infilled ditch was noted in places and dealt with by excavating shallow runnels over the infill (Figure 23a). These could be infilled in due course, though most were observed to support significant growths of *Chara* by the winter of 2013/14.

The 90 degree bend pipe intake was initially set to yield high but not quite bank-full levels in the upstream section of ditch (section A-D-E).

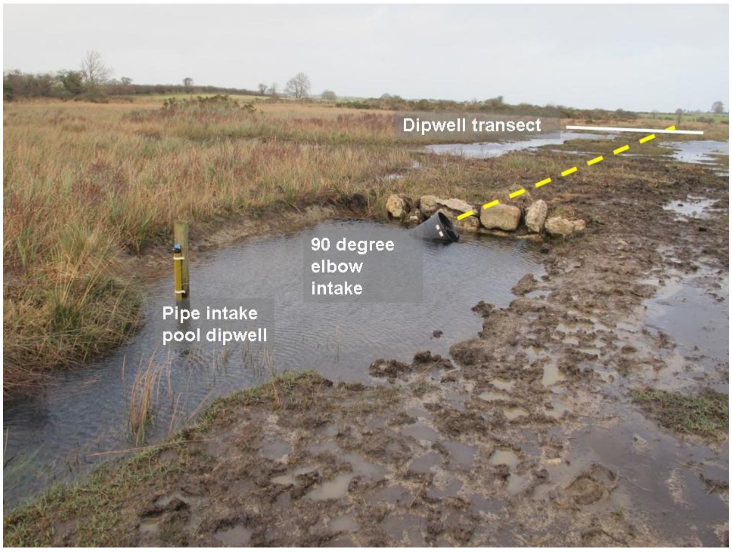


Figure 15. View looking NNE from point A down the alignment of the buried pipe (yellow dashed line). The adjustable U bend pipe intake is visible and also the dipwell located in the pipe intake pool. Photo taken 6 January 2014. Original image number IMG_3859.

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[5] Pipe manufactured by Naylor Drainage Limited, Clough Green, Cawthorne, Barnsley, S75 4AD – pipe product code &1356 DN 450 Metrodrain, twin wall black, solid unmarked. The pipe is corrugated, with the raised corrugations formed from the outer black plastic layer ands thus leaving an air gap between the black outer layer and the green inner layer. Pipe wall thickness ranges from 33 mm on the corrugations to 3 mm in the 'valleys' inbetween.

Figure 16. Close up of adjustable U bend inlet of bypass pipe; this also shows the approximate alignment of the buried pipe. Photo taken 22 December 2013, Original image number IMG_7456.

<u>5.2. Installation of dams in ditch section B-C (element 3).</u>

Complete infill and continuation of the bypass pipe into section B-C was considered but ultimately rejected for the following reasons, (i) it would have buried some dense patches of *Schoenus* (especially in the N bank of the ditch – see Figure 17), (ii) because of the lack of strong groundwater discharge either from the N or S, thus complete infill would not have yielded significant groundwater reconnection benefits, (iii) levelled profiles across the section had demonstrated that the areas which might benefit from any reconnection of groundwater seepage across the drain were topographically limited, and (iv) the need to retain open sections of ditch with flanking *Schoenus* tussocks for invertebrate interest. The option chosen for this section was to raise the ditch water level by installing plastic piling dams in pre-excavated trenches notched into each bank to prevent leakage, and cut deep enough to enable the dams to be set into the underlying clay-rich drift. The contractor elected to use 0.5 m wide interlocking hexagonal piling in 0.5 m wide sections which proved extremely robust and resistant to buckling.

Figure 17. Installation of hexagonal section plastic dams in ditch section B-C, 10 May 2013. The machine bucket is removing sediment and water from a trench excavated ready to receive the lengths of piling. Note the dense *Schoenus nigricans* strip on the N side of the ditch bank and one of the two newly created peat cuttings in compartment CB1NE beyond. Original image IMG_8178.

Four dams were installed (all on 10 May 2013), with the crest of the first (Dam 1 – see Table 7) set under laser levelling control to a level just beneath that of the top of the bypass pipe outlet. Relevant height and location details are given in Table 7.

Table 7. Elevation and NGR coordinates for key elements of the fly orchid spring groundwater reconnection project. Pipe elevations are coded (o) for outside of pipe and (i) for inside. Note the elevation for dam 3 which should be intermediate between dam 2 upstream and dam 4 downstream but which was erroneously set at the lowest elevation of any dam. Numbers in bold in column 1 for the four ditch dams are distance W from the downstream dam #4. All elevations based on laser level surveys in January 2014. Peat cutting dimensions based on tape measure survey, 23 January 2014.

Location	*NGR (all SH)*	*Elevation (m aOD)*	*Details*
Ditch B-C Dam 1 (W), **17.4 m**	50241.77723	Dam crest 29.437	4 x 50 cm sections
Ditch B-C Dam 2, **12.4**	50247.77723	Dam crest 29.355	4 x 50 cm sections
Ditch B-C Dam 3, **7.3 m**	50251.77721	Dam crest 29.254	4 x 50 cm sections
Ditch B-C Dam 4 (E), **0 m**	50258.77720	Dam crest 29.27	4 x 50 cm sections
Ditch A-B pipe inlet	50060.77629	Top of pipe (o) 29.823	
Ditch A-B pipe outlet	50133.77725	Top of pipe (o) 29.548 Top of pipe (i) 29.515	
Peat dam, ditch outlet	50176.77728	29.927 (W) to 29.968 (E)	13 x 50 cm sections
Peat dam #1, river	50229.77613	29.91	12 x 50 cm sections
Peat dam #2, river	50243.77633	29.725	12 x 50 cm sections
Water level in CB1E peat cutting (#1)	50238.77694	29.85	Area c. 159 m^2
Water level in SE peat cutting, CB1NE (#2)	50220.77740	29.861	Area c. 192 m^2
Water level in NW peat cutting, CB1NE (#3)	50190.77740	29.791	Area c. 356 m^2
Water level in CB3NW peat cutting (#4)	50258.77612	29.469	Area c. 30 m^2

5.3. Installation of plastic piling dams within the peat body down-gradient of the restored groundwater pathway.

Three lengths of peat dams were installed in the peat body down-gradient of the restored groundwater pathway in site management compartment CB1E (Figure 18). Two *c.* 6 m lengths were installed adjacent to the main drain in areas where winter overflow of water was causing some erosion of peat into the drain, with down-cutting of some of the runnels into the peat body (Figure 19). The third 6.5 m length was installed E of the bypass pipe outflow at point B to help retain directed spring water on the site. The piling was installed using a combination of installation in cut trenches and also by being pushed in vertically using the excavator bucket.

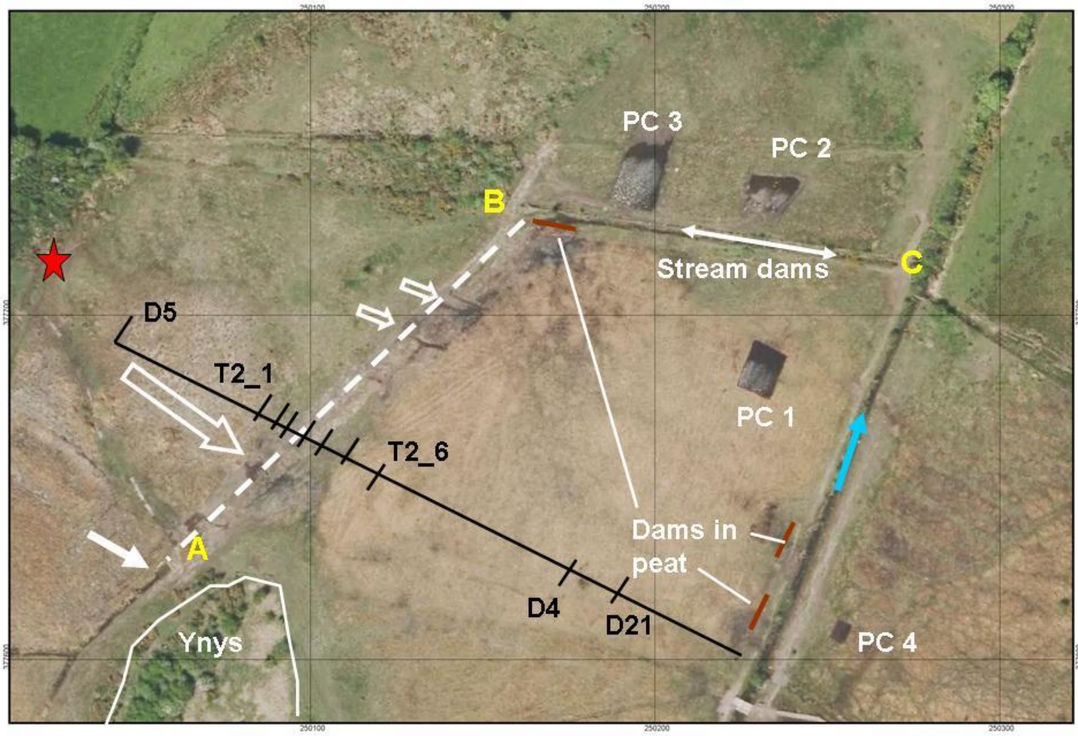

Figure 18. Annotated 2013 aerial photograph of the area of fen (compartment CB1E) down-gradient of the restored groundwater flow pathway at Cors Bodeilio NNR. This image was taken following completion of the restoration work described in this report. It shows the four peat cuttings (PC 1-4) used to supply peat for infill of drain section A-B (dashed white line), the three sections of plastic piling dams within the peat body (brown lines – not to scale), the approximate alignment of the water level monitoring transect T2 and its extension in both directions to connect with wells D5, D4 and D21 of the hydrological monitoring network at Bodeilio, and the approximate position of the four plastic piling dams in stream section B-C. Black tick marks on the dipwell transect indicate the approximate position of wells. Fine black lines are 100 m grid lines of the BNG. Centre of image is at SH 5015.7765, with N to top of image. See also Figure 9.

Figure 19. Location of one of the three plastic piling dams located at the edge of the peat body shown in Figure 18. The white arrows denote the start and end of the piling section. The image is looking NE with the main outflow drain on the R and with the direction of flow heading away from the observer. Photo taken 15 May 2013 shortly after installation – original image number IMG_8331.

5.4. Peat cuttings.

Four peat cuttings were excavated to provide a source of peat for the infill of ditch section A-B (Table 7), with all four also serving to create conditions suitable for early successional colonists. Cuttings were excavated using a medium-sized 360 degree excavator (Figure 20a), with light-weight tracked dumpers carrying the peat to the ditch (Figure 20b). The cuttings were excavated to a depth sufficient to hold between 15 and 25 cm of standing water, with cuttings 2 and 3 profiled to slope down from S to N.

Figure 20a. Excavation of peat cutting #1 on 13 May 2013. Original image number IMG_8278.

Figure 20b. Light-weight tracked dumper off-loading peat from peat cutting 1 at the outflow end of the bypass pipe, 13 May 2013.

6. HYDROLOGICAL CONSEQUENCES OF GROUNDWATER PATHWAY RESTORATION PROJECT

6.1. Overall trends

Infill of ditch section A-B has resulted in significantly wetter conditions along and down-gradient of the ditch during periods of discharge from fly orchid spring (Figure 21). These conditions extend to the outflow end of the drain (Figure 22), where one of the sheet-piled sections has aided retention of spring water at the edge of the peat body where it abuts the open section of the drain (section B-C).

Figure 21. 5 m high mast photograph looking NW of flooding down-gradient of fly orchid spring (red star) following infill of the ditch (former course shown as a dashed line): image 12/3/14. Flooding on this scale did not occur prior to the restoration work. The large white block arrow shows the approximate seepage gradient and surface flow in this direction is now common during periods of spring discharge. The white line shows the approximate alignment of transect T2.

Figure 22. Image looking SE from the bypass pipe outlet (see yellow arrow – this is point B of Figure 1) showing standing water (shown bordered by the white dashed line – note that standing water continues beyond into the *Cladium* stand), with the two white arrows denoting the plastic piling dam at the edge of the peat body. The standing water in the foreground is part of ditch section B-C, where water levels have been raised through installation of plastic dams in the ditch – see Figure 25b. Image IMG_5942, 10 June 2014.

Extensive areas of open water along and adjacent to the ditch line have become colonised by stoneworts (Figures 23a and b), including the runnels cut across the slightly raised ditch infill to encourage water movement SE of fly orchid spring.

Figure 23a. Extensive stonewort patches up and down-gradient of the infilled ditch and also in runnels excavated to enable cross-flow and visible in this image as two broad lines heading away from the observer. 30 April 2014, original file number IMG_5156.

Figure 23b. *Chara* colonising shallow calcareous pools adjacent to dipwell T2_3, 13 December 2013. Original file number IMG_3526.

Ditch water levels upstream of the bypass pipe intake are now significantly higher, with almost bank-full conditions noted during the winter and after periods of rainfall (Figure 24). Ditch water levels have also been raised in ditch section B-C (Figure 25 a & b), though bank-full conditions could not have been achieved without immersion of the bypass pipe outlet.

Figure 24. View looking upstream from point X towards point D (see Figure 1 for locations) on 24 December 2013. Note the high water level in the ditch and in the area of mown fen to the left (S) of the drain. Water level transect T1 crosses this drain from S to N (L to R in this image) in the distance. Original image number IMG_3689.

Figure 25a. View N from the south side of ditch section B-C with peat cutting number 3 in compartment CB1NE visible on the N side of the ditch. Image date 14 May 2013, original file number IMG_8309.

Figure 25b. View looking NW up ditch section B-C showing one of the hexagonal plastic dams in the foreground, peat cutting 2 on the N side of the ditch, and a dense strip of *Schoenus* tussocks on the northern ditch bank. Image date 14 May 2013, original file number IMG_8308.

6.2. Analysis of water level records.

The influence of the groundwater pathway restoration work on water levels down-gradient of the ditch is clearly detectable in comparisons of water table trends before (April 2013) and after (April-May 2014) infill for two periods with limited rainfall (Figure 26).

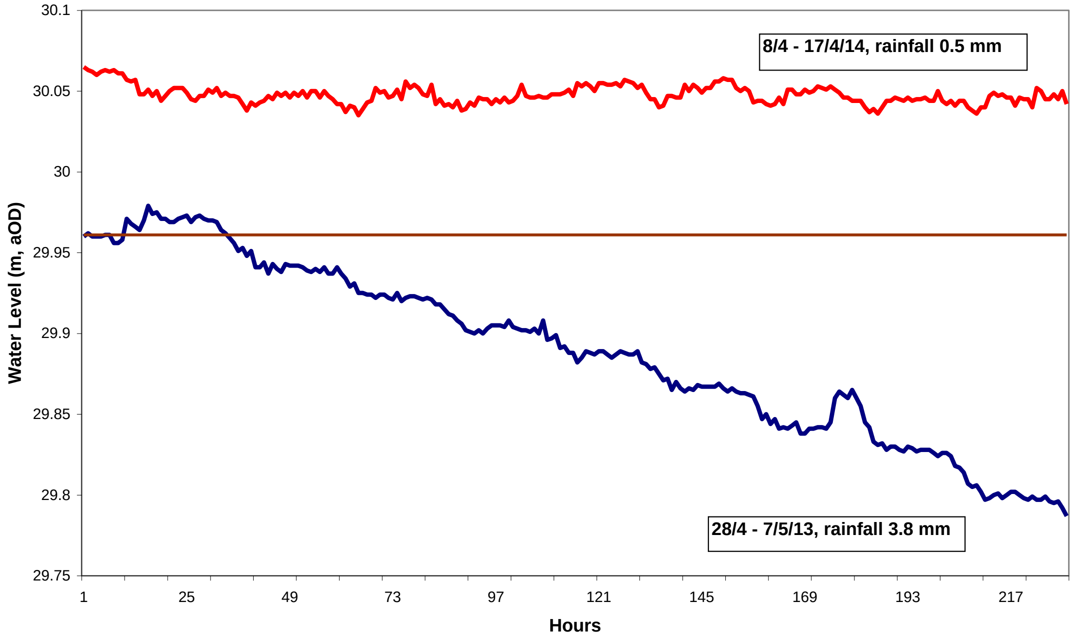

Figure 26. Comparison of water level trends down-gradient of ditch section A-B before (blue line) and after (red line) infill. These are hourly records of water level for dipwell T2-6 (see Figure 18 for location) over two broadly comparable ten day spring-time periods. Flow from fly orchid spring was occurring during both periods, with only minor rainfall recorded. The lower (blue) plot pre-dates infill of the ditch; the top (red) plot shows the situation after completion of the ditch by-pass work. The brown line shows ground level. Rainfall data sourced from http://www.llansadwrn-wx.info/obs copyright of Dr Donald Perkins; these data are for a station *c*. 7 km ESE of Bodeilio.

The 2013 (lower) plot shows a decaying water table level in the absence of rainfall and increasing evapo-transpiration, but the 2014 (upper) plot shows a higher water level with little evidence of decline in response to lack of rainfall. These data are for dipwell T2-6 (Figure 18) which lies *c.* 15 m from the ditch in an area of *Cladio-Molinietum* calcareous fen with patches of M13 as both mosaic elements and more discrete stands: it is reasonable to assume that the improved hydrological status at this location (i.e. higher and more stable water levels sourced from a calcareous spring) also applies more generally parallel to and down-gradient of the drain.

The immediate effect of infilling the ditch can be seen by comparing the water table response of dipwell T2-6 against changes in level for the same period at a selection of other Bodeilio wells for a period spanning infill of the ditch (Figure 27). The overall trend for the comparison wells was one of a decline in water table level However, well T2-6 immediately down-gradient of the infilled ditch exhibited a rise which can be attributed to reconnection of the groundwater pathway from fly orchid spring.

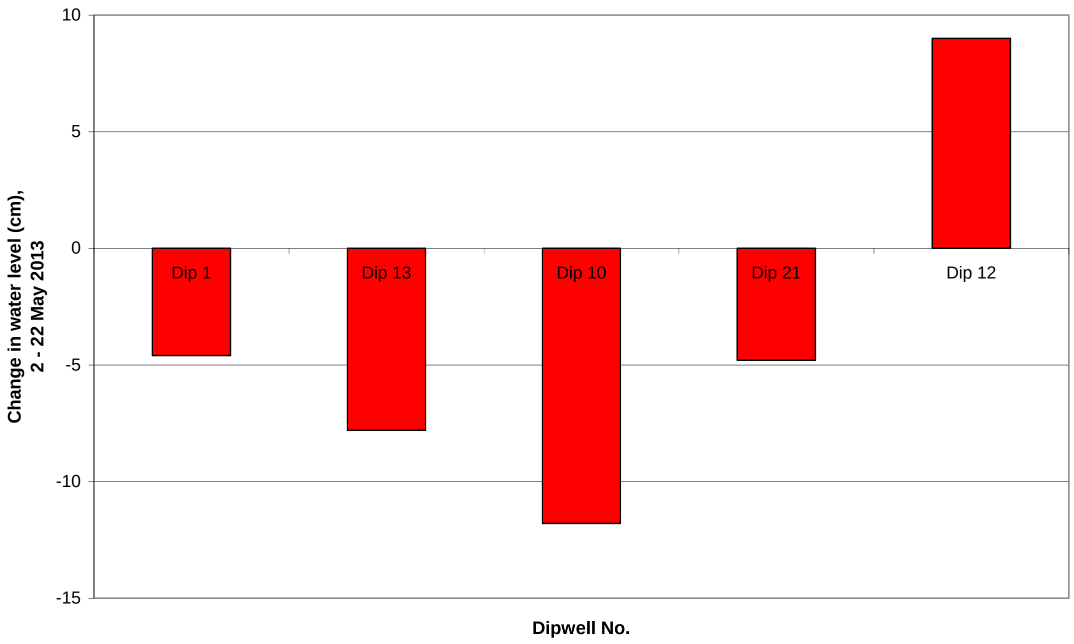

Figure 27. Change in water level recorded at five dipwells at Cors Bodeilio between 2 and 22 May 2013 and thus spanning the groundwater reconnection works described here. Dipwell 12 is the same well as T2-6, dipwell 21 lies in the same peat body and down-gradient of well T2-6 (see Figure 18). Wells 13 and 10 are located in periods of periodic seepage influence; well 1 is in a rheo-topogenous context. The rainfall total for this period was 30.6 mm rainfall (data of Dr Donald Perkins for Llansadwrn).

The longer term trend of water table behaviour following infill of the ditch is shown in Figure 28 which reveals that the main visible effect of ditch infill is tied to periods of flow from the spring-head, with significant drops in level occurring during periods when the spring is dry. The stable pattern of winter-time flooding resulting from the influence of fly orchid spring is striking and was not previously noted as a feature of this well prior to ditch infill (Figure 29), though unfortunately only a limited continuous water level record is available for the period before ditch infill.

Future analysis of the ongoing continuous water level record might identify a more subtle seepage influence even in the absence of surface flow, but this has not been attempted here and may be impossible due to the shortness of the continuous water level record prior to ditch infill.

Other dipwells in transect T2 show a similar response to T2-6 (Figure 30), with a smaller difference in levels between wells since ditch infill, particularly for the down-gradient well closest to the ditch (T2-4).

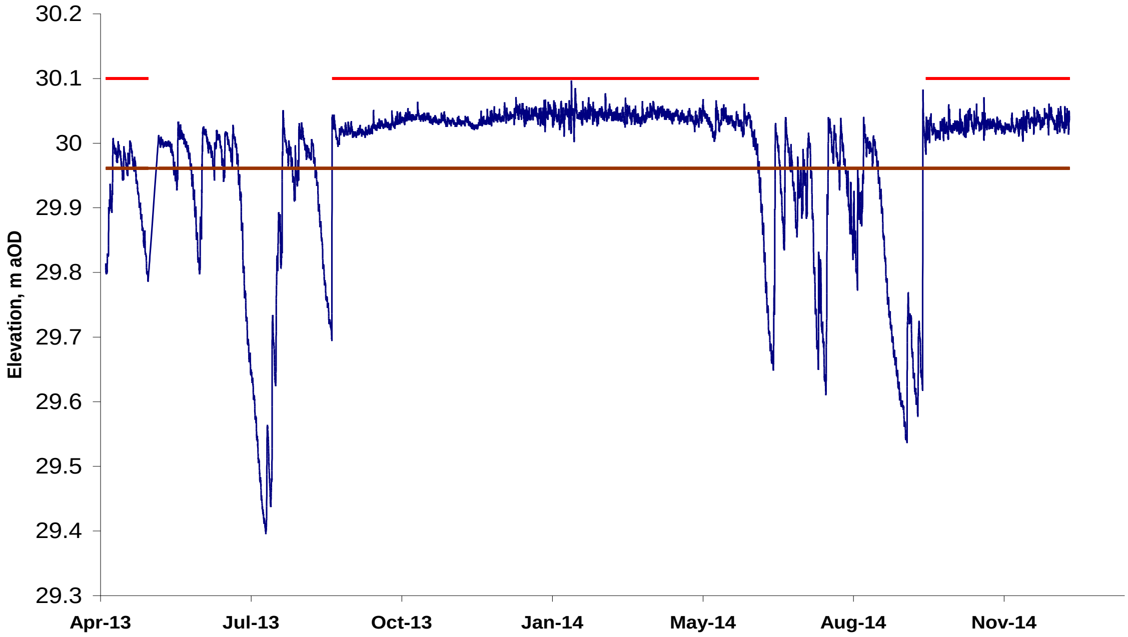

Figure 28. Hourly record of water level fluctuations at well T2_6 between April 2013 and January 2015. There is a hiatus in the record resulting from the removal of the logger on 9/5/13 and its replacement on 14/5/13 after infill of the ditch: the rise in levels between these periods probably relates to heavy rainfall in the intervening period. Periods when fly orchid spring was flowing are marked as a thin red line – the actual elevation of the spring is 30.92 m aOD but is plotted here at 30.1 m for ease of comparison with the other data: the brown line indicates the elevation of the peat surface. A significant rainfall event (26.5 mm) on 6/9/13 accounts for the last rapid rise in water levels in 2013 and renewed discharge from fly orchid spring: discharge from the latter across the now infilled ditch proves sufficient to maintain high levels until the following summer of 2014. The pattern for 2014 is similar, with a very significant rainfall event on 3/10/14 being followed by renewed flow from fly orchid spring and resumption of high and stable water levels for the rest of 2014.

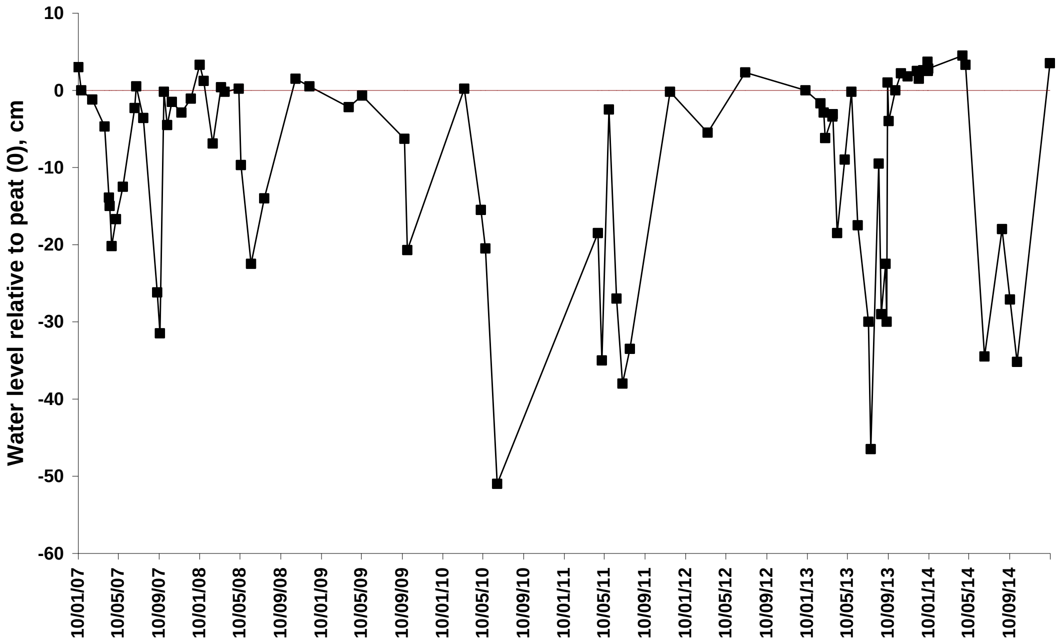

Figure 29. Manual dip record for dipwell T2-6.

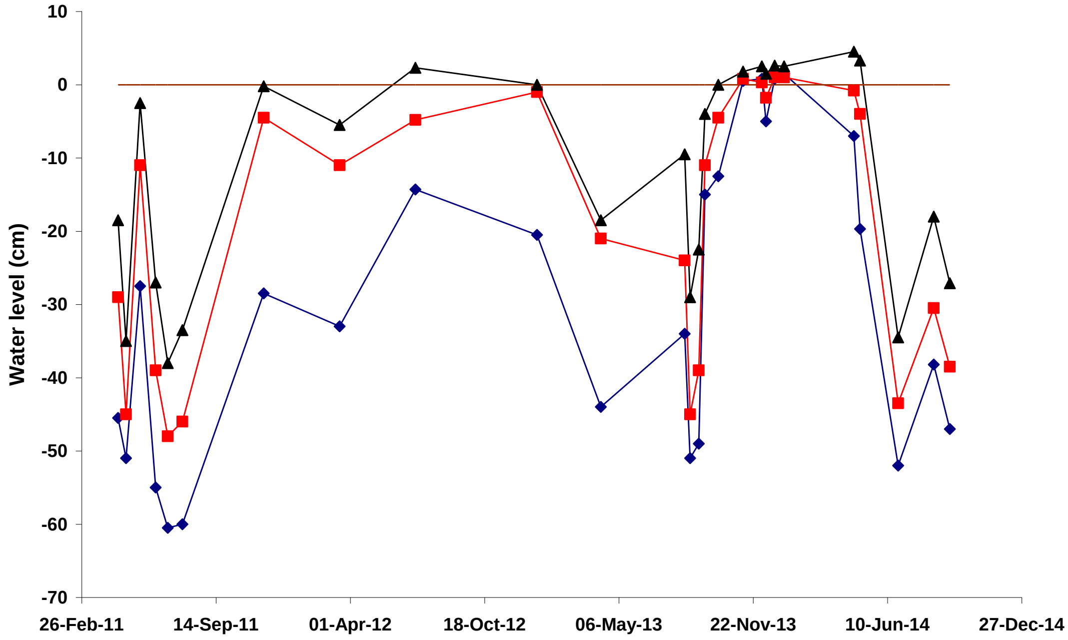

Figure 30. Record of manual water level measurements in the three transect 2 dipwells located down-gradient of the infilled ditch, namely wells T2-4 (blue line, diamonds – closest to the ditch), T2-5 (red line, squares) and T2-6 (black line, triangles, furthest from the ditch). The peat surface at 0 cm is marked with a thin brown line. Records for well T2-6 have been edited to provide a date series comparable with wells T2-4 and T2-5.

The influence of this project on water levels further away from the ditch is less clear (Figure 31). There is an indication of slightly wetter winter-time conditions, but little evidence of an effect on summer-time minima when fly orchid spring ceases to flow. However, the overall water table profile across the peat body down-gradient of the infilled ditch (Figure 32) does suggest there should be a wider hydrological influence resulting from this project, although the contour plot of ground elevations also shows a counter trend for drainage being focussed down-gradient of but along the line of the former ditch (Figure 10). This may be mitigated by the sheet piling installed at the end of the bypass pipe (Figure 22), particularly if this is extended to the east alongside drain section B-C.

6.2. Analysis of impact of project on upstream ditch water levels

The 90 degree elbow on the bypass pipe intake can be adjusted to raise or lower ditch water levels upstream (Figure 16). At the lowest (horizontal) setting of the elbow, the large diameter of the pipe should ensure free drainage at all times, with no sustained rise in ditch water levels upstream (other than perhaps temporary effects during very high rainfall) compared to the original ‘open ditch’ condition. However, as discussed above, the elbow has been angled to support higher water levels. The subsequent upstream ditch water level regime has been assessed against a series of pre-intervention manual stage measurements.

The most comprehensive pre-restoration record of water levels in ditch section A-B is for a location approximately 4 m downstream of the bypass pipe inlet. The record is water levels read relative to the top of the outlet of a concrete pipe culvert which was removed during installation of the bypass pipe in May 2013.

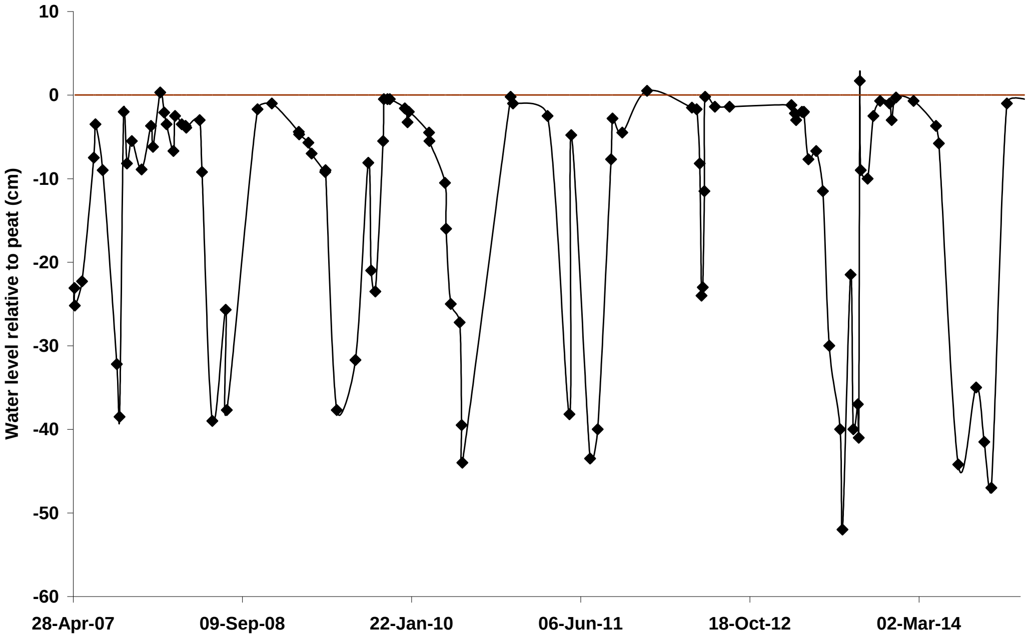

Figure 31. Record of manual water level measurements for dipwell 21 (see Figure 18 for location), *c.* 100 m from ditch section A-B. The lowest water level was recorded during the summer of 2013 – this yielded record lows at other wells remote from the influence of fly orchid spring. The peat surface at 0 cm is marked with a thin brown line.

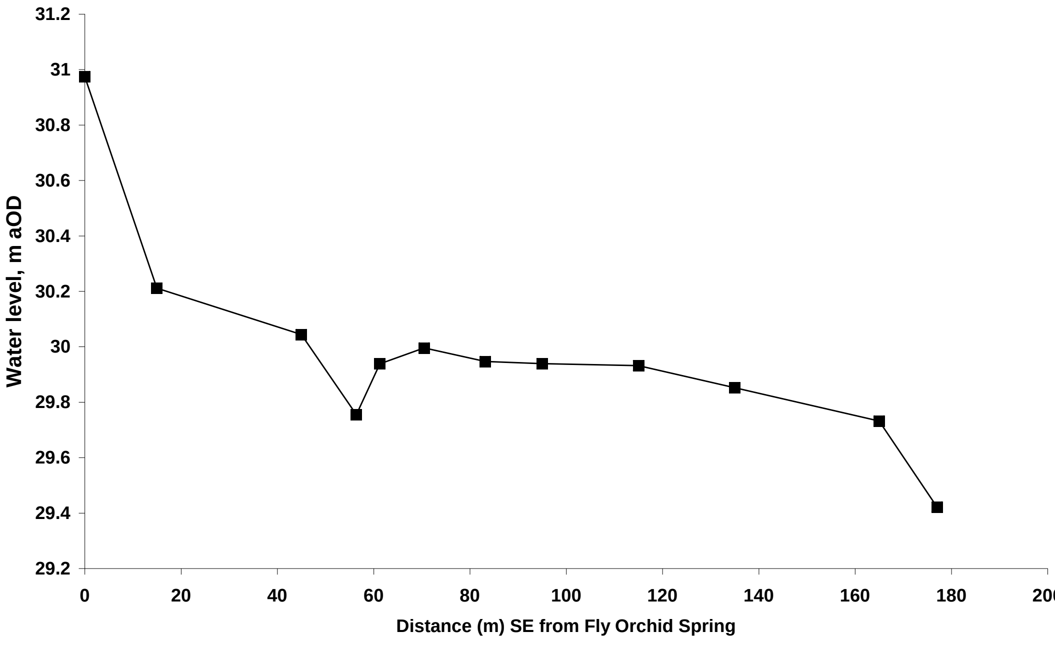

Figure 32. Water table profile between fly orchid spring and the main drain bridge, 6 December 2012.

The average ditch water level at this location was 29.63 m aOD between 2006 and 2012 (n=50) with a range of 30 cm (Table 8). This record can be compared against the hourly datalogger record for the 90 degree elbow pool at the bypass pipe inlet, which shows a higher mean level of 29.83 m aOD(based on 4701 hourly measurements between 24/6/13 and 6/1/14) with a range of 29.772 - 29.984 m aOD[6].

Further manual measurements of ditch water level are available for station C6 of Jones (in-prep.) and LIFE project transect T1 (Table 8, see also Figure 33 for C6 only). Both datasets show historic average levels 0.3 m lower than the water level measurement of 16/1/14, with the latter also exceeding the maximum recorded ditch stage height prior to restoration. The summertime measurements of 26/6/14 are significantly higher than the pre-restoration mean levels for all three stations.

Table 8. Summary of manual water level measurement record for ditch sections A(x)-B and A-D at Cors Bodeilio NNR and two sets of post restoration measurements – see Figure 37 for locations. Station C2 was located c. 4 m downstream of the U bend pipe intake. The NGR for T1 is for the adjacent dipwell T1_2. Data for C2 and C6 are from Jones (in-prep.). All data are m aOD.

Ditch station number	*C2*	*C6*	*T1*
NGR	50071.77640	50001.77608	49925.77605
Period of measurements	7/11/06 – 5/1/12	3/7/07 – 7/7/12	21/4/11 – 7/7/12
No. of measurements	55	16	7
Datum elevation		29.701	29.719
Mean	29.63	29.727	29.742
Max	29.831	29.909	29.894
Min	29.531	29.661	29.694
Level on 16/1/14	29.93	30.026	30.089
Level on 26/6/14 (cm rel. to datum / m aOD where relevant)	29.832	14 / 29.841	13.1 / 29.85

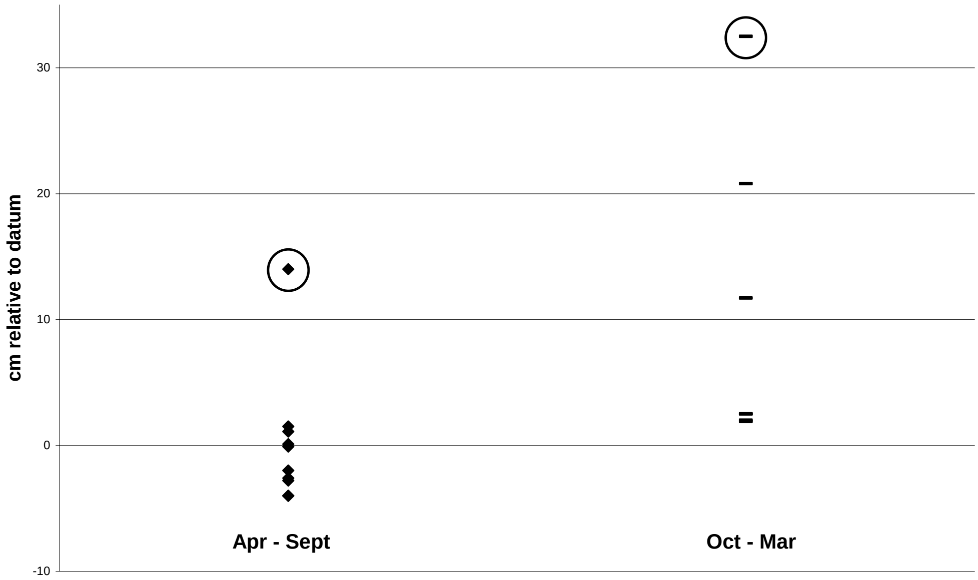

Figure 33. Comparison of pre and post restoration (encircled) measurements of ditch water level at station C6 on ditch section A(x) – D split into 6 month periods. See Figure 37 for location. Both post-restoration measurements (for 16/1/14 and 26/6/14) lie significantly above the respective pre-restoration maxima.

[6] The bypass pipe 90 degree bend is actually some 4m upstream from the original C2 monitoring point, but this would only contribute a modest rise in water levels due to drainage gradients alone.

Further comparison of pre versus post restoration ditch water levels for the CB1 system is shown in Figure 34 for the seven locations mapped on Figure 37 downstream from the boundary ditch with Bodeilio Farm. All points show a significant rise in ditch water level since the PM Surveys topographic survey of February 2012, with the difference decreasing with progression upslope towards the western site boundary. Water levels on the 16th. January were close to bank full (Figure 34), with very subdued water table gradients into the adjacent fen (see below) and some evidence of recent limited over-banking judging from *Cladium* litter strandlines within a few metres of the ditch. The very significant increase in storage provided by over-banking at an approximate elevation of 30 m[7] should prevent any significant further rise in levels in the boundary ditch (Figure 12 and 37 and shown at 0 m in Figure 34) just east of the boundary with Bodeilio Farm land. Furthermore, ground level adjacent to the boundary ditch lies at about 30.4 m aOD, some 0.2 m lower than the boundary fence (PM Surveys drawing PMS-12006, 8 February 2012), thus further ruling out any additional risk of nuisance flooding resulting from this work.

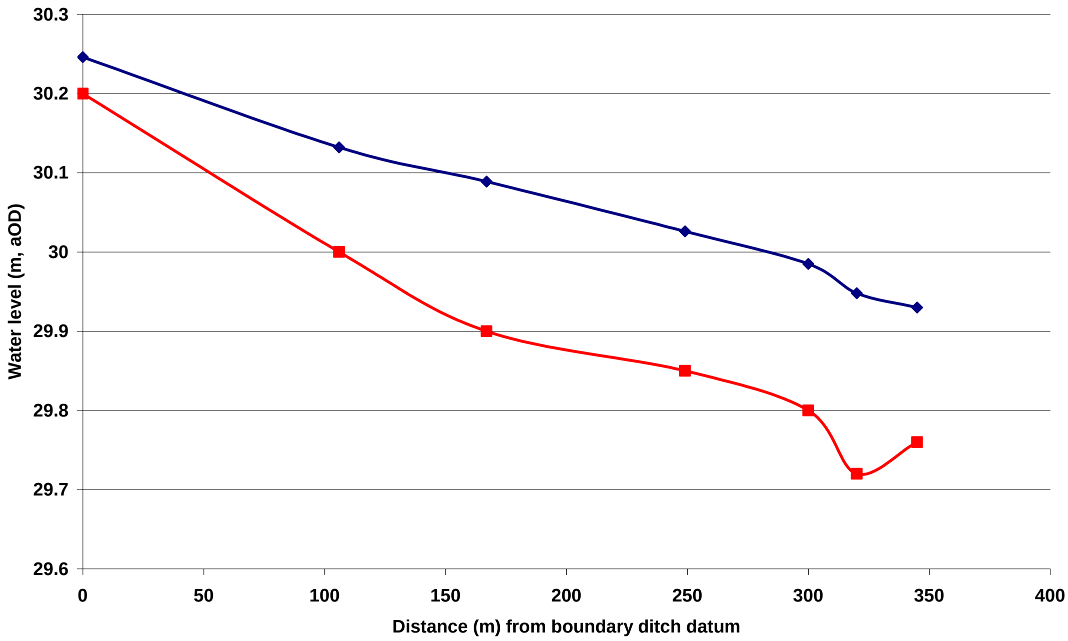

Figure 34. Comparison of estimates of ditch water level elevation for 7 stations running from (and including) the Bodeilio Farm boundary ditch pin datum (left, at 0 m) to Fly Orchid Spring bypass pipe inlet pool (right) based on the PM Surveys (red) assessment of February 2012 and the levelling survey of 16 January 2014 (blue). The apparent dip and then rise in levels in the PM Surveys record may be a measurement error or a local reversal of gradients due to impeded flow resulting from vegetation infill of the ditch. See Figure 37 for locations.

Comparison of water levels in the ditch system upstream of the bypass pipe and adjacent fen water table levels indicates the expected close coupling between the two. These levels compare with adjacent fen ground levels immediately to the NW of the bypass pipe intake of around 30 m aOD (PM Surveys drawing 12006, 8 Feb. 2012), thus indicating shallower water level gradients towards the drain post restoration. This was confirmed by a spot levelling comparison on 16 January 2014 which showed a ditch water level elevation of 29.948 m 25 m NW of the 90 degree pipe pool compared against a water table elevation for the adjacent stand of M13 of 30.117 (see Figure34). Further details of water level gradients at transect 1 are provided in Annex 6.

[7] This is the general elevation of the peat surface either side of drain section A(x)-D.

Figure 34. Photo looking NW from point indicated on Figure 37 for original photo number IMG_3861. Image shows high ditch water levels in foreground immediately upstream of the bypass pipe intake and correspondingly high levels in the adjacent stand of M13 in the middle distance. Photo taken 6 January 2014. Surface runoff to the drain from the adjacent M13 was evident in January 2014.

Hourly records of ditch water elevation are available for two locations upstream of the bypass pipe intake, namely a well installed in the 90 degree elbow pool and another much further west at the confluence of the two main lateral CB1 drains (Figure 37). The hourly record runs from 24 June 2013 to the present day and relevant well details are provided in Table 3.

Comparison of the two water level records shows (not surprisingly) that the same key rainfall and dry weather events are recorded (Figure 35a & b), but that the confluence station generally shows more significant changes in relation to rainfall, with some evidence of a greater drop in level during dry weather (Table 9). The former observation is more easily observed in an extract of the hourly water level plot for a specific significant rainfall event (Figure 38a & b) and is probably the result of vegetation in the ditch section downstream of this station inhibiting the dissipation of rapid increases in water level, particularly when compared with the more readily drained bypass pipe inlet station which is adjacent to the orifice of the 90 degree pipe elbow. Rapid but short duration increases in level of 25+ cm have been recorded at the confluence station and these can approach the elevation of the boundary drain at the western edge of the compartment , though as already mentioned above overbanking between the confluence and bypass pipe intake pool would ultimately place a limit on how high water levels might rise in response to rainfall.

Water level recession in periods of dry weather is subdued, especially for the bypass pipe intake well. This is likely to reflect the slow release of water from the wetland into the drainage network as a result of low surface gradients, the significant vegetation and litter cover and the expected relatively low hydraulic conductivity of the peat. It may also reflect the influence of sustained groundwater discharge into the western fen counteracting the influence of drainage to a degree. Bodeilio Farm Pond is thought to be an important source of groundwater in this part of the site (SWS, 2010), but there is also evidence of a groundwater upwelling in the western part of CB1 at the western end of LIFE transect T4 (see Annex 7). Relatively open patches of M13 alkaline fen has been recorded amongst closed *Cladio-Molinetum* in this area: these may also be indicative of relatively stronger groundwater influence. More significant water level recessions in dry weather might be expected for the confluence well given the slightly larger catchment of the bypass pipe intake pool well.

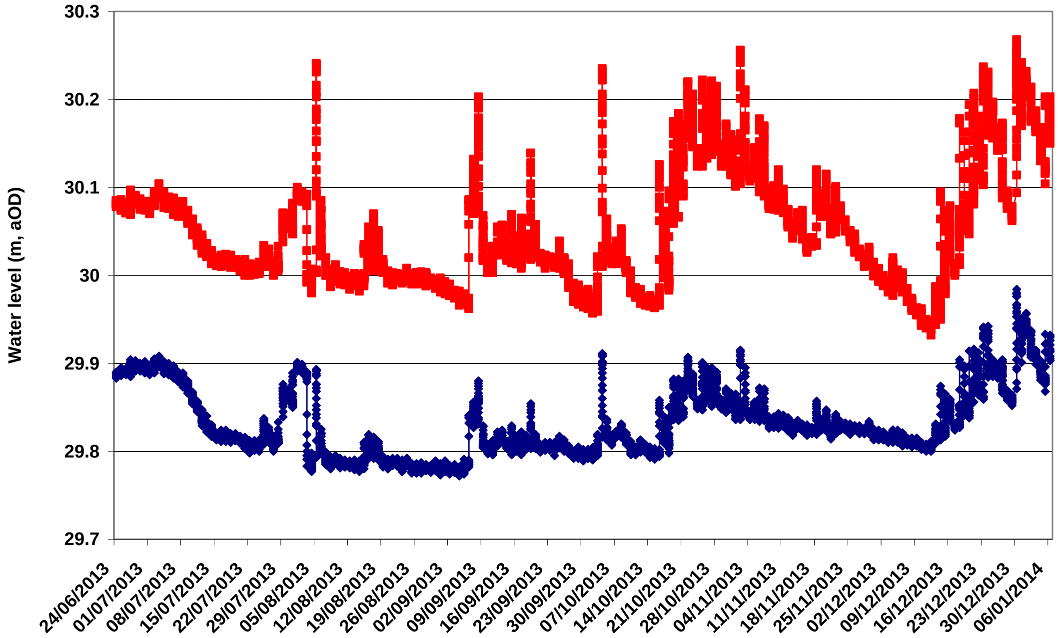

Figure 35a. Hourly plot of ditch water level elevation (m aOD) for the confluence (red) and bypass pipe inlet pool (blue) stations for the period 24 June 2013 to 6 January 2014. See Figure 37 for well locations and Table 3 for installation details.

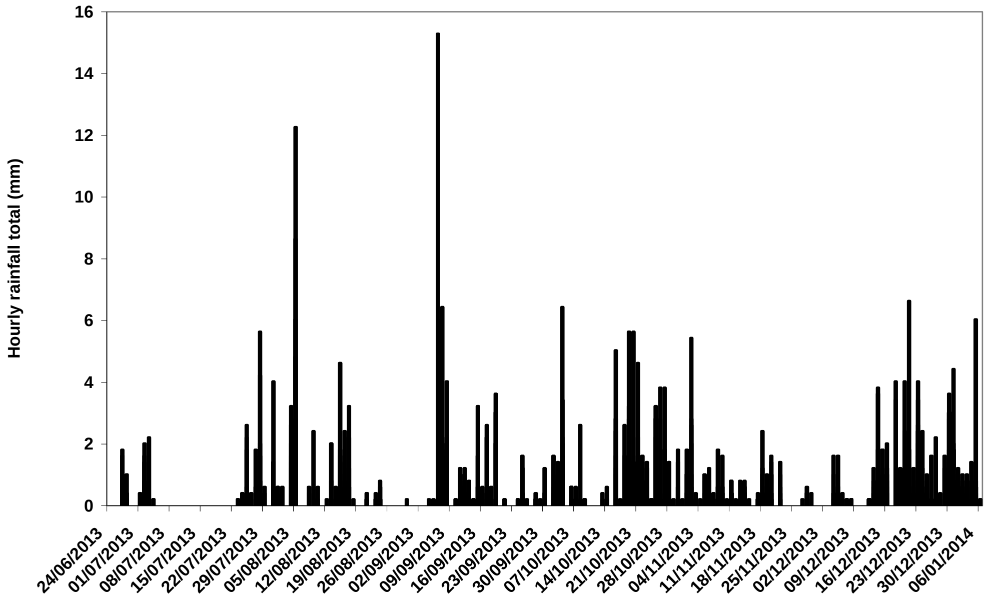

Figure 35b. Hourly rainfall record (mm) for the period 24 June 2013 to 6 January 2014 at Cors Bodeilio NNR.

Water levels elsewhere in the ditch network of CB1 are likely to have been influenced by the rise in level at the bypass pipe inlet pool, but monitoring has been confined to the points described above. However, a single post-restoration measurement for a datum pin on LIFE transect T4 located in a shallow ditch running SSW from point x (marked as a dotted line on Figure 1) yielded a water level of 30.069 m aOD on 16th. January 2014, higher than any of the 6 previous measurements (mean = 30.008 m aOD), and some 4 cm higher than previous mid winter measurements during wet periods. This ditch intercepts seepage discharging west from the Ynys and has been subject to some previous small-scale peat damming work. Unfortunately, the significant step-up in levels to the adjoining *Cladio-Molinietum* stand is such that restoring a seepage gradient across the current ditch line running from point x to Q (Figure 1) does not appear feasible – see Annex 7.

Installation of the 90 degree elbow on the bypass pipe intake has enabled the establishment of high ditch water levels and high water table levels in the adjacent peat. The design of the system coupled with the topography of the peat surface both prevents nuisance flooding affecting neighbouring land, and the adjustable nature of the pipe elbow provides a means of drawing water levels down should this be necessary. The shallow gradient of the peat surface and of water levels in the ditch appears to rule out any further requirement for ditch dams between points A and D (Figure 1). Two further measures were identified as desirable at the start of the project and remain as priorities for the after-LIFE plan[8], namely (i) deweeding of selected ditch sections to encourage open water and reduce sudden rises in water level due to impeded drainage, and (ii) the creation of 'benches' at the edges of the ditch to create a range of water depths adjacent to the deeper water of the ditch axis. Ditch section A-D (Figure 1) is the ideal location for this work which will address a long-standing requirement to increase the extent of open calcareous ditch sections and pool areas at the site. Some meandering of section A-D should also be considered.

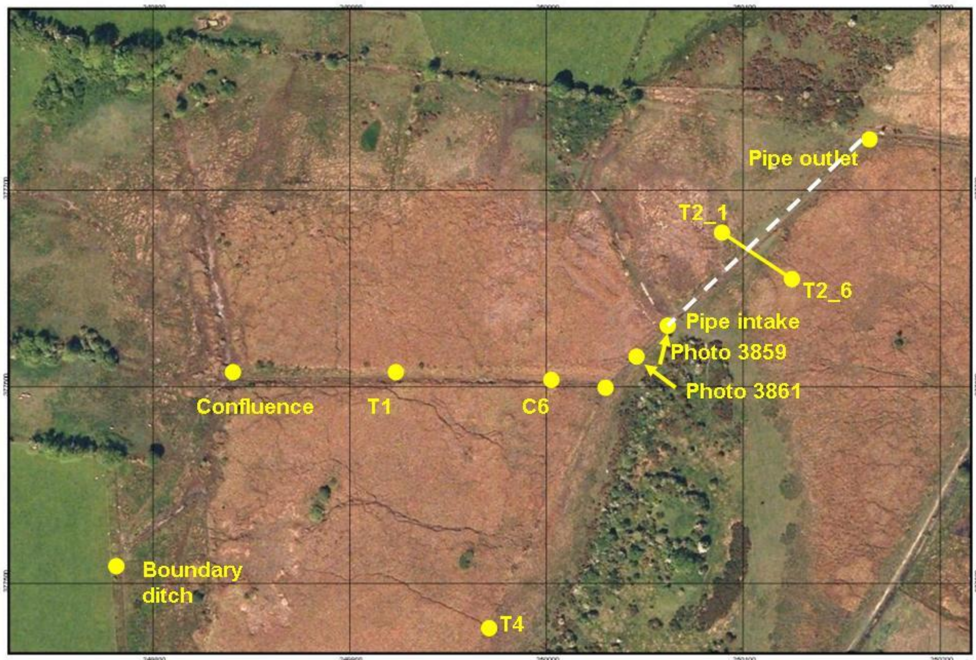

Figure 37. Locations on the ditch system west of the Cors Bodeilio Fly Orchid Spring bypass pipe. Automatic level loggers are installed in wells at the 'confluence' and 'pipe intake' stations, with the latter close to former manual measurement station C2. Station C6 is part of the regular manual dip round (Jones in-prep.) and dates from 2007. Transects T1 and T4 and the Boundary Ditch station were installed by the *LIFE* project. Other un-named stations are not subject to routine monitoring. Fine grid lines are at 100 m intervals and aligned to BNG. Transect T4 runs from just ESE of point T4 WNW to the Boundary Ditch datum pin – see Annex 7 for further details.

[8] Production of an after-*LIFE* plan is a requirement of EU *LIFE*+ funding and will prescribe ongoing management of the sites.

Table 9. Influence of selected significant rainfall and dry weather events on drain water levels in compartment CB1 at Cors Bodeilio NNR. See Table 3.3 and Figure 6.2 for location details for the two water level monitoring stations. Rainfall totals have been extracted from the hourly rainfall record for Cors Bodeilio provided by the ARG100 rain gauge in the meteorological enclosure in compartment CB3.

Date	***Time***	***Rainfall (mm)***	***Water level change, confluence (cm)***	***Water level change, pipe intake (cm)***
4 Aug 2013	02:00 – 19:00	13.7	+1.4	+1.2
5 Aug 2013	01:00 – 13:00	44.6	+22.5	+9.3
6 – 8 Sept 2013	15:00 – 10:00	62.9	+18.7	+7.3
3 – 4 Oct 2013	14:00 – 11:00	26.8	+_27.3	+10.9
24 Aug – 6 Sept	18:00 – 14:00	0.6	-3.3	-0.4
4 – 23 July 2013	08:00 – 12:00	0	-9	-9.5
22 – 28 Nov 2013	22:00 – 21:00	0.4	-6.5	-1.3

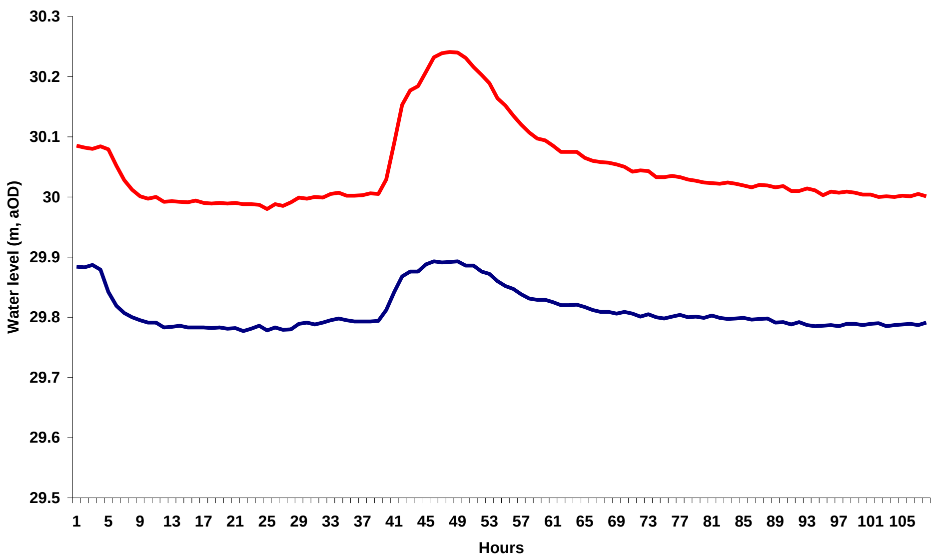

Figure 38a. Hourly plot of ditch water level elevation (m aOD) for the confluence (red) and bypass pipe inlet pool (blue) stations for the period 3/8/12 12:00 hrs to 7/8/13 23:00 hours.

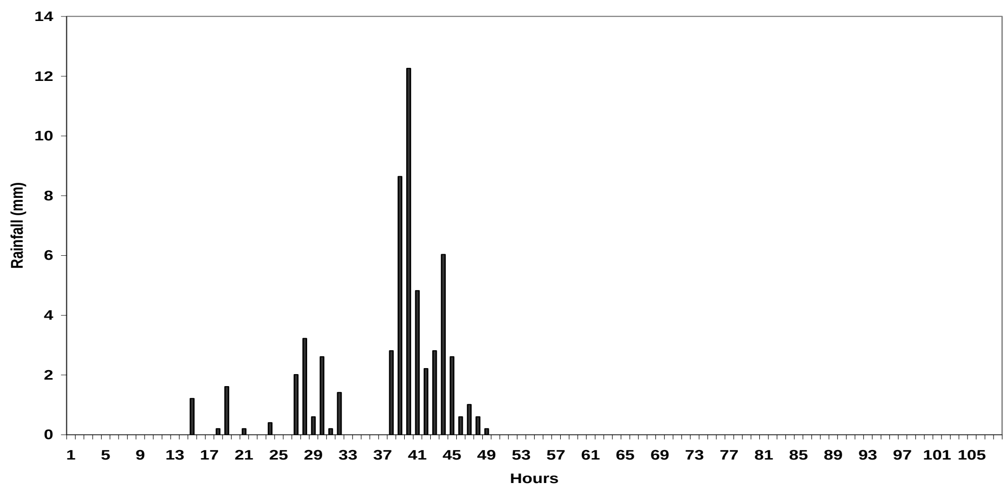

Figure 38b. Hourly rainfall record (mm) for the period 3/8/12 12:00 hrs to 7/8/13 23:00 hours at Cors Bodeilio NNR. Significant rainfall on the 4 and 5 August is shown here – see also Table 9).

7. CONCLUSIONS AND REQUIREMENTS FOR FURTHER WORK

The work described in this report has succeeded in restoring a critical groundwater pathway between a seasonally significant source of calcareous water and rich-fen vegetation long-isolated from this influence by surface drainage. This has been achieved using a method which also allows control of drainage ditch water levels across an extensive block of fen to the west, whilst also preventing any adverse hydrological impacts on agricultural land beyond the site boundary. The restored influence of calcareous groundwater should enrich the peat with calcium ions. The long-term ecological benefits of this work will be monitored, but at this early stage it is expected that *Cladio-Molinietum* forms of calcareous fen will show an increased frequency of wet calcareous fen indicators such as *Chara* sp., *Carex lepidocarpa*, *Carex lasiocarpa*, *Baldelia ranunculoides* and *Potamogeton polygonifolius*. The increased length of the groundwater flow pathway is most obviously realised during periods of spring flow; the influence of drain infilling in allowing below-ground seepage to influence areas down-gradient of the original drain route has not yet been assessed.

Restoration of the groundwater pathway means that capture of the average daily discharge of 71 m^3 from fly orchid spring by the drainage ditch network is delayed, with a generally reduced yield to the main outflow drain expected except for very wet periods. The effect of this on downstream flows and flood risk has not been assessed by this project, but it is reasonable to assume that it is broadly beneficial. The restored groundwater influence should also ensure rewetting of the peat body adjacent to the former ditch line, with beneficial consequences in terms of carbon retention and possibly even sequestration.

The primary lesson learnt from the project is that the bypass pipe should have been anchored *in-situ* rather than relying on the mass of infill to keep it in place. Minor remedial work is needed to anchor the floated section in place. In all other respects the methodology was wholly satisfactory. Acquisition of topographic survey information was especially for scheme design.

Periodic deweeding of sections of the drainage ditch network upstream of the bypass pipe should be undertaken and there is also scope for excavating shallow flooded shelves along edges of ditch section A-D (Figure 1) to increase the range of water depth regimes available to plant colonists and invertebrates.

The use of hexagonal plastic piling for raising ditch water levels and water levels within the peat has worked well and can be recommended for similar applications elsewhere. The plastic-piled dam at the end of the bypass pipe (see Figure 22) should be extended E to prevent outflow of water over peat.

The rise in ditch water level upstream of the bypass pipe intake does not appear to have posed an additional risk to grazing stock, but the possible case for enclosure of the intake pool should be reviewed. There is no increased risk of nuisance flooding for adjacent agricultural land.

Ongoing hydrological monitoring should include the following:

- Monthly or at least twice yearly (to coincide with maximum and minimum water levels) manual monitoring of water levels in dipwells 5, T2.6, 21 and the pipe intake pool on a permanent basis.

- Automated monitoring of water levels in these same wells until at least December 2016, or until assessment of the effect of below ground seepage down-gradient of the bypass pipe has been completed.
- Monthly monitoring of water levels in the T2 transect until at least December 2015.
- Periodic measurements of flow from fly orchid spring on a permanent basis: this is a cost-effective and invaluable means of assessing aquifer function at a critical location for the SAC.
- Periodic assessment (ideally at least 6 monthly) of fly orchid spring outflow chemistry and calcium gradients across the infilled ditch.
- Periodic checks on deposits within the bypass pipe which might ultimately reduce flow.

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Finally, we thank the European Union *LIFE* programme, NRW and CCW for funding this project.

ANNEX 1. Discharge measurements for Fly Orchid Spring, Cors Bodeilio National Nature Reserve. Values are means of between 3 and 5 'bucket and stopwatch' measurements.

Date	Mean discharge (l/s)	SD (l/s)	Date	Mean discharge (l/s)	SD (l/s)
04-Mar-09	0.2	0.008	23-Sep-11	0.689	0.052
10-Mar-09	0.25	0.017	07-Oct-11	0.512	0.19
23-Mar-09	0.468	0.035	24-Nov-11	0.535	0.02
30-Mar-09	0.23	0.011	19-Dec-11	2.249	0.172
02-Apr-09	0.122	12	05-Jan-12	1.822	0.016
03-Apr-09	0.105	0.014	27-Jan-12	1.324	0.045
09-Apr-09	0.01	0.001	29-Feb-12	1.113	0.067
05-Sep-09	1.461	0.067	16-Mar-12	0.557	0.023
11-Sep-09	0.945	0.047	14-Apr-12	0.07	0.003
14-Sep-09	1.118	0.051	24-Apr-12	0.314	0.01
16-Sep-09	0.763	0.073	30-Apr-12	0.617	0.057
18-Sep-09	0.721	0.098	14-May-12	1.173	0.045
20-Sep-09	0.63	0.051	23-May-12	0.747	0.114
24-Sep-09	0.379	0.024	28-May-12	0.38	0.028
02-Oct-09	0.08	0.002	01-Jun-12	0.206	0.022
07-Oct-09	0.08	0.001	06-Jun-12	0.086	0.006
24-Oct-09	0.099	0.012	08-Jun-12	0.165	0.015
30-Oct-09	0.049	0.004	09-Jun-12	0.125	0.013
01-Nov-09	0.43	0.022	10-Jun-12	0.077	0.008
12-Nov-09	1.78	0.082	11-Jun-12	0.044	0.003
19-Nov-09	2.824	0.44	12-Jun-12	0.014	0.014
19-Dec-09	1.43	0.031	15-Jun-12	0.015	0.0015
02-Jan-10	1.87	0.06	16-Jun-12	0.174	0.004
10-Jan-10	1.21	0.057	17-Jun-12	0.13	0.003
14-Jan-10	0.99	0.172	07-Jul-12	1.279	0.177
12-Feb-10	1.005	0.052	19-Aug-12	1.777	0.033
01-Mar-10	0.742	0.09	05-Oct-12	2.79	0.286
06-Mar-10	0.622	0.04	30-Nov-12	1.987	0.123
08-Mar-10	0.528	0.04	05-Dec-12	1.941	0.277
11-Mar-10	0.461	0.018	14-Jan-13	1.539	0.146
15-Mar-10	0.408	0.028	25-Jan-13	1.247	0.087
01-May-10	0.223	0.004	30-Jan-13	1.939	0.127
04-May-10	0.125	0.015	18-Feb-13	2.33	0.174
18-May-10	0		28-Feb-13	1.03	0.037
21-Jul-10	0.2		04-Mar-13	0.795	0.103
11-Nov-10	2.46	0.128	21-Mar-13	0.572	0.038
19-Nov-10	1.682	0.158	26-Mar-13	1.25	0.055
27-Nov-10	1.175	0.056	27-Mar-13	1.077	0.116
15-Dec-10	0.647	0.039	09-Apr-13	0.468	0.045
23-Dec-10	0.592	0.052	10-Apr-13	0.438	0.039
05-Jan-11	1.208	0.042	18-Apr-13	0.221	0.019
18-Jan-11	2.298	0.102	02-May-13	0.0597	0.001
28-Feb-11	1.339	0.052	07-May-13	0.003	
14-Mar-11	0.823	0.061	10-May-13	0.061	0.002
28-Mar-11	0.241	0.023	18-Oct-13	0.407	0.021

Annex 2. Extracts[9] from specification for groundwater reconnection ground-works at Cors Bodeilio NNR: Anglesey & Llyn Fens *LIFE* Project.

2. BRIEF

Works are to be carried out on Cors Bodeilio NNR, Talwrn, Anglesey (SH 50130 7770) and involve installation and burying of a pipe/culvert from X/A-B. The contractor is expected to submit a detailed plan of works seeking advice from the LIFE Project Team whenever necessary. The contractor will also be provided with a copy of topographic survey information (see Annex 1 and 2).

Distances; X to A = 40m, A to B = 140m, B to C = 110m.

2.1 Spring water flows from F (see attached map) across the land as shown by the arrows at Q and is then intercepted by the ditch X to B. We require that the water flowing from F is able to cross the ditch, fan out and irrigate the land shown hatched on the map. This area (pink area on map) is currently deprived of calcareous water because of the intercepting ditch (X to B). However, it is critical that the re-connection does not stop, or impede the water that already flows from X to B and onto C (e.g. use of culvert).

2.2 We require that the water levels in B-C are raised by use of plastic piling. A number of (number and intervals to be suggested by contractor) impermeable seals should be installed at equal distances along B-C. Plastic piling should be re-enforced. Impermeable seals must be installed to the same elevation as the lower edge of invert installed at X/A. Water must flow from X/A-B-C.

2.3 A water level control structure is required at the pipe inlet. In order to inform future works we need to be able to control the water levels allowed to flow through the pipe. A separate price should be included for installing the pipe (by following all ‘important factors and constraints’) from X-B (additional length X-A) and the water control system at X instead of A (see ‘f’ below).

2.4. Peat excavation is required for infilling the ditch and creating new habitat. Areas marked outlined on the map may be excavated. Size and whether or not all of these areas are to be excavated are dependent on volume of material required to fill ditch. Excavation depth will be a maximum of 300mm (further guidance will be given on site by LIFE staff).

2.5. Piling is required to reduce erosion of peat near C-D. A separate price should be quoted for the purchase and installation of plastic piling (depth of 0.5m across a length of 6 metres). Peat (surface horizons) from excavation will be required to fill where peat has been eroded behind the installed piling.

2.6 Linear metre bog mat costs if required (including delivery, setting out and removal from site)

<u>Important factors and constraints</u>

a) Water “at” and “upstream” of point X/A should be able to flow freely through the pipe/culvert and ditch with raised water level, along the whole length of the ditch (X/A to B to C) joining the main Afon Nodwydd (C-D) at C.

[9] Only relevant sections are included – generic material common to all LIFE project contracts is not included.

b) It is also important that apart from water entering the ditch at point A, no water will flow along the old course of the ditch once in-filled. Water must flow from F perpendicular to the ditch. It is suggested that impermeable material is used along cross sections of the ditch to ensure the perpendicular flow of water. Suggestions of how to achieve this should be put forward by the contractor.

c) There are very rare and sensitive plants along the edges of the ditch X - B (note; this includes the sloping sides of the ditch and some horizontal areas directly adjacent) which must be removed carefully, stored and replaced (i.e. replaced where spoil bank has been removed: not on top of the in-filled ditch) once the infilling has taken place.

- Minimal tracking is required to carry out this operation and works methodology must account for this.
- Remove the vegetation and topsoil in these locations (under the guidance of LIFE staff) to a maximum of 300mm which is likely to include most of the ditch length.
- A specialist turf stripping bucket must be used for this task.
- Contractors should work methodically and vegetation should be re-planted within 1 week of being removed.
- Turf should be carefully and sequentially stored alongside ditch to limit number of passes by machines.
- 20% should be added to the volume required for ditch filling to allow for peat settling. (Shallow runnels through this additional 20% should be made to allow for surface water flow from F to pink area.)
- It is likely all works will need to be carried out along both sides of the ditch where the spoil bank is at an elevation that may inhibit the passage of water from F to C-D. (Note; the existing culvert at A is the only crossing point)
- Where the remaining spoil bank consists of material which is of lower permeability than peat, or will not allow water to reach the ditch (detailed areas to be agreed with LIFE team), it should be re-profiled/excavated in sections (eg bucket width), to reduce resistance to water flow in the desired direction. Methods should be put forward by contractor.

d) Where excavation/ditch cleaning is carried out (before installation of pipe) the surface horizon of any soil/silt material and vegetation scraped from within the ditch should be retained and replaced on the top horizons of the ditch after infilling.

e) The pipe laid X/A-B will require inspection chambers to enable future maintenance, the contractor to advise how many.

f) At point X/A, the pipe will need a way to manually adjust and control water levels in the ditch preceding point A and the pipe A-B-C (e.g. a 90° bend). Contractors should put forward suggestions for control structure design. Point A may need some lateral excavation to allow room for this.

g) 2 prices and a recommendation should be quoted for the pipe X/A – B for a pipe of 400mm diameter and 450mm diameter or other.

h) ‘A’ also marks an existing culvert (300mm). This should be removed from site and replaced with a continuation of the pipe installed along the length of the ditch.

i) In the first instance, material to infill the ditch is available from the existing old and low spoil bank. Care must be taken in order to avoid too much excavation and interference with the desired flow from F to pink area and across to river ‘C-D’.

j) Secondary infill material for the ditch and piling infill is from the creation of peat scrapes (see 2.4) in the surrounding areas.

Please quote separately for peat excavation at (approximate areas marked on map)
- 1 only,
- 1 & 2
- 1 & 2 & 3.

k) Thirdly, the area outlined in green on the map which could be used if peat yielded from previously defined areas is insufficient/too expensive

l) Any vegetative material (root zone) within the peat excavated from areas noted in 'j) and 'k)' must be placed in the bottom of the ditch being in-filled to avoid re-growth.

m) All vehicle access to site will be restricted to one pass in and one pass out at the end of the job. This will mean operatives walking back to the car park and welfare facilities

n) . Pilling to reduce erosion should be 20mm above ground level at the start and finish of the installed piling length, where peat has not been eroded. Where peat has been eroded the piling will be higher above ground surface. Every sheet of piling should be at the same elevation. It is suggested that 'Z'shaped pilling in lengths (depth) of 0.5m are used. This section is marked on the map attached. Peat from the surface horizons of excavated areas marked on map should be used to 'turf' areas in front of and behind the piling. This will limit erosion. 'Turf'-ed material should be added until elevation of eroded areas are at the same elevation as surrounding areas that have not been eroded. (further installation guidance is provided below ('o)'). With tussocks and sometimes small roots tools e.g. an old panel saw may be required to cut the profile of the piling in to the peat before installation.

o) Plastic piling to raise water levels in the ditch should be re-enforced with stringers, the design and quote of which should be put forward by contractor at tender submission.

- Each dam will serve to raise the water level in ditch B-C and adjacent to C-D (marked on map). Interlocking sheets of plastic piling are to be inserted across drainage channels at locations agreed and marked on site by CCW. Sheets will be driven into place using a rubber maul in order to minimise damage to the piling. Occasionally piling will split, if this occurs it should be removed and replaced or if this is not possible cut level with a handsaw to below the split and then knocked in to the correct height.

- Each dam should be constructed using the following procedure. If the dam is to be constructed across dense vegetation it will be necessary to brush cut a 1.5 metre swath across the ditch. If 10 or less lengths of piling are to be used then the dam will have a gentle curve in the direction of flow, if more than 10 are to be used then the dam should be straight. The first piling length should be knocked into the centre of the ditch to about half its length and then each subsequent length put in, alternating from side to side and knocking in to half their length. The piling lengths should then be knocked down to the correct height working from the centre. It is important for dams that are longer than 6 lengths of piling that the pilings remain upright and not skewed, and the finished dam is level; the use of a long level will be required to achieve this and for especially long dams across cuttings a levelled string line. The final height of the dam will be governed by the elevation of the invert pipe (see 2.2 above).

- Each dam should have at least two whole piling in the bank on either side. It is important that after insertion of the piling into the bank that the bog surface is trodden bank against the piling to achieve a better seal and then a peat sod with the turf removed trodden in around the piling on the bank.

- The contractor will transport the piling to site from the Cors Bodeilio Car Park.

General Requirements

- Work will be undertaken on soft, peaty ground with the water table at or close to the surface. Use of specialised tracked machinery / low ground pressure will be essential (eg bogmaster and bog master dumpers). The contractor will need to state all the types of machinery to be used
- Bog mats may be required to prevent damage to sensitive habitat if it is essential to travel across these areas. These areas are clearly marked on an attached map. Further clarification will be available from the LIFE team. Bog mats will be required and should be priced per metre (see 2.6).
- Access for this work will be via the Cark park and bridge marked on the attached map.
- Any machinery over 12 tonnes and 10 feet wide will be unable to pass over the bridge at G but may be able to enter from adjacent fields (subject to neighbouring landowner permissions). Again this will be one pass in and one pass out at the end of the job for a maximum of two machines.
- Access is restricted by gates 10 foot wide and a bridge capable of holding 12 tonnes
- There is also a boardwalk for access on foot.
- Welfare should be located in the Cors Bodeilio Car Park.
- Any damage must be rectified by the contractor and the cost borne by the contractor.
- Costs associated will be at the same rate as the day rates etc included in the Framework tender

4. BACKGROUND TO SITE AND WORK ON SITE

Cors Bodeilio is a Site of Special Scientific Interest (SSSI), National Nature Reserve (NNR) and Special Areas of Conservation (SAC). This means that working methods will be restricted, or specialised, due to the conservation value of the land. Particular care and attention should be paid to avoid **alkaline fen** communities. See attached map; SH57/08P Cors Bodeilio: Vegetation Map.

5. OTHER CONDITIONS OF WORK/CONTRACT

The contractor should allow for the removal of rubbish and debris arising from the contract and leave the sites in a clean and tidy condition.
The contractor shall not sub-let or assign any of the work identified in this contract without the written consent of one of the nominated officers and subject to such terms as may be required.
All contractors should store materials, chemicals and fuels safely to prevent any spillage to land or to water.
All contractors must correctly dispose of any waste produced using the relevant waste documentation.
All spill/emergency incidents should be reported to LIFE staff immediately.

6. LOCATION OF WORK

See attached maps.

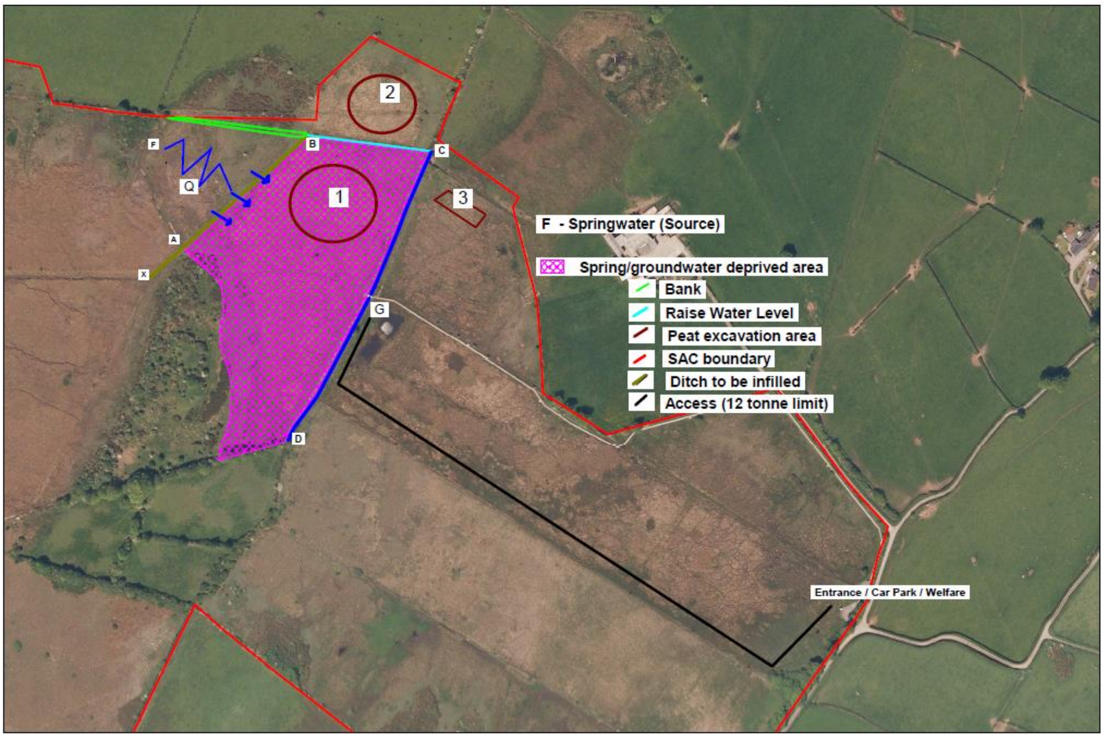
7. TIMESCALES AND MILESTONES

All companies wishing to tender must attend a site visit with a CCW officer on 1.02.2013

Works must be completed and invoiced by 10 march 2013

8. TENDERING DETAILS AND AWARD OF CONTRACT

In order to enable tender production evaluate the potential contractors will be invited to attend a site visit to Cors Bodeilio NNR on the 28th of January, 2013 at 10:00 – 13:00.



Rhoswen Leonard, Peter Jones & Justin Hanson
Anglesey & Llyn Fens LIFE project

Annex 3. January 2012 specification for topographic survey for those parts of Cors Bodeilio NNR relevant to groundwater reconnection project.

Topography survey of part of Cors Bodeilio National Nature Reserve

Introduction

Topography survey of part of Cors Bodeilio (Figure 1) is required to inform hydrological restoration and terrain re-profiling work planned as part of the Anglesey & Lleyn Fens LIFE project.

Cors Bodeilio is located on the Isle of Anglesey, off the coast of NW Wales

Figure 1. General location of Cors Bodeilio NNR. The site is accessed most easily from the A5025 at Pentraeth, following the minor lane to Talwrn. Off-road car-parking is available on-site at SH 507773 at the SE corner of the site in a small car-park.

Scope of works

The requirement for survey is limited to the NW part of the site as shown in Figures 2 and 3. This is easily accessed by a 15 min walk from the car-park along a part board-walked route. The survey involves two main components:

1. Measurement of ditch base and adjacent ground level elevations (both banks) along a total ditch network length of *c*. 1640 m as shown in Figure 2. Gradients are gentle across the site and measurements at 10 m linear intervals are likely to be sufficient.

2. Measurement of ground-level at a measurement density of approximately 160 points per hectare within an area not exceeding 7 ha and shown in indicative outline in Figure 3. Part of this area includes private farmland for which CCW will obtain access consent.

All measurement points should be related to Ordnance Datum – a local site datum exists. Two benchmark stations will be established by CCW within the area outlined in Figure 3 – height and coordinate measurements should be recorded for these. Spatial (x, y) coordinates should be recorded to a minimum of ten figure NGRs – e.g. SH 92410.66537.

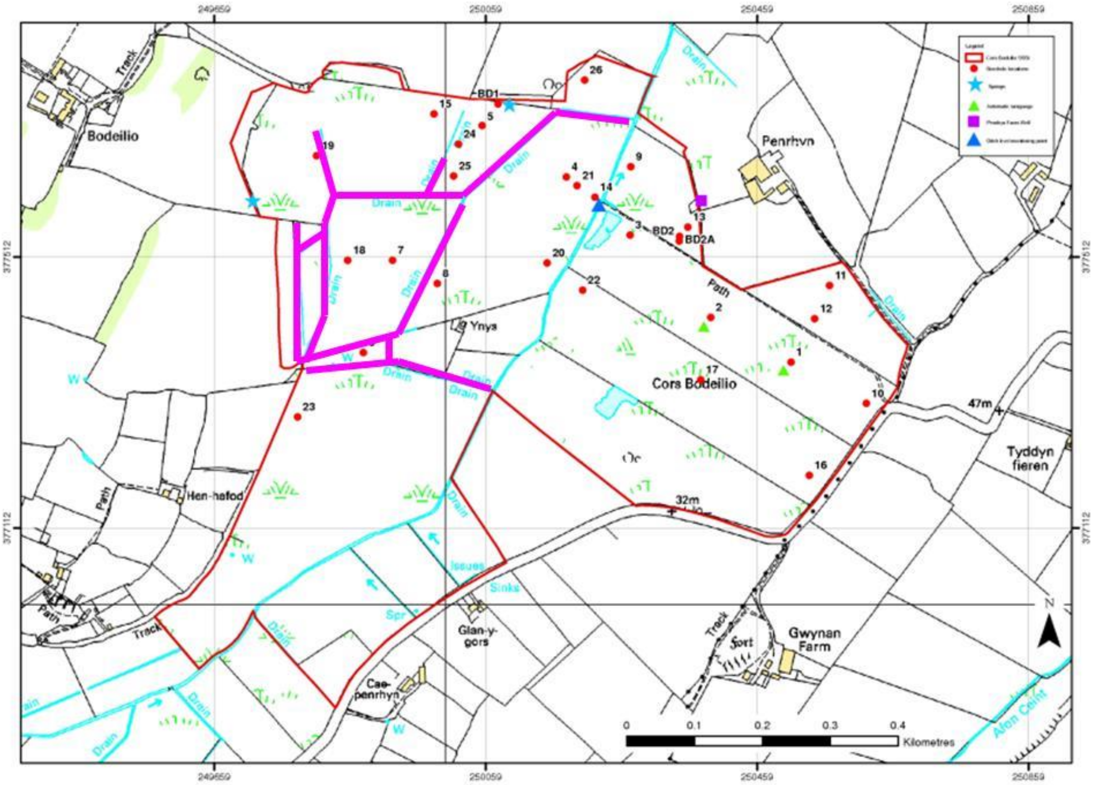


Figure 2. Map of the ditch network (shown in purple) to be included in this survey.

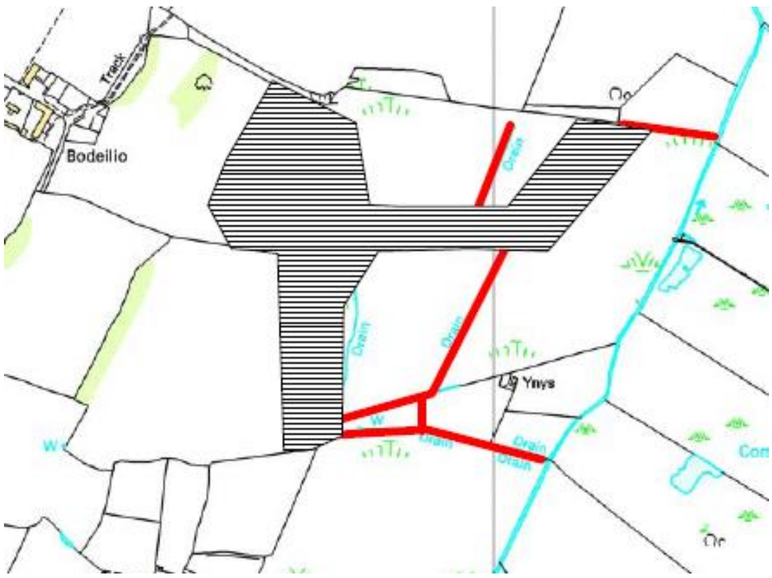


Figure 3. Indicative outline for ground-level survey (7.4 ha, but survey to be limited to 7 ha). Exact survey outline to be agreed with CCW on first field day.

Outputs

Map outputs should be produced as high resolution pdf files with all numbers visible when printed at A3 and with contours drawn at 0.1 m height intervals. X, y and z heights should also be produced as a separate excel file.

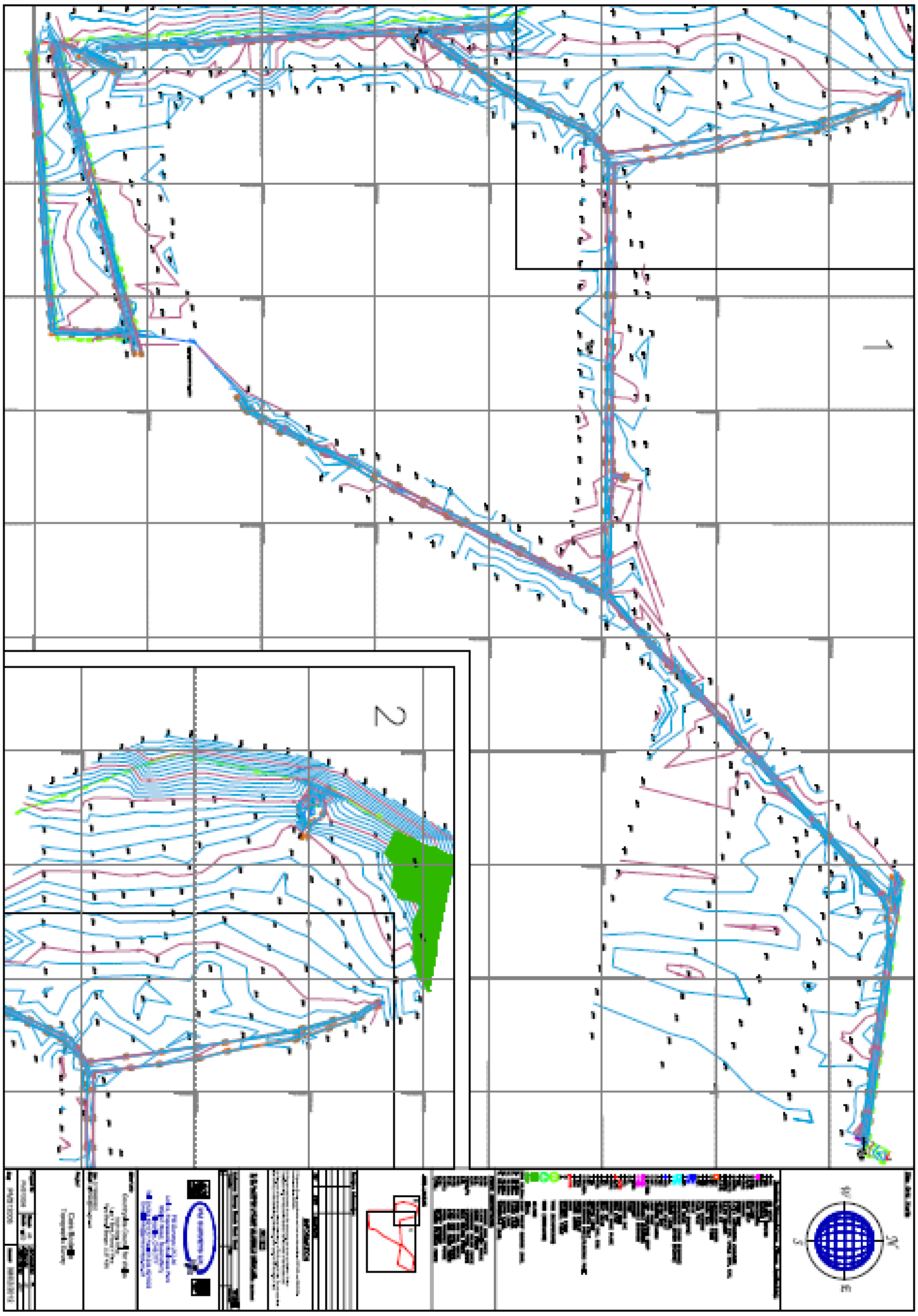
Life team contacts

LIFE team contact: Dr Peter Jones 07769960932, Mrs Janine Guest 07909962653/01248 385559.

Timescale

Map outputs are required by 4 February 2012.

Annex 4. Topographic survey of study area by PM Surveys Limited – drawing number PMS-12006 (8 February 2012). Survey conducted as a contract commissioned by the Anglesey and Lleyn Fens LIFE project.



Annex 5. Installation details for automatic water level loggers.

Table A.5.1. Logger suspension details. All Diver loggers are mounted from holes drilled into the side of the dipwell lines.

Dipwell no / logger number	*Suspension point to sensor line measurement (cm)*	*Suspension point distance below TOC (cm)*	*Total distance from TOC to sensor line (cm)*
T2_3 / H5691	64	2	66
T2_6 / H8561	75.8	4.7	80.5
U bend / H0336	89	3.7	92.7
Dip 5	73.7	2.2	75.9

Table A.5.2. Automatic water level logger notes.

Well No.	T2_3	**Diver No**	H5691
Site	Cors Bodeilio	**File name**	sws_h5691_140106105114_H5691_T2_3
Logger runs	9/4/13 10:00 hrs to 7/5/13 10:00 hrs. 14/5/13 14:00 hrs to present	**Total suspensor length (cm)**	66 cm (well config after 15/5/13 to present) Calculated as 91.9 for 9/4/13 to 7/5/13 based on sum of manually measured depth to WT of -51 TOC on 9/4/13 and height of water above sensor measured by sensor of 48.6 cm, = 99.6.

Well No.	Bypass pipe intake pool	**Diver No**	H0366
Site	Cors Bodeilio	**File name**	sws_h0366_140106114826_H0366_Ubend
Logger runs		**Total suspensor length (cm)**	

Annex 6. Water levels recorded at water level transect T1, Cors Bodeilio NNR (see Figure A.7.1 for location).

This transect consists of four wells either side of the ditch, with a steel datum pin location in the ditch. Data presented here cover only wells D1 and D2 on the south side of the ditch and the ditch itself. There is only a limited run of data for this location, but comparison of the water level elevations for June 2011 (pre-restoration) and June 2014 (post restoration – see shaded rows) show a flattening out of the water table gradient adjacent to the ditch and a substantial increase in ditch water level, even though peat water levels are lower in 2014. The ditch water level is actually higher than water levels in the adjacent peat body for the 26/6/14 measurement. Rainfall totals for the preceding seven days were 3.7 mm for 26/6/14 and 19.5 mm for 16/6/11 (http://www.llansadwrn-wx.info/obs/), this further underlines the significance of the rise in ditch levels following installation of the bypass pipe intake level control.

Location	*T1_D1*	*T1_D2 (closer to ditch)*	*T1_ditch*
NGR	49920.77596	49921.77601	49921.77604
Original TOC height above peat (cm)	7.3	8.1	
Distance along transect (m), S-N	0	4.65	8.03
Height of TOC/datum	30.205	30.165	29.719
21 April 2011 (cm rel to datum /m aOD)	-26 / 29.945	-26.5 / 29.9	0.5 / 29.724
3 May 2011 (cm rel to datum /m aOD	-37 / 29.835	-36.5 / 29.8	-1.5 / 29.704
24 May 2011 (cm rel to datum /m aOD	-17 / 30.035	-20 / 29.965	1 / 29.729
16 June 2011 (cm rel to datum /m aOD	-32 / 29.885	-31 / 29.855	0 / 29.719
4 July 2011 (cm rel to datum /m aOD	-40 / 29.805	-39.5 / 29.77	-0.25 / 29.716
26 July 2011 (cm rel to datum /m aOD	-38 / 29.825	-37 / 29.795	1 / 29.729
7 January 2014	30.123	30.101	30.078
26 June 2014 (cm rel to datum /m aOD	-39.7 / 29.808	-35.7 / 29.808	13.1 / 29.85
16 January 2014	30.125	30.106	30.089

Annex 7. LIFE project Transect No. 4 at Cors Bodeilio

This is a levelled transect of dipwells and ground elevation points running WNW from the W side of the main Ynys feature out across the *Cladio-Molinietum* stand of compartment CB1 (Figure A.7.2). The transect was installed by Pete Jones, Janine Guest and Rhoswen Leonard on 25th. March 2011. The transect begins in the M13 *Myrica* seepage face of the Ynys at SH 49988.77473, crosses a minor ditch feature, continues WNW out over the dense stand of *Cladium* and terminates in the boundary ditch at the western edge of the compartment at datum pin SH 49787.77518.

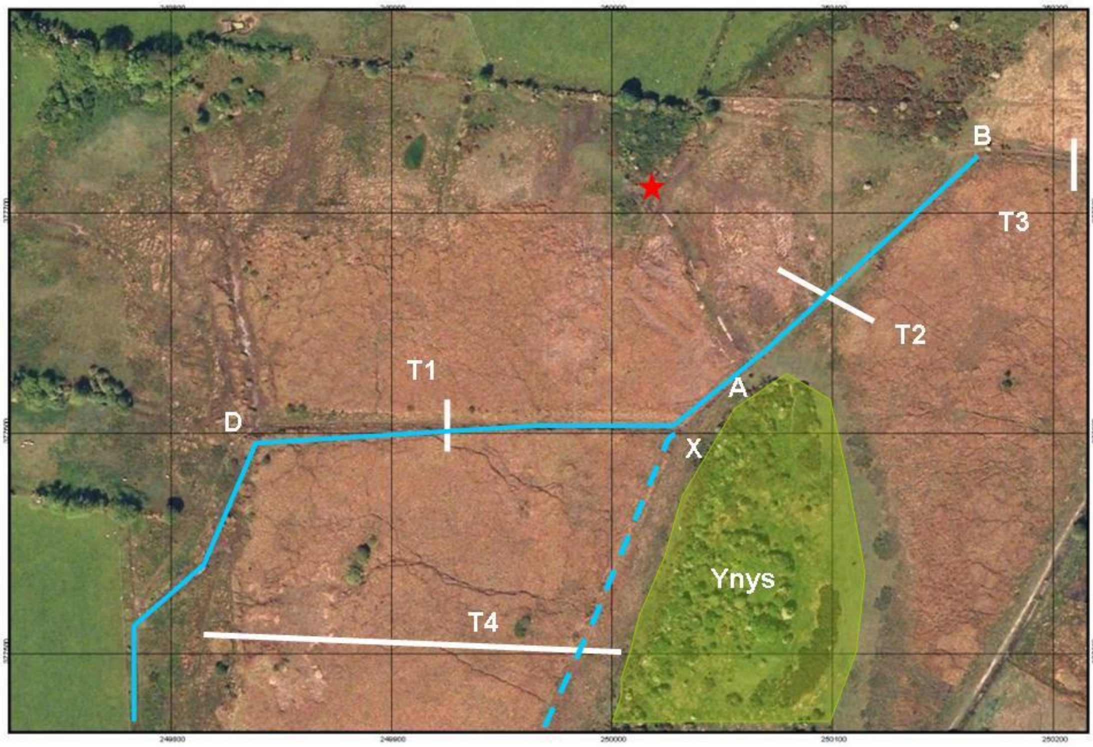


Figure A.7.2. Location of water table/ditch profile transects in the western part of Cors Bodeilio, showing the location of T4 described here.

The water table profile is domed and strongly asymmetric, with the highest point recorded from dipwell 18 of Jones *et al*. (in-prep.) at 150 m (Figure A.7.2). This is a stand of M13 in which the *Cladium* cover has been managed by hand-strimming initiated by Mr Les Colley, the former Site Manager, and then continued and extended as part of the LIFE project. It may be that the occurrence of the groundwater high is indicative of groundwater discharge – the presence of M13 would be consistent with this. The Ynys margin seepage face (left-hand side of the plot) shows sub-surface water levels initially and then some ponding before the ditch line. The relative dryness of the upper part of the seepage face may be natural. Water levels are again subsurface immediately to the WNW of the drain, but much wetter conditions occurs to the W.

Complete infill of the ditch west of the Ynys was considered at an early stage of the LIFE project but the levelling exercise reported here indicates that very limited hydrological benefits would arise. The base of the Ynys seepage face supports some very species-rich patches of M13 and these may benefit from the function of the ditch in maintaining a seepage gradient. However, the limited rise in level of the ditch attributed to the current setting of the bypass pipe intake is likely to be beneficial, especially in high summer.

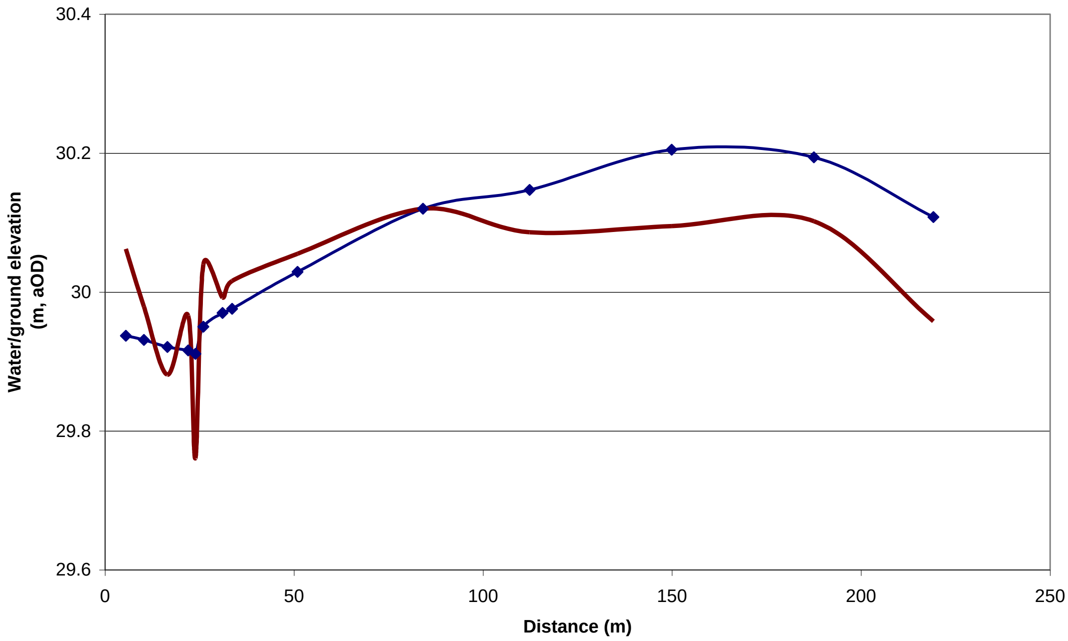


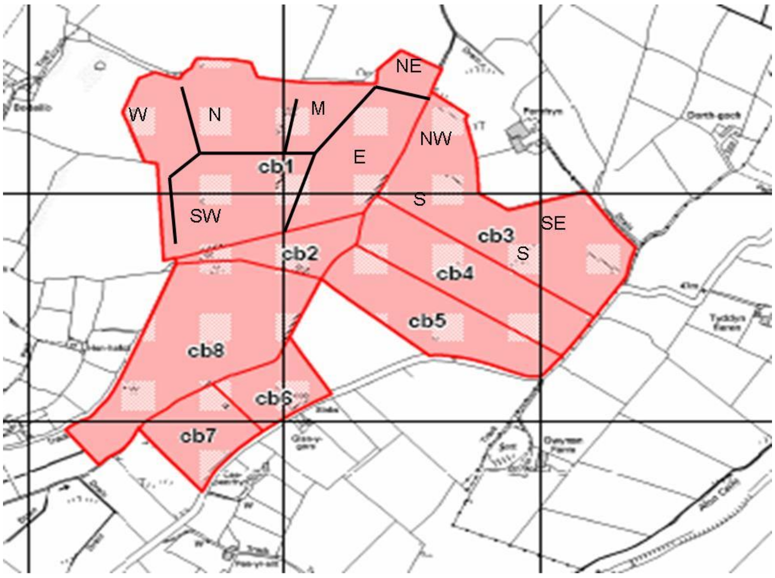
Figure A.7.2. LIFE transect T4 water level elevation (blue) and peat surface (brown) plot for 25 March 2011: all heights are m aOD. The plot runs from ESE to WNW and is thus a plot of water level and peat surface profile as if seen from the north (cf. Figure A.7.1). The ditch below the Ynys is the 5th. point from the left. Several of the long-term monitoring dipwells of Jones *et al*. (in-prep.) occur along this transect, namely dipwell 8 at 5.5 m, dipwell 7 at 84.1 m and dipwell 18 at 149.9 m. Datum pins occur in the ditch just WNW of the Ynys at 23.9 m and in the ditch at the western edge of the compartment in the boundary drain (219.1 m)

Table A.7.1. Water level records for the ditch just WNW of the Ynys at 23.9 m.

Date	***Water level relative to datum pin (cm)***	***Elevation of ditch water level, m aOD***
25-Mar-11	2.1	29.95
08-Sep-11	7.4	30.003
05-Jan-12	10	30.029
07-Jul-12	10.7	30.036
27-Mar-13	10.9	30.038
22-May-13	6.5	29.994
Average, pre restoration		30.008
16-Jan-14	14	30.069

Annex 8. Cors Bodeilio compartment numbers.

Numbers prefixed 'CB' are the official NRW unit numbers, with letter suffixes added to aid sub-division of units. Bold black lines show drains sub-dividing compartment CB1. CB1E includes the Ynys ridge, with the three small Ynys fields included in CB2. CB3NW is separated from CB3S by the boardwalk. The old compartment bank and former boardwalk route separate CB3SE and CB3S. Compartments CB5-8 inclusive are under private or community ownership.



Annex 9. Stratigraphy for Bodeilio transect T2, 18 January 2011 unless otherwise stated.

Depth (cm)	***Stratigraphy***
Dipwell 5, SH 50054.77706. GL 30.155 m aOD, 7/11/06	
0-5	Soft unconsolidated marl
5-50	Dark brown well humified peat with abundant large black TH (turfa-herbacea) macrofossils.
50-71 +	Stiff marly clay – basically grey but with marly flecks and patches. Gritty to feel with both angular and sub-rounded clasts from 3 – 25 mm. Core could have been continued beyond 71 cm
Dipwell T2_1, SH 50093.77677	
0 - 17	Well humified dark grey/black fen peat with live roots.
17 – 49	Dark grey stiff silty clay over very sandy clay. Sub-angular gravel up to 15 mm – become more gravel dominated with depth and still sandy.
49 +	Clayey sandy gravel.
Dipwell T2_2, SH 50093.77677	
0 - 20	Well humified peat and live roots.
25 – 40	Stiff grey silty clay with small sharp stones. Boulder encountered at -40 cm. Other holes explored nearby but none cored beyond 30 cm.
Dipwell T2_6	
0 – 27 – 43?	Well humified black fen peat and live roots/seeds. Hit water at 3 cm.
43 - 80	Change to dark grey silty clay and sloppy peat. Very stiff silty grey clay to 80 cm.
80 - 93	Sub-angular gravel in a clay matrix.