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Llyn Anafon: Ecological assessment of the aquatic flora to support HRA, 2017

ECRC Research Report Number 185

Goldsmith, B., Shilland, E.M. & Turner, S.

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Ecological assessment of the aquatic flora to support HRA, 2017

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Executive Summary

Llyn Anafon lies within the Eryri SAC, North Gwynedd, Wales (500 m amsl). Originally a natural lake, the level was raised by approximately 1.5 m in 1929 to provide potable water. Although now out of active commission for water supply, the site owners Dwr Cymru / Welsh Water (DCWW) maintain the responsibility for the dam and the site remains within the jurisdiction of the Reservoirs Act 1975. Deterioration of the retaining dam resulted in the most recent Section 10 report to conclude that the risk of failure exceeded acceptable levels and that a long-term solution is required in the interests of public safety. This report triggered DCWW to consider a series of engineering options ranging from full repair to complete removal of the dam, with decommissioning being the favoured plan for the long-term sustainability and safety of the site.

Llyn Anafon is recognised as one of the best examples of its habitat type (Oligotrophic lake) within the SAC, and is one of only a few UK sites to support population of two internationally rare pondweed hybrids (*Potamogeton x gessnacensis* and *P. x griffithii*), and the only SSSI site in Wales where *P. alpinus* is found. Being a European protected site, any planned alterations to the dam and lake necessitate a Habitat Regulations Assessment. This report details the key Habitat Directive features within the lake that may be compromised by the engineering options and provides recommendations for the most ecologically robust approaches to the preferred options.

Five aquatic plant surveys have been conducted at Llyn Anafon since 2007, with nineteen aquatic plant species recorded in 2016. The site supports an exceptional flora including the typical *Littorelletea* flora and distinctive local elements that indicate the lake to be in favourable condition with respect to Habitats Directive status.

Additional studies of the rare hybrid pondweeds, show the populations to be stable within the lake, and distributed within definable depth ranges below current TWL. Based on the current depth ranges, removal of the dam will reduce the overall habitat availability for aquatic plants from approximately 4.7 ha to 2.9 ha. In the case of *P*. x *griffithii* the suitable depth habitat will be reduced from 2.4 ha to only 0.47 ha. Dam removal will not impact on the area of available depth habitat of the shallow-growing *P.* x *gessnacensis,* but this plant is currently restricted to sheltered bays, where wind and wave action place less stress on the floating leaves.

Under the proposed dam decommissioning, there will be a permanent loss of lake surface area which will move the site away from favourable condition. Any planned engineering work will therefore require the potential ecological risk to be minimised and if necessary mitigated to ensure minimal damage to the SAC feature and species therein. Exposure of lake sediments gives rise to potential increases in turbidity and nutrient release that may also damage the protected habitats.

The following recommendations have been proposed:

1. The water level should be lowered every two years in small decrements over a 10-year period to allow natural migration of plants into new habitats.

2. Collate and analyse additional data on past water level changes to determine the extent and duration to which aquatic plants have been exposed over that last 15 years. The findings will inform best practice during the construction phases.
3. Undertake additional spatial analysis to determine the optimal decremental drops in water level to achieve an even reduction in total lake area with each drop.
4. Implement monthly water quality monitoring as soon as possible, ideally allowing for one year of monitoring prior to any intervention.
5. Install continuous water clarity monitoring for the duration of the intervention.
6. Undertake annual CSM surveys of the aquatic flora to inform and biennial spatial surveys of the rare pondweeds.

The most ecologically robust plan for decommissioning the dam will be led by the motoring data. Each sequential lowering should only be undertaken under conditions where the negative impacts are within acceptable levels or where mitigation (e.g. in-site translocations) is effective.

1. Introduction

1.1. Llyn Anafon

Llyn Anafon lies within the Eryri Special Area of Conservation (SAC), North Gwynedd, Wales (SH697698) at an altitude of 500 m. Originally a natural lake, the level was raised by approximately 1.5 m in 1929 to provide potable water to Llanfairfechan and the surrounding villages. Although now out of active commission for water supply, the site owners Dwr Cymru / Welsh Water (DCWW) maintain the responsibility for the dam and the site remains within the jurisdiction of the Reservoirs Act 1975. At top water level (TWL), Llyn Anafon is approximately 5.56 ha in area with a maximum depth of 11 m and mean depth 2.4 m.

Llyn Anafon is classified within the Habitats Directive (EU 1992, 92/43/EEC) as an "Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*" (EU Habitat Code: H3130). It is unique within the uplands of the Eryri SAC for having a very species rich aquatic flora, making it of particular conservation interest and importance. In addition to an exceptional "characteristic" flora (as defined in JNCC 2015), the botanical interest is further enhanced by the presence of two very rare hybrid pondweeds; *Potamogeton x gessnacensis*[1] and *Potamogeton x griffithii*[2], both of which are restricted to only one or two other lake sites within the UK (Preston 1995). Both hybrid pondweeds pre-date the construction of the dam at Llyn Anafon with the "type" material for *P. x griffithii* collected there in 1882 and specimens of *P. x gessnacensis* collected in 1891 (Preston 1995). Llyn Anafon is also the only protected lake site in Wales to support Reddish pondweed (*P. alpinus*) and is unusual for a site at this altitude to have a species (probably a hybrid) of Water crowsfoot (*Batrachium Ranunculus*). In addition to the characteristic oligotrophic components of the flora, these rarities are classed as "locally distinctive elements" of the site and are assessed as part of the site condition process (JNCC 2015).

The status of Llyn Anafon as a SSSI and a European protected SAC (and one of the best examples of its habitat type (H3130) within the SAC), necessitates that any planned alterations to the site are thoroughly investigated prior to changes being made and that any adverse effects are effectively mitigated.

The reinforced earth dam at Llyn Anafon has shown signs of leakage from the time of construction with efforts being made to address this problem as early as 1931 (Mott MacDonald 2008). Concerns about the extent of the leakage and dam safety resulted in a report commissioned under Section 10 of the Reservoirs Act 1975 (Mott MacDonald 2006) which identified "significant seepage….. from two main sources" with associated problems of loss of fines from the dam. The main recommendations from the report were that:

- The water level should be lowered by 1.0 m as soon as reasonably practical by adjusting the opening on the draw off scour valve.

[1] *P. x gessnacensis* – Hybrid of *P. natans* and *P. polygonifolius*.
[2] *P. x griffithii* – Hybrid of *P. alpinus* and *P. praelongus*.

- The leakage through the dam either should be staunched permanently or the level in the reservoir cill lowered sufficiently to reduce the leakage through the dam embankment to negligible levels by 31 December 2009.

For the longer-term integrity of the dam a number of remedial actions were proposed, ranging from full repair of the dam to maintain current TWL, through to removing the dam completely to restore the pre-construction water level of approximately 1.5 m below TWL. The isolated location and expense of the former option makes its viability highly impractical, while the removal of the dam has been deemed potentially unacceptable due to its ecological impact (Goldsmith *et al.* 2009).

Prior to deciding on the solution to address the dam safety issue of concern, potential implications of the project at the site need to be assessed against the ecological integrity of the Eryri SAC.

In order to maintain the favourable status under the Habitats Directive, a lake of this type (H3130) should maintain stable conditions with good water quality and a characteristic *Littorelletea uniflorae* and *Isoëto-Nanojuncetea* flora. Furthermore, the following attributes should be considered in assessing implications of the proposed project:

- Loss of extent (surface area or depth distribution) other than due to climatic conditions.
- Natural sediment loads should be maintained.
- A natural shoreline and substrate type should be present for the lake
- "Indicators of local distinctiveness" should be conserved. The *Potamogeton* hybrids are considered part of this feature for L. Anafon (CCW 2008).

Most aquatic plant species are relatively sensitive not only to water quality (pH, nutrient status, turbidity) and substrate types, but also where they actually grow within a favourable site. Typically, in upland oligotrophic lakes the aquatic vegetation forms zones relative to water depth with shallow water species, for example *Littorella uniflora* often occurring in the lake margins up to 1.0 m water depth, then *Lobelia dortmanna* in slightly deeper water and *Isoetes lacustris* deeper still, up to 4-5 m in clear lakes and sometimes with deep-water stoneworts beyond this depth (e.g. *Nitella* spp.). These zones are evident at Llyn Anafon, and along with other characteristic species extend to a maximum depth of approximately 4.5-5.0 m below the TWL of the site (Goldsmith *et al.* 2009).

The two hybrid pondweeds occupy different depth zones, with *P. x gessnacensis* occurring primarily in shallow water (Approx. 30-110 cm below TWL) while *P. x griffithii* is mainly recorded from deeper water (Approx. 2.0-3.4 m below TWL). This optimal depth distribution is obviously of concern with respect to any proposed lake level change and should be a primary consideration for any future works that will have either a temporary or permanent impact on the water level.

In addition to the concerns regarding the potential of direct impacts due to water level changes, indirect impacts may also adversely affect the site if the water level is lowered. Exposed lake sediments are more easily eroded than catchment soils and may be re-suspended into the lake as well as transported downstream. An increase in turbidity and any additional siltation on to the leaves of submerged plants will adversely affect their ability to photosynthesise effectively. Furthermore, re-suspended sediments can also release previously bound-up nutrients and dissolved organic carbon (DOC) into the water column resulting in increased algal growth and increased colour (brown staining) respectively and ultimately shifting the status of the lake away from favourable ecological condition. Although more likely to be relatively short-term, impacts on the downstream river biota may also be observed.

Following the ecological assessment in 2009, DCWW agreed to maintain the lake at TWL and monitor the rate of loss and dam safety. The most recent (2016) Section 10 report produced under the Reservoir Act outlines that '*from a reservoir safety perspective ongoing monitoring and patching* [to address leakage] *is not recommended, particularly in light of the constraints on access to site*.' The inspecting engineer goes on to recommend '*that a long term solution is developed to address the poor and deteriorating condition of the dam, to the consent of an All Reservoir Panel Engineer*'. This has been set with a statutory deadline of January 2019. The reservoir is currently designated as 'high risk' under the Reservoir Act 1975.

DCWW undertook an appraisal for possible options to meet the recommendation of the Inspecting Engineer. 'Llyn Anafon Leakage (MITIOS) Option Analysis Report' (January 2017, Arup for DCWW). Two options were proposed

- remove the spillway gradually over a 5-year period, thus allowing the flora and sediments to slowly adjust to a new final water level 1.5m below current TWL
- To undertake repair work using new concrete reinforcement to cut off the leaks, strengthen the dam and maintain water levels at current TWL.

Both options have a potential to cause ecological damage to the aquatic flora, and as such, a current assessment of the flora is required to inform the necessary impact assessments.

ENSIS Ltd. were commissioned to undertake the ecological appraisal of the aquatic flora within Llyn Anafon to provide data to support the Habitat Regulations Assessment (HRA). The focus being on the characteristic elements of this site type (H3130 flora) and the specific and distinctive elements therein; the rare pondweed hybrids being key.

1.2. Aims

The primary aim of this assessment is to determine the current status of the aquatic flora and habitats, with the primary focus on the two nationally rare pondweeds and those species deems as "characteristic" of oligotrophic lakes as defined within the Habitats Directive (see JNCC 2015).

This report sets out to undertake the following:

- To collate and compare existing data on the aquatic habitat and flora within Llyn Anafon.
- to report on the current conservation status of Llyn Anafon with respect to the aquatic flora.
- To present a geo-referenced survey of the distinctive elements of the aquatic flora in Llyn Anafon (*Potamogeton* hybrids, *P. alpinus* and *Ranunculus* sp.).

- To establish the key Habitat Directive features that may be compromised by the engineering options and advise on possible mitigation outcomes.

2. Methods

2.1. Previous data

Comparative assessments are drawn from the three Common Standards Monitoring (CSM, JNCC 2005, 2015) surveys undertaken at Llyn Anafon in 2007, 2013 and 2016 (Burgess *et al.* 2013; Goldsmith *et al.* 2014; Shilland & Goldsmith 2017) and a previous survey of the rare *Potamogeton* hybrids conducted by ENSIS in 2009 (Goldsmith *et al.* 2009).

2.2. Aquatic plant survey and mapping - field

Field surveys were conducted at Llyn Anafon on 24th July 2017 by three ENSIS staff Dr Ben Goldsmith (aquatic botanist), Ewan Shilland (aquatic botanist and limnologist) and James Shilland (field technician). Water level was recorded relative to the outflow sill, which at the time of survey was 2 cm) at the south end of the sill and zero at the north end. The reservoir was there assumed to be at top water level (TWL) and all water depths are given relative to the sill (±2.0 cm).

Figure 1 Bathymetric survey underway

A bathymetric survey was conducted in 2009 and repeated in 2017 using a Lowrance LMS-520 GPS-linked echo sounder mounted on a small inflatable boat (Figure 1). The thousands of geo-referenced depths are then interpolated using a 5.0 m grid to give a bathymetric map with a depth accuracy of approximately 0.1 m using the current TWL as a zero datum. These data provided an assessment of the potential habitat for the aquatic plant species and allow for the extent of potential lake habitat available to aquatic plants under the different water level scenarios

Previous aquatic plant surveys undertaken by ENSIS, in 2007, 2013 and 2016 were conducted using the Joint Nature Conservation Committee's Common Standards Monitoring (CSM) methodology (detailed in JNCC 2005, 2015) on behalf of the Environment Agency (EA) and Countryside Council for Wales (CCW) / Natural Resources Wales (NRW). This method focusses on discreet sections of the lake (based on 4, 100 m long shoreline sections, each with a perpendicular transect out into deep water) rather than a whole lake survey, and is designed to achieve repeatable and representative data for site condition assessment and WFD classification. The CSM methods do not set out to achieve a full coverage of a lake and (unless specifically required) cannot be used to determine the full extent of species within a lake.

With the focus of this survey being the extent and performance of the rare species, a more detailed survey was required to ascertain the spatial and depth distribution of the rare *Potamogeton* hybrids confirm their current status within the site and any changes that may have occurred since 2009.

A small inflatable boat was used to systematically search the entire site for the target species. Plants were located visually, either by their presence at the surface or by using a bathyscope (underwater viewer). Water clarity was relatively high and good visibility achievable to 3.0 m depth; in deeper water, a grapnel was used to confirm the presence or absence of plants. Where present, the locations of *P.* x *griffithii* and *P.* x *gessnacensis* plants or beds were recorded with GPS and depth measurements taken using a hand-held echo sounder (Plastimo Echotest) or a calibrated pole in shallow water (less than 1.0 m). The GPS track was used to ensure good coverage of the site was achieved. Plant abundance was assigned on a DAFOR scale: 5 - Dominant (>50%), 4 - Abundant (26-50%), 3 - Frequent (11-25%), 2 - Occasional (5-10%) and 1 - Rare (<5%).

The depth range and optima were calculated for the Potamogeton species based on their current distribution within the site relative to TWL. A Geographical Information System (GIS) was then used to overlay the current distribution of the *Potamogeton* hybrids on to the bathymetric map and used to compare the current distribution to that recorded in 2009.

These data are discussed in relation to mitigating the effects of any engineering work on the future conservation value of the lake in terms of its characteristic flora and species of local distinctiveness.

3. Results

3.1. Previous data

Table 1 Aquatic macrophyte data from CSM surveys of Llyn Anafon. Note that the water level was approximately 1.0 m below TWL during the 2007 survey.

Submerged and floating vegetation	% occurrence 2007 (n=120)	% occurrence 2013 (n=105)	% occurrence 2016 (n=126)
Callitriche brutia var. *hamulata*	45	49	32
Chara virgata	37	10	14
Elatine hexandra	**3**	**0**	**0**
Isoetes lacustris	**57**	**18**	**19**
Juncus bulbosus	38	73	58
Littorella uniflora	**10**	**50**	**47**
Lobelia dortmanna	**8**	**10**	**12**
Myriophyllum alterniflorum	10	10	19
Nitella flexilis agg.	23	3	10
Nitella translucens	14	0	2
Potamogeton alpinus	2	2	2
Potamogeton x *griffithii*	17	13	9
Potamogeton berchtoldii	7	0	10
Potamogeton x *gessnacensis*	1	7	6
Potamogeton polygonifolius	+	0	1
Ranunculus aquatilis/peltatus	0	5	3
Sparganium angustifolium	**17**	**17**	**6**
Sphagnum sp. aquatic	8	2	1
Subularia aquatica	**0**	**0**	**2**
Utricularia minor	**21**	**7**	**21**
Species richness	**18**	**15**	**19**

When looking at the previous survey data in Table 1, it should be noted that in 2007 the water level was approximately 1.2 m below TWL. The CSM methods use structured depth surveys for the littoral areas and therefore there is an overrepresentation of deeper-growing perennial species at sites with draw-down. In 2007, *Isoetes lacustris* for example, was common at sample depths of 25, 50 and 75 cm, whereas it is normally found at depth of 1-2.5 m when the site is at TWL. Conversely, the increase in frequency of *Littorella uniflora* from 2007 to 2013 can be accounted for by this species favouring shallower water, and thus many plants were stranded above the lower 2007 water line, and not therefore recorded within the submerged macrophyte survey. Consideration is therefore made for the different water depth when comparing species data.

3.2. Habitats Directive assessment

The assessment of SAC site condition is based on a combination of physical, chemical and biological targets (see JNCC 2015). With the exception of recent dissolves oxygen measurements, water quality data are unavailable for the site and the values used in Table 2 are from previous monitoring conducted by Ensis in 2008

– 9; presented here for information only. The condition monitoring would benefit from a minimum of quarterly water quality measurements (see recommendations below)

The following Table 2 presents an assessment of the site condition based on the aquatic flora, and habitats for the SAC feature (Oligotrophic lake). Each attribute is ascribed a target, and ideally all attributes should fall within the target range for a site to be considered as favourable. Generally, if the biological attributes are declining or fall outside the target, the site will be placed in unfavourable condition. Where physical attributes fall outside the target, expert judgement is required to ascertain if there is sufficient threat to the site for it to be placed in unfavourable condition or placed at risk. The latter should be complimented by additional monitoring to ensure the failed attribute does not cause further decline to the habitat feature and its characteristic elements therein.

Table 2 Favourable condition assessment based on 2016 survey data. Water quality data are taken from 2008/9 and require updating.

Attribute	Oligotrophic Target	Status	Comment
Surface area	No loss of surface area of standing water	**X**	Concerns over dam safety have resulted in periods of draw-down over past 15 years. Current plans to permanently lower the water level by up to 1.5 m would result in c. 40% loss of extent.
Macrophyte community composition	At least 3 characteristic species;1 must be a *Littorelletea* species .	✓	6 characteristic species present in 2016 (see Table 1 in bold)
	≥ 6/10 sample spots (boat & wader survey) have ≥ 1 characteristic species	✓	67 % of all vegetated sample points had at least one characteristic species present
	No loss of characteristic species	**?**	*Elatine hexandra* recorded in 2007 (as rare), but not subsequently. Permanent loss is unknown.
	No significant decline in total frequency of characteristic species between surveys		Noting the impact of lowered water level in 2007, there does not appear to have been any significant decline.
Negative indicator species	Non-native species absent or present at low frequency	**X?**	None recorded in 2016, but *Elodea nuttallii* present in 2017 New record at this site.
	Filamentous algae cover values of “3” in no more than 20% of sampling point (i.e. non-*Chara*)	✓	Filamentous algae present, but mainly at low cover. 4.6 % of sample points scored “3”

Attribute	Oligotrophic Target	Status	Comment
Macrophyte community structure	Characteristic vegetation zones should be present and no deterioration from baseline conditions.	✓	Where suitable substrates occur, there is clear zonation of *Littorelletea* taxa with depth with a species rich assemblage present inclusive of *Potamogeton* hybrids at definable depth zones (see below). Macrophytes recorded to 3.5 m depth. No deterioration.
	Maximum depth distribution should be maintained	✓	Z_{max} (recorded) = 10.9 m, Z_s > 3.6 m. Z_{max} = 3.5
	At least the present structure should be maintained	✓	No significant change in species composition or ubundance.
Water quality ENSIS data: 2008-09. **No recent data available**	***Oligotrophic target***: Stable nutrient levels: TP target / limit = 10 μgl^{-1}	✓	TP = 6.8 μgl^{-1} (range 5.6–9.1).
	Stable pH values: pH ~ 5.5 – 7.0	✓	pH = 6.71 (range = 6.55 – 6.84)
	Mean annual total nitrogen TN < 1.5 mgl^{-1}	✓	TN = 0.31 mgl^{-1} (range 0.20–0.41)
	Adequate dissolved O_2 for health of characteristic fauna (> 7 mgl^{-1})	✓	Waters were well oxygenated throughout the water column. DO = 7 - 9 mgl^{-1} at 10 – 0.5 m
	Acid neutralising capacity (ionic ANC) >40 μeqL^{-1} (annual mean)	✓	ANC-ionic = 93.10 μeql^{-1} (2008/9)
	No excessive growth of cyanobacteria or green algae	✓	No visible blooms and historic Chl *a* concentrations low (2008/9 mean = 1.26 μgl^{-1}; range = 0.65–2.60)
Hydrology	Natural hydrological regime	**X?**	Originally natural. Dammed & water level raised by ~1.5m in 1929 for use as water supply reservoir; now disused. Until recently, water levels fluctuated due to dam leakage and resultant safety issues.
Lake substrate	Natural shoreline maintained	**X**	Shoreline naturalised at TWL 1.5 m above original shoreline. Retaining dam of laid natural stone below the waterline.
	Natural and characteristic substrate maintained	✓	Away from the dam, sediments appear consolidated in deeper water, with more organic (peat) silts in the shelters littoral zones and mineral substrates (pebbles, cobbles, boulders) on the exposed shores. Mostly characteristic of upland oligotrophic lakes.

Attribute	Oligotrophic Target	Status	Comment
Sediment load	Natural sediment load maintained	**?**	Unknown. Where water levels vary there is a potential for re-suspension of exposed lake sediments resulting in increased turbidity & potential release of previously bound-up nutrients & DOC into water column; potential siltation onto leaves of submerged plants, so inhibiting photosynthesis.
Indicators of local distinctive-ness	Distinctive elements maintained	✓	One of only 3 sites in GB for *P. x gessnacensis*; Only site in Wales for P. x griffithii; Only SSSI in Wales for *P. alpinus*. Unusual habitat - base & acid influences - unique in uplands of Eryri SAC for its very species rich aquatic flora. The distinctive elements are at potential risk due to suitable habitat loss as a result of draw-down.

Status: ✓ = favourable; X = unfavourable; ? = unable to assess

Overall the flora summarised in Table 1 is representative of the habitat type and shows no significant decline of the key species and for the most part is therefore considered to be favourable. The characteristic elements of the flora (as defined within the CSM guidance, JNCC 2015) all appear to be in good condition and importantly for Llyn Anafon, the distinctive elements (the rare *Potamogeton* hybrids and *P. alpinus*) the flora show no evidence of decline.

Figure 2 *Elodea nuttallii* at Llyn Anafon 2017

There are two key attributes that place the site at serious risk however, and potentially compromise the favourable status. The first is the recent appearance of the non-native invasive species, Nuttall's waterweed (*Elodea nuttallii* Figure 2). Only a simple population was recorded in the site, measuring less than 1 m^2, located towards the south end at SH6991869668. This species, a native of North America, was first recorded in the UK in 1966, but is now widespread throughout lowland Britain, where it is mostly restricted to mesotrophic and eutrophic water bodies. It rarely occurs at higher altitudes, the next highest UK record being at 315 m at a small site in Ceredigion (BRC 2107). Its occurrence in Llyn Anafon is therefore atypical for this species and the likelihood of it surviving and flourishing in the site is considered to be low. Future monitoring will be essential to determine its survival, spread or decline and impact on the site. Any evidence of increase or spread within Llyn Anafon would place the site in unfavourable condition. The presence of this invasive species has been reported to DCWW, who are seeking to address the issue forthwith.

The other major threat to the site is the "Hydrological regime". For a site to be favourable within this attribute, it should maintain a hydrology akin to the baseline at time of designation. At Llyn Anafon, this is assumed to be a top water level governed by the sill of the outlet without significant or prolonged increases or decreases in water levels. During the past 15 years, we know this to have been compromised with periods of draw-down caused by necessary maintenance work to the scour valve and also due to safety concerns for the dam structure and integrity at TWL. More recently, during the past 7 years, we understand the water levels to have mostly been maintained at current TWL. For a site of this type, water level changes are potentially damaging, particularly for characteristic species such as *Lobelia dortmanna* and *Isoetes lacustris,* which are restricted to relatively narrow water depth zones. Similarly, we know the rare *Potamogeton* hybrids to be relatively sensitive to water depths, and thus prolonged change is likely to result in stress to the plants and places them at risk within the site. The uncertainly surrounding the future of the dam therefore places site at significant risk of species and habitat loss and therefore compromises the favourable condition status.

3.3. Potamogeton hybrids

Unlike the majority of the characteristic aquatic flora which is well represented in many other oligotrophic lakes in the Eryri SAC, the two hybrid pondweeds *Potamogeton x gessnacensis* and *Potamogeton* x *griffithii,* as well as *P. alpinus*, are recorded nowhere else within the SAC. The distribution of these rare taxa is therefore considered in more detail by the whole-site survey, using geo-referenced points to assess the spatial and depth distributions.

Figure 3 shows the distribution of *P.* x *griffithii* and *P.* x *gessnacensis* recorded in 2017, and Figure 4 the comparison between 2009 and 2017. The extent of *P.* x *griffithii* has changed significantly between the two sampling periods. In 2009, there was a complete band of this taxon growing mostly between 1.5-3.5 m. The 2017 data show the population to have fragmented, and although increasing slightly in area in the south of the site, it has declined in the northern half of the lake. Despite the extent of this species having changed, the depth distribution in 2017 remained similar to 2009, with optimal depth (based on frequency, weighted by abundance) being 2.8 m (Figure 5).

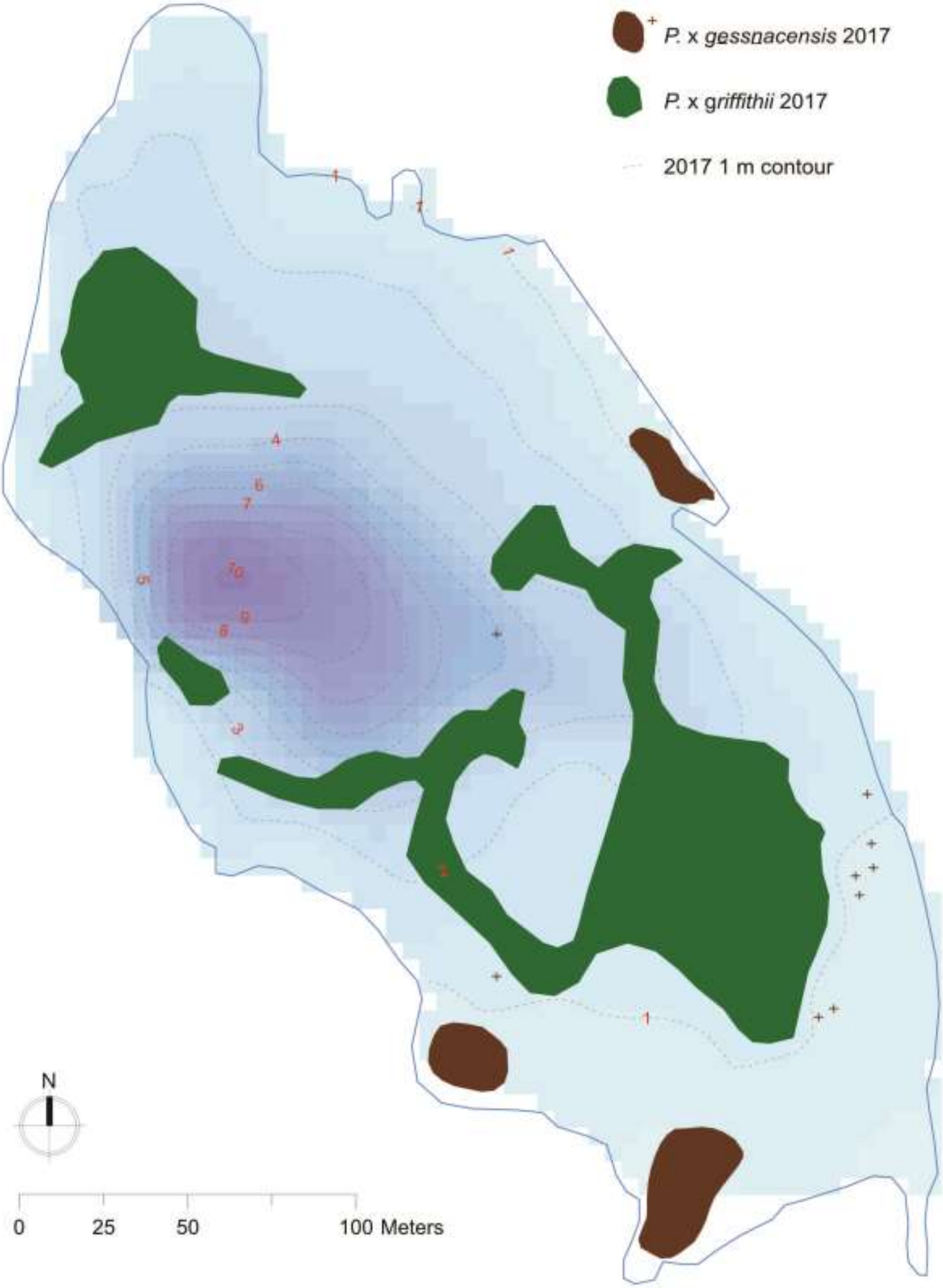

Figure 3 Distribution of *P. x griffithii* and *P.* x *gessnacensis* in July 2017.

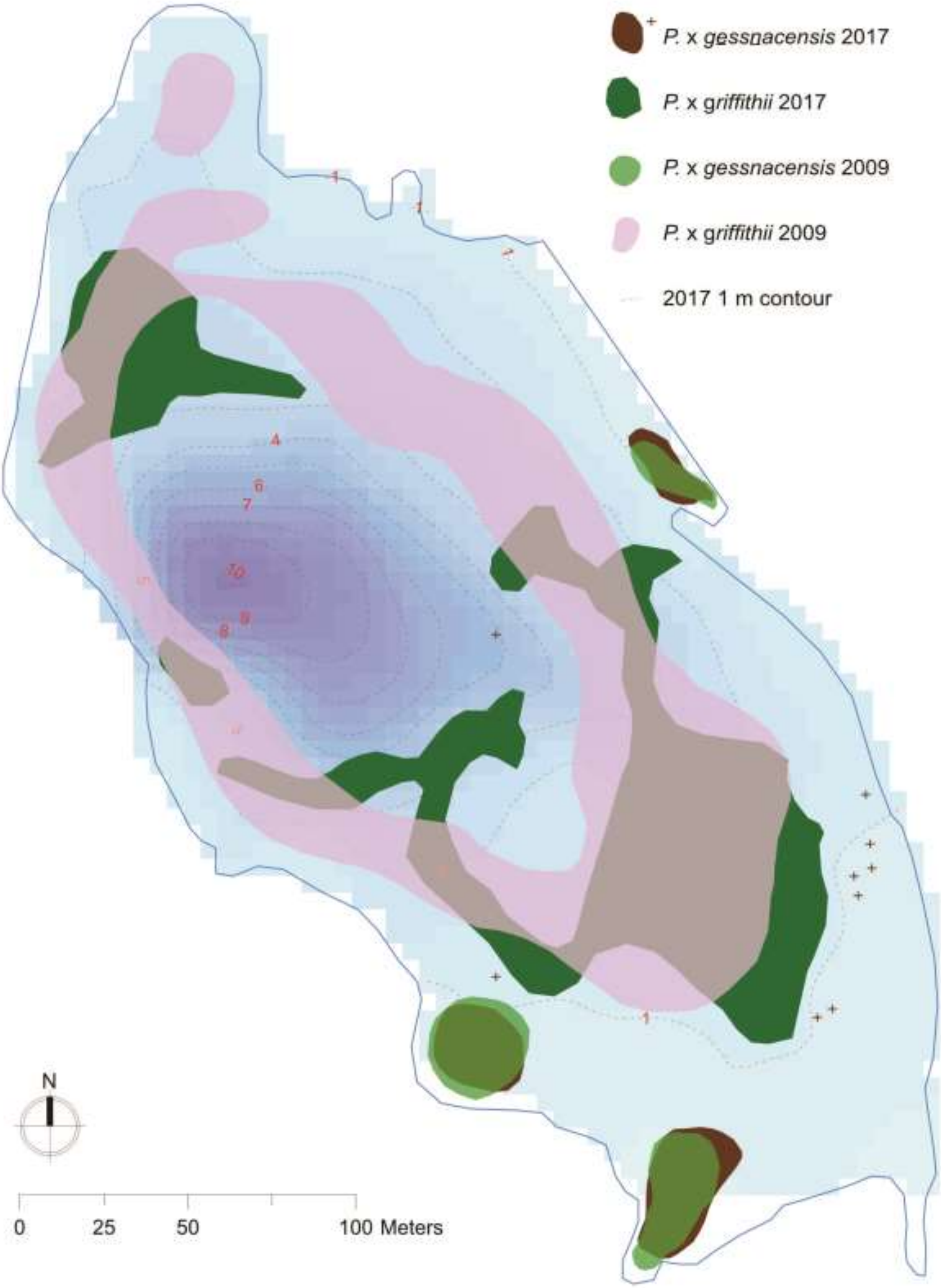

Figure 4 Comparative distribution of *P. x griffithii* and *P.* x *gessnacensis* in July 2017 and 2009.

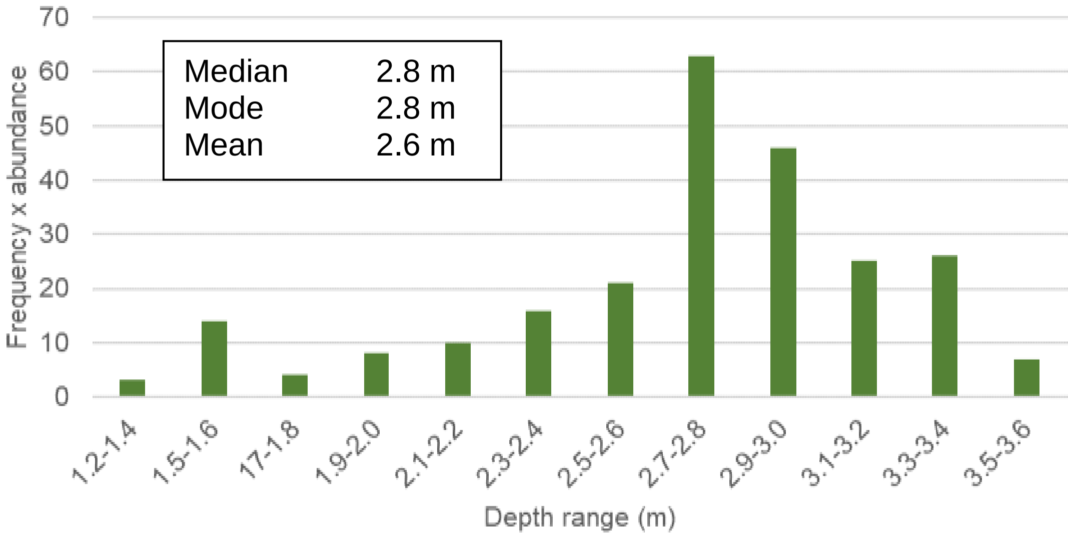

Figure 5 Frequency of occurrence with depth for *P. x griffithii*, weighted by plant abundance

Potamogeton x *gessnacensis* on the other hand, shows very little change in its extent between 2009 and 2017. There is a small bed towards the southeast shore that was not seen in 2009, but otherwise the three main beds appear to remain almost unchanged. The distribution of *P.* x *gessnacensis* was restricted to depths of less than 1.5 m, with the majority of plants being at depths of 0.5 to 1.0 m, performing best (highest abundance) at 0.6 – 0.7 m (Figure 6). While there is seemingly adequate depth habitat within Llyn Anafon, it remains restricted mainly to sheltered embayments, the floating leaves no doubt intolerant of high exposure to wave action.

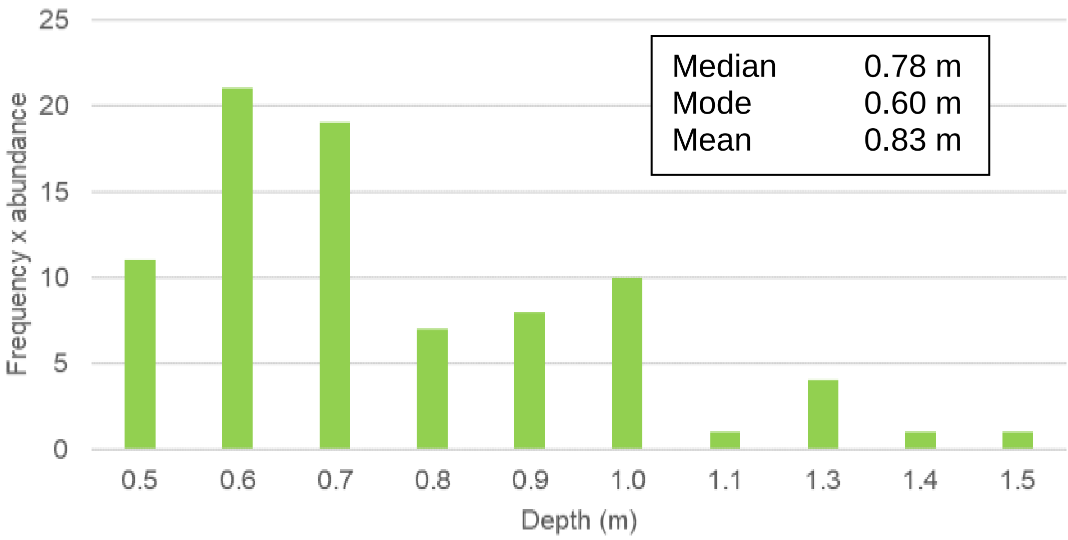

Figure 6 Frequency of occurrence with depth for *P. x gessnacensis*, weighted by plant abundance

Potamogeton alpinus remains rare in the site and with little difference in distribution to 2009. It is restricted to a small area in a pool (0.7 m deep) formed where the main inflow enters the lake at the southern end, and a small number of plants extending beyond the inflow pool within a channel running out into open water to a maximum depth of 1.3 m.

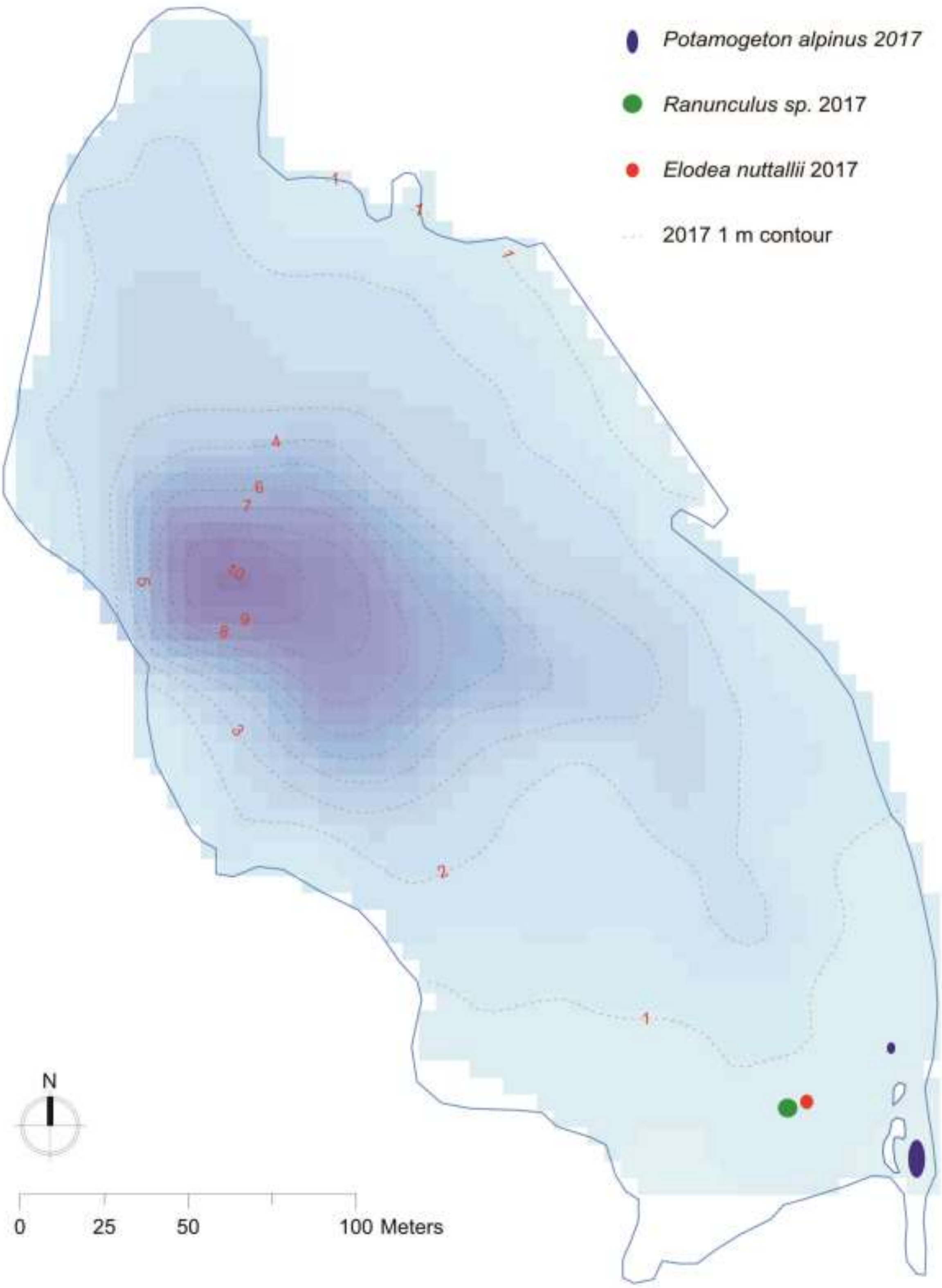

Figure 7 Distribution of *P.* alpinus, *Ranunculus* sp. and *Elodea nuttallii* in July 2017

Also in this shallow area at the south end, was a small bed of Water crowsfoot (*Ranunculus* sp.). This is an unusual plant to find in the uplands, and the exact identity remains uncertain. The plants had both lamina (3-5 lobed crenate) and capillary leaves akin to *R. peltatus,* but the flowers were small with petals only 8 mm which is more typical of *R. aquatilis.* The nectar pits were difficult to define, but were more circular than pyriform, thus also like *R. aquatilis.* It is thought likely that this is a hybrid of the two species. The presence of a *Batrachium Ranunculus* at a site of 500 m is unusual, and testament to the unique nature of the site.

Occurring close to the *Ranunculus* sp. was a small bed of the invasive and non-native *Elodea nuttallii* (Figure 2 & Figure 7). As noted above, if this species were to become established and spread within the site, it has the potential to significantly impact on the characteristic and distinctive elements of the native flora due to its highly competitive habit and dense growth form which smothers lower growing taxa. We are unaware of any other records higher than 315 m, thus it is hoped that the species will not proliferate in Llyn Anafon. Monitoring will be essential to track this species within the site and to determine its impact relative to overall site condition.

Figure 8 *P. x gessnacensis* (top), *P. alpinus* (lwr. left) and the flower of *Ranunculus* sp. (lwr. right)

4. Discussion / comments

4.1. Current ecological status and site condition

Based on the five aquatic plant surveys conducted by ENSIS at of Llyn Anafon (2007-2017), the flora has remained relatively stable. The characteristic oligotrophic components (a requisite of the SAC feature) are in favourable condition and show little change over the past decade, despite the site having undergone periods of draw-down during this period.

The two *Potamogeton* hybrids that form the primary focus of this study, are relatively common in the site and well distributed. The area of *P. x gessnassensi* has changed very little since 2009, and while *P. x griffithii* appears to have decreased slightly in its extent, it still inhabits significant areas of the available habitat in 1.5 to 3.5 m of water (relative to TWL). The reason for the apparent loss of this species from the northern end and along the east and west sides is unclear. The plants are sterile and do not produce turions (Preston 1995), and therefore plants may only proliferate vegetatively from rhizomes or stem fragments, which one would assume to reduce the resilience of the population; although it has survived here since before 1882 when the hybrid was first discovered and describe here by J. E Griffith (Preston 1995). Without one of the parent species present, (the nearest known location of *P. praelongus* is Llynnau Cregennan, 75 km to the south), there is unlikely to be any viable seed bank present at Llyn Anafon. Indeed, this hybrid is a relic, being found at no sites where both parents still occur, making it all the more important that it be properly protected in Llyn Anafon.

Potamogeton x *gessnacensis* is also sterile and without turions, and like *P.* x *griffithii*, has been present in Llyn Anafon since at least 1884, when it was collected and mistakenly identifies as *P. natans.* Herbarium material was later re-examined and confirmed as the hybrid by Dandy (1975). Once again, the persistence of a plant that sets no seed within a site is remarkable.

The reliance of these hybrids on vegetative reproduction is something that requires consideration within any plans to change the water levels. On the one hand, it is positive to note that these hybrids have managed to persist at Llyn Anafon during the disruption and perturbation of building the dam and for the 90 years since then when one assumed there have been periods of draw-down as a result of inspections, water supply and maintenance. We do not however know enough about their biology to know how they will respond to a permanent lowering of water level, and the potential indirect effects of sediment resuspension and nutrient release from erosion of exposed sediments.

Understanding the potential impacts of water level change on the flora may be enhanced by assessing the aquatic survey data in relation to past water level changes. While we are aware that the site has been drawn down on a number of occasions over the past 15 years, the water level data were not available at the time of reporting. We recommend a further assessment of the timing and extent of the water level changes within the lake to help to understand the potential impacts on the plant populations.

Due to the uncertainty of how the plants will cope, it is recommended that long-term annual monitoring of the aquatic vegetation is incorporated into any future plans involving changes to the water level in Llyn Anafon. Furthermore, there should be clearly defined intervention processes in place to halt the lowering of water levels if there is evidence to suggest the distinctive features are at risk of being lost; that is, if the populations of either of the two hybrid *Potamogetons* decline by more than 20% in two successive years or by more than 40% in any one year.

While the *Potamogeton* hybrids form the primary concern due to their national rarity, *Potamogeton alpinus* is also considered as a distinctive species within Llyn Anafon, which is the only protected site in Wales where it occurs. Its rarity within the site requires attention if water levels are to be changed. Its current location in the small pool where the main inflow enters the reservoir is particularly pertinent, as this area will almost certainly be lost or at least significantly disrupted if the TWL is lowered. Once again, annual monitoring will be vital in determine the extent to which this species can cope with any imposed changes within the site.

Under the guidance set out for SAC freshwater lakes in the UK (JNCC 2015), the permanent loss of lake surface area due to deliberate intervention will move a site away from favourable condition. Given that Llyn Anafon lies within the Eryri SAC and supports a favourable and distinctive flora which is in favourable condition, any planned management necessitates that a full Habitats Regulations Assessment (HRA) be carried out to secure compliance within the European Directive.

4.2. Options for dam safety

The Llyn Anafon Leakage (MITIOS) report (ARUP 2017) identifies two engineering options to address the dam leakage and safety. In summary, these are to either achieve a full repair of the dam to maintain TWL, or to remove the spillway in stages over a 5-10 year period, to achieve the level of the original lake; approximately 1.44 m below current TWL.

The ARUP report details logistic and high cost implication of the dam repair as well as significant environmental (and potentially archaeological) impacts caused by the necessity to upgrade the access track for heavy plant and lorries. It is also recognised, that any attempt to repair the dam, will require a long-term strategy to maintain the dam structure indefinitely. In light of this, it is proposed that the removal of the dam, to return the lake to its natural level, provides the best long-term solution. It is recognised that his poses environmental concerns and that mitigation will be required to ensure damage to the protected site and species therein is minimised. This includes the recognition that draw-down should be achieved slowly and that large areas of lake sediment will be exposed. An immediate drop of 1.44 m is considered as being very high risk for the ecological integrity of the lake and if implemented, is likely to result in the loss of characteristic and distinctive elements of the flora. The proposal is therefore to lower the lake by approximately 0.3 m per year over the course of five years (see below for recommendations to extend this time period).

Table 3 shows the relative loss in lake area with each successive 0.3 m drop in water level. Of note is that the constant drop in water level, causes an inconsistent loss in lake area, particularly between the first and second lowering and again between the third and fourth.

The initial proposal put forward by ARUP was for the lowering to be achieved over a 5 year period. Subsequent discussions with the Reservoirs Inspector (Alan Brown, Stillwater Associates Ltd.), clarified that the period for lowering may be extended to 10, or more years, on the proviso that engineering solutions are in place to rapidly lower the water levels during and directly after high magnitude flood events that may increase the risk of dam failure (see: Appendix I – Alan Brown, Workshop notes DCWW 19/10/17). It is recommended that if a permanent water level lowering is effected, the risk to the habitat and species will be reduced further if undertaken over a minimum 10-year period, rather than the initially proposed five years.

Any changes to water level, temporary or permanent place the SAC feature at risk of deterioration causing loss of condition. Any planned engineering work will therefore require the potential ecological risk to be minimised and if necessary mitigated to ensure minimal damage to the SAC feature and species therein. The vertical lowering presented in Table 3 may require adjusting to achieve a more equal loss of area for each lowering step. To be calculated using the more detailed bathymetric survey data collected by Neil Harding, NHTB (data not available for this report).

Table 3 The impact of lake level change on lake area based on a 10 year plan.

Timing	Water level below TWL (m)	Lake area (ha)	Lake area lost (ha)	Percentage loss of lake area	Relative % loss with each step
Present	0.0	5.56	0.00	0.0	0.0
Year 1	0.3	5.42	0.14	2.5	2.6
Year 3	0.6	4.90	0.66	11.9	9.4
Year 5	0.9	4.29	1.27	22.8	11.0
Year 7	1.2	3.84	1.72	30.9	8.1
Year 9	1.44	3.51	2.05	36.9	5.9

4.3. Environmental considerations and mitigation

The preferred options (3 and 4) outlined within the ARUP report (2017), will necessitate a temporary lowering of lake level to allow the engineering work to be conducted. The exact level required is not stated, but it is recognised that any draw-down should only be to the level required for logistics and safety and that the time should be kept to a minimum.

A draw-down of up to 2 m, will expose the majority of the characteristic and distinctive flora to desiccation (for shallower species) or additional wave action (for species normally found growing in deeper water). Timing should therefore be considered. The warmer summer months are likely to place the plants at higher risk of desiccation, and the coldest winter months pose a risk of frost damage to exposed plants and their propagules. It is recommended that mid-September to mid-November would therefore provide the lowest risks to the plants. It is recommended that the water level data from past draw down events are used to gain additional evidence to assess the tolerance of the plants to exposure.

Water quality is a key component of the protected feature, and any proposed management work poses risks of deterioration. Prior to any works being conducted, water quality monitoring should be implemented (to UKAS standards) at monthly intervals for at least six months, preferably a year, to provide a current baseline against which to assess future impacts. The recommended determinands are listed in Table 4 below. Monthly water quality monitoring should be continued throughout any proposed management work and until at least one year after the intervention has been completed.

Option 3, to repair the dam and maintain the current top water level, poses the least risk to the site if effected quickly and with minimal disturbance to the reservoir. This option while potentially better in the short to mid-term, does not however guarantee the long-term future of the site. The dam will require maintenance and governance beyond the tenure of the current managers (DCWW) into a time period beyond the foreseeable future. The long-term uncertainty of Option 3, coupled with the potential for high environmental impact of the construction phase (to the access route), makes the discontinuance of the current dam the favoured option for the long-term sustainability of the habitat. Option 4 also offers the opportunity to undertake the return of the site to its original level under controlled and monitored conditions. The remaining discussion therefore focusses on Option 4, involving the removal of the spillway and decremental lowering of lake level by 1.44 m over 10 years.

4.4. Option 4 – Decremental lowering by 1.44 m

As stated above, the initial engineering work should be conducted with the minimal necessary lowering and effected as quickly as possible to minimise the period during which the lake is drawn down. The engineering plan should detail the methods and contingencies in place to ensure the works are conducted without delay, with an emphasis on the additional risks posed by the remote nature of the site. Conducting these works in the time period mid-September to mid-November is considered to present the lowest risk to the Habitat Directive features.

The first water level drop of 0.3 m would ideally be made after the site has had a full year to recover at current TWL following any preparatory engineering phases. A survey of the plants will be necessary to confirm that there are no major impacts.

Annual monitoring of the plant populations should form a key component of the lowering process (see Section 5). Successive lowering should be planned in conjunction with monitoring. If any of the distinctive or characteristic elements of the flora are shown to be decreasing by over 40% frequency in any one year, or by 20% in two successive years, the lowering should be halted to allow additional time for recovery and, if deemed necessary, to effect within-site translocation of the affected species.

Potamogeton x gessnacensis is currently restricted not only to relatively shallow water, but also to the more sheltered bays, these locations will change as the water levels drop, thus making within-site translocation a high mitigation priority for this hybrid. Translocation of other species, including *Potamogeton alpinus*, should only be done on the evidence of annual monitoring results as above.

Translocation of plants to other lakes within the Eryri SAC is not considered a viable option at this time due to a lack of suitable evidence. Llyn Anafon is noted as being unique, not only for its diverse and unusual flora, but also the geology of the area, which is likely to have a strong baring on the conservation interest of the lake. No recommendations on translocation sites can be made without further consultation with NRW and a strong evidence base for a receiver site with suitable water chemistry, sediment quality and physical structure to support the distinctive elements found in Llyn Anafon.

4.5. Sediment exposure

The initial engineering phase, and subsequent decremental lowering of water levels will inevitably expose areas of fine sediment that have built up of the last 90 years since the reservoir level was raised. This is most acute around the southern end of the lake where TWL depths are relatively low and sediment depths are generally between 30-80 cm. A 1.5 m drop in water level will expose approximately 39 % of the current TWL lake area much of which consists of fine lake sediments overlying either rock or old catchment soils and peat. Once permanently exposed, high local rainfall (in excess of 2200 mm annually) and altitudinal exposure to high winds, greatly increases the likelihood of these sediments being re-suspended into the lake through the processes of surface run-off and wave action.

Exactly how sediment re-suspension would impact the lake and its biota and for how long after their initial exposure, are impossible to predict, but periods of increased turbidity and possibly also increased water colour from the erosion of exposed peat are considered likely. Any increase in turbidity and / or colour within the water column will impact on the site and compromise one of the principal characteristic features of this habitat type (H3010) i.e. clear water with good light penetration.

The impacts of increased turbidity and reduced light penetration on the deep-water flora are potentially serious, with many of the characteristic species, as well as *Potamogeton x griffithii* growing in deeper water. The effects of suspended material are most likely to come in pulses after heavy rain or strong winds and be relatively short lived, but the increased sedimentation on to the leaves of submerged plants will further reduce their ability to photosynthesise and hence affect performance. It is paramount therefore that the effects of sediment re-suspension are minimised following any permanent drawdown of the site.

Methods for physically stabilising sediments, including mulching, chemical treatment, seeding and overlaying with matting are considered as being inappropriate for Llyn Anafon, due to both the logistical difficulties of implementation and the potential environmental impacts that such treatments may have in such a low disturbance, and low input area. If the water level is to be permanently lowered, it is suggested that re-suspension of sediments will most effectively be mitigated by the lowering the water level at set height intervals as planned and monitoring the impacts. We recommend water clarity is monitored automatically by the instillation of an in situ optical turbidity sensor.

Nutrient release from re-suspended sediments is another potential factor that could impact on the ecological balance of Llyn Anafon. Although it is unlikely that recent sediments have anything more than background levels of nutrients (phosphorus and nitrogen) bound up within them, Llyn Anafon is a very low nutrient system and therefore any increase in nutrients could adversely impact the site. Even small increases in nutrients can stimulate the growth of one species (e.g. *Juncus bulbosus*) to the competitive disadvantage of others. Small increases in nutrients may also promote the growth of filamentous and planktonic algae, to the detriment of higher plants in the lake. The relatively small size and volume of Llyn Anafon, and high rainfall means Llyn Anafon will have a high turnover of water, which should increase the rate of flushing of nutrients from the site. Water quality monitoring will provide evidence to support this and identify any concerns with nutrient release.

One further impact of suspended sediments is the potential effects on the river biota downstream of the dam. The amount of re-suspended lake sediments leaving the lake is likely to be relatively low and the steep grade and fast flow of the Afon Anafon should minimise any impacts by preventing siltation. Of greater concern are the high levels of silt and coarse materials that will be generated by the proposed engineering works on the dam and spillway. Physical erosion and scouring caused by increased suspended material and bed load could be damaging to the river biota and it is therefore recommended that if data are not already available, surveys are conducted throughout the length of the Afon Anafon to determine a baseline for the aquatic flora and fauna and if necessary ensure steps are taken to protect any features of conservational importance during the works.

5. Key recommendations

The recommendations provided here are in relation to the option of discontinuing the dam. This is the option currently considered as the most suitable to address the reservoir safety issue of concern highlighted in the Section 10 report and provide the most sustainable long-term ecological stability.

1. **Increase the duration of the planned lowering to 10 years.** It was initially understood that the lowering needed to be achieved quickly to address the safety concerns, and thus a 5 years plan was proposed. Subsequently, the Reservoirs Inspector has indicated that a longer time-frame would be acceptable under the proviso of a high capacity syphon being installed to ensure the reservoir could be rapidly lowered after flood events.

   Ecological integrity will be greatly improved by allowing a minimum of two-year intervals between each successive lowering.

2. **Review the impact of past water level changes.** The HRA should assess the duration and extent of past water level changes (data to be sought from DCWW) to determine what conditions plants have been exposed to over the last 15 years. This information will help to inform the recommendations for setting appropriate time limits on the initial engineering phase, during which water levels will need to be dropped by at least 1.5 m. Recommendations on the timing and duration of the lowering should be re-assessed in relation to the empirical findings.

3. **Review depth data to optimise water level lowering.** The availability of high-resolution bathymetric survey data (undertaken by Neil Harding, NHTB), allows for more accurate spatial analysis of the planned water level lowering. It is recommended that the data are used to calculate the sequential drops in water level required to achieve an even reduction in total area with each drop, rather than an arbitrary 0.3 m for each lowering.

4. **Implement monthly water quality monitoring as soon as possible**, ideally allowing for one year of monitoring prior to any intervention. Sub-surface samples should be taken each month from the outflow area (end of pier) and analysed by a UKAS accredited laboratory (e.g. NLS) for the determinands listed in Table 4 (noting minimum levels of detection (MRV)).

   Water quality results should be analysed as soon as available and used to inform management actions. Any significant increases in nutrients (TP > 10 μgl^{-1}, TN > 0.5 mgl^{-1}) should trigger concern and high values for more than 3 consecutive months should result in competent authorities being mobilised to determine possible causes.

   Monitoring should continue until one year after all management is completed.

Table 4 Water quality determinands for monthly monitoring

Determinand	Unit	MRV	Notes
pH	pH	0.05	
Suspended solids	mg/l	3	
Alkalinity - Total	mg/l	5	
Conductivity @ 20C	µS/cm	10	
Dissolved Organic Carbon	mg/l	0.2	
Orthophosphate	mg/l	0.001	Detection limit 3µg/l
Total Phosphorus (TP)	mg/l	0.003	Detection limit 3µg/l
Chlorophyll *a*	µg/l	0.5	
Total Nitrogen (TN)	mg/l	0.05	
Total oxidised Nitrogen	mg/l	0.005	
Nitrate Nitrogen	mg/l	0.005	
Nitrite Nitrogen	mg/l	0.004	
Sulphate	mg/l	0.5	
Total Soluble Iron	mg/l	0.003	
Sodium	mg/l	0.02	
Potassium	mg/l	0.02	
Magnesium	mg/l	0.02	
Calcium	mg/l	0.02	
Chloride	mg/l	1	
Total Soluble Manganese	µg/l	10	
Silicate	mg/l	0.02	
Copper	µg/l	0.5	
Zinc	mg/l	0.02	

5. **Undertake continuous water clarity monitoring.** Lowering water levels has the potential to cause the resuspension of lake sediments and erosion of newly exposed peats.

   Monitoring is best achieved by the installation of a continuous optical sensor attached to an anchored buoy. The impacts of turbidity should be assessed in relation to rainfall and climate to determine both short-term impacts and any long-term impacts within the site.

6. **Undertake annual aquatic plant surveys.** CSM monitoring of the aquatic vegetation should be conducted annually to assess the extent to which the characteristic plant assemblage is coping with each decremental lowering of the reservoir.

   Additional biennial (every two years) surveys of the *Potamogeton* hybrids and *P. alpinus* should be conducted (as presented in 3.3 above), and an on-site consultation made with NRW staff to assess the requirement for within-site translocation of plants.

Translocations would be best achieved by SCUBA diver of snorkeler, and involve the movement of freshly uprooted material from suitable donor areas, to areas of optimal habitat (in terms of depth, location and sediment type).

If there is evidence of significant decline in any of the characteristic or distinctive species (40% in one year or 20% in two consecutive surveys), it is strongly advised that the lake remains at its current level for one additional year, before a further assessment is made. Subsequent lowering should only occur if the flora has stabilised or recovered, or if additional mitigation is successfully implemented (e.g. translocations show positive results).

Monitoring should only cease after all management works (lowering) have been completed and the habitat ad species therein demonstrated to be stable.

While the lowering of the water level by 1.44 m places Llyn Anafon at significant risk of environmental stress that will impact on its protected status, the above recommendations are presented as the optimal solution to mitigating the risks and return the site to its original water level without the loss of its distinctive and characteristic flora.

The most ecologically robust plan for decommissioning the dam will be led by the motoring data. Each sequential lowering should only be undertaken under conditions where the negative impacts are within acceptable levels or where mitigation (e.g. in-site translocations) is effective.

6. References

ARUP (2017) *Llyn Anafon Leakage (MITIOS). Options Analysis Report* 250618/R02 Final report to Dwr Cymru Welsh Water. January 2017

BRC (2017) Online Atlas of the British and Irish Flora. *Elodea nuttallii*. Available on line at: https://www.brc.ac.uk/plantatlas/plant/elodea-nuttallii [Accessed Oct 2017].

Burgess, A., Goldsmith, B., Hatton-Ellis, T. 2013. *Site Condition Assessments of Welsh SAC and SSSI Standing Water features, 2007-2012*. CCW Report No. 983. 286pp, Countryside Council for Wales, Bangor

CCW (H. Hughes) (2008). *Core Management Plan Including Conservation Objectives for Eryri SAC*. CCW Report, Bangor. 89pp.

Dandy, J. E. (1975). *Potamogeton* L., in STACE, C. A., ed., *Hybridization and the flora of the British Isles*, pp. 444-459. Academic Press, London.

European Union (1992) Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora (EC Habitats Directive). *Official Journal of the European Union L* 206 , pp7 – 50.

Goldsmith B, Salgado, Bennion, H. & Goodrich. 2014. Lake Ecological Surveys (Wales) 2013. NRW Evidence Report No 28. 19 pp, Natural Resources Wales, Bangor

Goldsmith, B., Hughes, M. & Shilland, E. (2009). Habitats Directive assessment of Llyn Anafon with respect to proposed water level changes. Final Report to Mott MacDonald (November 2009). ECRC Research Report No.138.

Joint Nature Conservation Committee (JNCC). 2015. Common Standards Monitoring Guidance for Freshwater Lakes (Version March 2015). Interagency Freshwater Group Report, JNCC, Peterborough. An electronic version of this report is available at: http://jncc.defra.gov.uk/pdf/0315_CSM_Freshwater_lakes.pdf

Joint Nature Conservation Committee (JNCC) 2005. Common Standards Monitoring Guidance for Freshwater Habitats and Species (Standing Water), 1st version. ISSN 1743-8160 (Online). Available online at http://jncc.defra.gov.uk/page-2232

Mott Macdonald. 2006. Llyn Anafon Reservoir. Reservoirs Act 1975 – Section 10. Inspection Report. Report No. 220054/GLA/016

Mott Macdonald. 2008. Llyn Anafon Spillway Slot. Pre-Construction Information. (Unpublished report).

Preston, C.D. (1995) Pondweeds of Great Britain and Ireland. BSBI Handbook No. 8. BSBI, London. 352 pp.

Shilland, E,M., Goldsmith, B. & Hatton-Ellis, T.W. (2017), Ecological Surveys of Welsh Lakes 2016, NRW Evidence Report No 204. 73 pp, Natural Resources Wales, Bangor.

7. Appendix I – Alan Brown, Workshop notes DCWW 19/10/17

A. Reservoir leakage and risk of restored reservoir dropping below overflow

Context

The glacial boulder layer in the foundation is a layer that that we have agreed we cannot practicably seal. Note this layer will remain for Option 4 (Discontinuance) and could lead to the restored lake drop below TWL in summer. We should estimate leakage in this layer now, and with the reduced head when the dam has been removed, as if this quantity is excessive then the "restoration option" may need engineering works to ensure that the restored lake does not drop/ dry out in summer. Although prior to lake construction leakage may have been low, the increased head over 80 years due to presence of the reservoir may have washed out fines and thus increase leakage

Outline scope

1. What was typical/ extreme drop in WL each summer when used (abstraction) for water supply?
2. Derive flow duration inflow curve into reservoir
   a. Based on extrapolation from flow duration curve at gauged station in similar catchment
   b. Compare to reservoir level records (implied outflow)
3. Rainfall at site
   a. How long are periods with no significant rainfall?
   b. Comment on implications for reservoir dropping below overflow
4. Leakage (sensitivity study of say upper and lower bounds and best estimate)
   c. Infer current leakage from reservoir level records and V notch
   d. Is it increasing in the current condition? If so what could it be in 100 years' time?
   e. How will ongoing corrosion of residual sheetpiles at depth affect this?
   f. How would it reduce for the restored lake? Also Long term how is it likely to change for the restored lake?
   g. Could this be larger than Q90 inflows, so reservoir drop below overflow in summer?
   h. Should lake restoration include any seepage reduction measures?

B. Engineering to restore resilience of rim to natural cwm (Option 4)

Comment on what works would be required, at feasibility level i.e. more detailed than current note. To include

1. Long section on restored river channel (i.e. cross section from base of lake, over rim of cwm and say 50m downstream)
2. Comment on Need for, and options to, measures to mitigate (include feasibility level description of options i.e. key dimensions/ design criteria)
   a) near surface seepage/ internal erosion?
   b) risk of long term degradation / erosion of river bed - stabilise bed of river channel with concrete cut-off trench? How deep/ wide?
   c) risk of erosion/ washout along trench backfill to pipes through foundation? (I anticipate we would want to prove as-built drawings are correct, plus possible have a section where we remove pipe and backfill and put in concrete plug)

C. Contingency plan for control of reservoir lowering

1. what are (environmental) risks/ contingency plans that could mean the staged drawdown has to be suspended? (Ben thought we agreed 10 years, and could be longer)
2. Flow chart as request by NRW?
3. If completing drawdown to the natural cwm level could take a long time (10 years +) we probably need a high capacity siphon outlet so could empty reservoir in emergency if sudden deterioration?
4. Prepare outline (feasibility) design of siphon outlet that would provide drawdown capacity recommended in the recent guide to drawdown capacity. To include both hydraulic capacity/ size and options of location of intake/ outlet and level/ detailing of pipe across sheetpile wall

D. Flood risk during construction work (applies to both options 3 and 4)

The existing notes just say it is a problem. Provide further detail i.e. quantified feasibility level including

1. what return period storm can proposed drawdown accommodate? (e.g. for temporary works – 1.44m?, and during staged drawdown)
2. if storage is less than 1 in 100 chance per year flood describe viable methods of reducing risk, and annual chance of dam failing wither these measures in place

E. Reconstruction option (as alternative for HRA)

Context: is existing Note on Option 4 adequate as evidence for IROPI test? My perception is that is leaking in detail?

Possible scope to strengthen case for option 4

1. define options for spillway size/ location
2. sketch of outline dimensions of spillway
3. foundation treatment under spillway
4. all buildability issues, including
    a. intermediate compound at village end of track (for material storage, share cars up to site)
    b. flood risk during construction
    c. quantities of excavation (track widening, discontinuance) and fill
    d. number of vehicle movements up track
    e. contractor to assess access issues, both in village and along side of hill, and what works required to make safe