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Habitats Directive assessment of Llyn Anafon with respect to proposed water level changes

Final Report to Mott MacDonald

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Executive Summary

This report was commissioned by Mott MacDonald in response to concerns over the structural integrity of the dam at Llyn Anafon, a now disused water supply reservoir owned by Dwr Cymru Welsh Water and lying within the Eryri Special Area of Conservation (SAC), North Gwynedd, Wales (SH697698). Llyn Anafon is classified as “Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*” under the EU Habitats Directive. It has an exceptional characteristic and distinctive aquatic flora that includes two extremely rare *Potamogeton* (Pondweed) hybrids. Water quality is also very high and the site is arguably one of the best examples of this habitat type within the SAC. Recent work commissioned under Section 10 of the Reservoirs Act 1975 identified significant seepage from the dam with a significant loss of fine material, with potential implications for the safety of the structure. The report recommended the water level be lowered by 1.0 m with immediate effect and that a long term solution to the defective dam be sought. The resultant lowering of the water level has had a direct impact on the otherwise favourable condition of the site and places the habitat and species therein at risk.

The need to find a long-term solution to the leaking dam has led to a number of different engineering options being put forward which include: the complete repair of the dam; the partial removal of the spillway (lowering by 1.0 m); and the removal of the entire mid-section of the dam to restore the original lake level at approximately 1.5 m below current TWL.

In order to assess the current status of the site in relation to the Habitats Directive and to determine what effects the proposed water level changes might have on the aquatic habitats and flora a survey of the aquatic macrophytes and a detailed bathymetric survey was undertaken in July 2009. A total of 19 aquatic species were recorded, of which 9 are considered as characteristic of this habitat and four of which are exceptional records and add distinctive interest to the site.

GIS was used to determine the extent of viable depth habitat available to the two rare *Potamogeton* hybrids. Based on their current distribution, these data were then applied to different drawdown scenarios to assess the extent to which this habitat would be changed. In addition the overall loss of open water area was calculated under different water level scenarios and also the area of lake sediments that would be exposed.

This report examines different water level scenarios and discusses them in relation to their potential impact on the aquatic habitats. Findings demonstrate that 1.0 m drop in water level would result in just over 25 percent of the lake area being lost, and the exposure of 1.48 ha of lake sediments which would then be at risk of eroding and being re-suspended in the lake. Furthermore the extent of viable depth habitat for *P. x griffithii* would be reduced three-fold and a third less would be available to *P. x gessnacensis*.

In light of the exceptional aquatic flora of Llyn Anafon the ideal engineering solution would be to repair the dam and maintain water levels at the current TWL. However, in recognition that this may not be practical, the alternative option of lowering the spillway by 1.0 m is examined. While this will inevitably impact on the quality and extent of habitats at Llyn Anafon, a gradual and stepwise lowering of water levels over four years is proposed as being the most favourable method of preserving the characteristic elements of the flora. Furthermore, the implementation of any major engineering work on a site of this importance places the habitat at risk and necessitates that a stringent monitoring scheme is in place from the outset of the work.

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1. Introduction and Background

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 commission for all but "emergency" use, the site owner Dwr Cymru Welsh Water maintains 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 10.9 m and mean depth 2.4 m.

Llyn Anafon is classified with 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). In addition to its inherent natural beauty, Llyn Anafon is almost 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, this 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 of these 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). 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 mitigated.

The reinforced earth dam at Llyn Anafon has apparently shown signs of leakage from the time of construction with efforts being made to address this problem as early as 1931 (Mott MacDonald 2008). More recently, leakage concerns resulted in a report being 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.
- 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 by Mott MacDonald, 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.

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

While these recommendations address the dam leakage issues, their implications for the ecological integrity of the site are potentially very damaging and are in immediate conflict with Llyn Anafon's status within the Habitats Directive. In order to maintain 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 maintained:

- The lake should exhibit no loss of extent (surface area or depth distribution) other than due to climatic conditions.
- Natural sediment loads should be maintained (drawdown is likely to result in sediment exposure and re-suspension).
- 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.* in prep.).

The two hybrid pondweeds occupy different depth zones, with *P. x gessnacensis* occurring primarily in shallow water (Approx. 30-100 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 the lake level changes proposed under the different engineering options for the dam repair. During the survey conducted in 2007 (Goldsmith *et al.* in prep.) water levels were approximately 80-100 cm below TWL, resulting in almost the entire population of *P. x gessnacensis* (and other shallow water species) being stranded above the waterline and exposed to desiccation. It is understood that Dwr Cymru Welsh Water have attempted to maintain water levels at 1.0 m below since 2007, but observations by the authors and local and other accounts (CCW 2005) report the water level to have fluctuated considerably from TWL to 1.5 m below TWL since 2005. It is understood that this relates to control problems with the scour valve.

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 the ability of plants 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.

The removal of a dam, for whatever reason, is easy to portray as a relatively simple process, whereby one opens up the dam and lets nature take its course to restore the environment back to a pre-intervention environment. This may well not be the case however and led Shuman (1995) to conclude: "….a comprehensive environmental assessment of dam removal and reservoir retention alternatives is necessary to overcome both the often simplistic view of dam removal and to establish a more complete understanding of both restoration and retention alternatives".

1.1 Project Objectives

With the recognition that remedial action is required on the Llyn Anafon dam in the interests of public safety, it is necessary to establish the current extent of the target species and habitats within the lake and to assess the potential options for minimising any impact at the site.

The primary aim is therefore to assess the current status of the aquatic habitats and flora (including two nationally rare pondweeds). The extent of the target species and habitats will be mapped against current location and depth and these data used to assess the potential impacts of the proposed engineering work if water levels are lowered. The results will be discussed in terms of the ecological impact to the site within the requirements of the Habitats Directive. Furthermore, the survey data will provide an accurate baseline which will be required for future monitoring if any work is carried out on the dam.

Plate 1 ***Potamogeton x gessnacensis***

2 Methods

Llyn Anafon was visited by three ENSIS –ECRC staff on 5th July 2009. Using a small inflatable boat, a full, geo-referenced bathymetric survey was conducted[3] using a Lowrance LMS-520 GPS-linked echo sounder. This provided many thousands of geo-referenced depths which were 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 (surveyed to the outflow lip). An accurate digital boundary of the lake was also recorded with GPS by walking the entire shoreline at the TWL mark and a series of additional GPS points taken on foot around the lake at 30 cm water depth to gain coverage where the boat mounted GPS is less effective. These data can also be used to calculate the extent of potential lake habitat available to aquatic plants and furthermore the loss or change in potential habitats under the different water level scenarios proposed for the different engineering options.

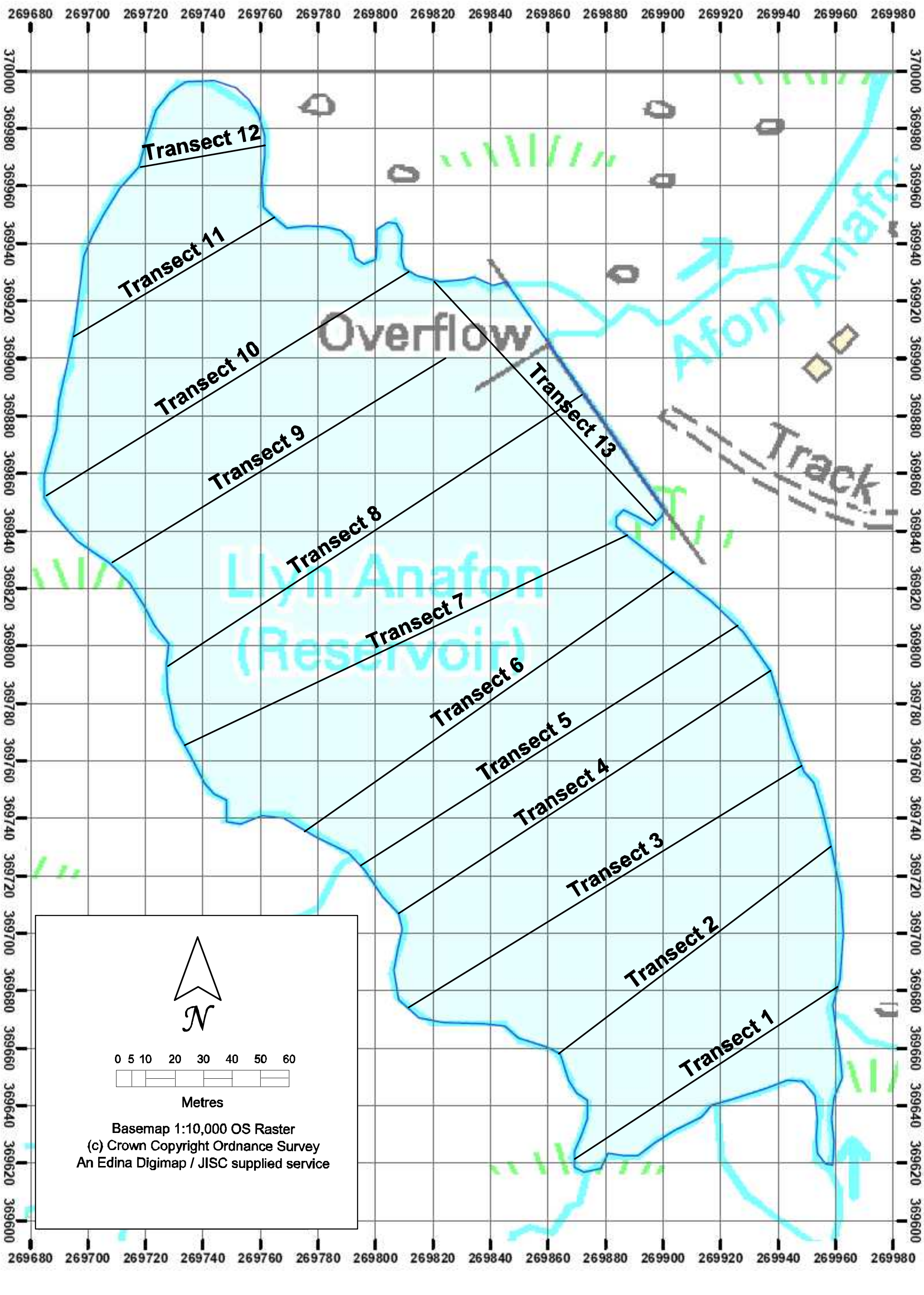
An aquatic plant survey was conducted by ENSIS-ECRC staff in 2007 as part of a Water Framework and Habitats Directive projects funded jointly by the Environment Agency (EA) and Countryside Council for Wales (CCW). The Common Standards methodology (JNCC 2005) used in 2007 focussed on sections of the lake rather than a whole lake survey and thus the data generated were used only as a guide for the current project. An additional survey of the aquatic vegetation was therefore required in July 2009 to ascertain in particular the spatial and depth distribution of the rare *Potamogeton* species to confirm their current status and habitat requirements. Plant abundance was assigned on a DAFOR scale for the site: Dominant (>50%), Abundant (26-50%), Frequent (11-25%), Occasional (5-10%) and Rare (<5%).

A series of thirteen transects were rowed across the lake by boat (Figure 1.1) and along each transect the aquatic vegetation viewed with a bathyscope (underwater viewer). Water clarity was relatively high and good visibility achievable to 4.0 m depth; in deeper water a grapnel was used to confirm the presence or absence of plants. Being of primary interest for their local distinctiveness, the locations of *P. x griffithii* and *P. x gessnacensis* plants or beds were recorded with GPS where observed and depth measurements taken using a hand held echo sounder (Plastimo Echotest) or calibrated pole in shallow water (less than 1.0 m). The presence and abundance of all other aquatic plant species was recorded. In additional to the boat transects, additional searches were conducted using the boat in open water and by wading in shallow areas and any further species occurrences recorded. The data points were recorded and marked onto a geo-referenced map to ensure adequate coverage within the lake.

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* species on to the bathymetric map and used to compute the available areas within the lake for each species. GIS was also used to assess changes in the availability of habitat area based on various water level change scenarios from the various engineering options. 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] Although a previous bathymetric survey was conducted in 1985, we will require a current GIS layer onto which aquatic plant data can be added.

Figure 2.1: Map of Llyn Anafon showing macrophyte survey transects.



3 Results

3.1 Aquatic macrophytes

A total of 19 aquatic plant species were recorded from the two surveys at Llyn Anafon conducted by ENSIS-ECRC staff in 2007 and 2009 (Table 3.1). Of these, nine species are considered to be "characteristic" under the Habitats Directive "Oligotrophic to mesotrophic standing waters (H3130)" lake type (JNCC (amended) 2005). Furthermore, at least 60 percent of the vegetated sample plots in the lake had characteristic species present and the site exhibits the vegetation zones typical for the lake type.

Table 3.1: Aquatic plant species recorded at Llyn Anafon, 2007 & 2009. Characteristic oligotrophic species in bold type.

Submerged & Floating leaved species	2007 DAFOR[4]	2009 DAFOR
Callitriche hamulata	O	F
Chara virgata	A	A
Elatine hexandra	**R**	**R**
Isoetes lacustris	**F**	**O**
Juncus bulbosus	F	A
Littorella uniflora	**O**	**F**
Lobelia dortmanna	**R**	**O**
Myriophyllum alterniflorum	R	O
Nitella flexilis agg.	O	F
Nitella translucens	R	R
Potamogeton alpinus	**R**	**R**
Potamogeton x griffithii	**F**	**F**
Potamogeton berchtoldii	R	R
Potamogeton x gessnacensis	**R**	**O**
Potamogeton polygonifolius	R	R
Ranunculus sp. (*Batrachium* hybrid?)	Not recorded	O
Sparganium angustifolium	**R**	**O**
Sphagnum sp.	R	R
Utricularia minor	**O**	**O**
Emergent / marginal species		
Carex rostrata	R	R
Juncus acutiflorus	R	R
Juncus articulatus	R	O
Juncus effusus	R	O
Menyanthes trifoliata	Not recorded	R
Ranunculus flammula	R	O
Ranunculus hederaceus	R	Not recorded

Allowing for the different methods utilised in collecting the plant data, there is very little apparent change over the past two years. *Potamogeton x gessnacensis* appears less abundant

[4] Abundance data were collected using different methods and should not therefore be compared directly without noting this.

in 2007, but this is likely to be a result of the low water levels at the time of the 2007 survey which left this species mostly stranded above the water line and therefore affecting its performance as well as likelihood of being recorded. Similarly the aquatic *Ranunculus* species recorded in 2009 was in shallow water and would have been well above the waterline in 2007. Accounting for the differences in water levels, the depth distribution of the aquatic flora is broadly similar in both years with *Littorella uniflora* being recorded between 0-200cm, *Lobelia dortmanna* from 60-220cm (only locally common) and *Isoetes lacustris* from 75-250cm (below TWL); a typical zonation for oligotrophic lakes. In deeper water there were dense beds of stoneworts, with *Nitella* common from 1.3 m to a maximum of approximately 4.2 m and *Chara virgata* tending to occupy the deeper water to a maximum of 5.0 m.

The two *Potamogeton* hybrids occupied very different zones within the lake and due to this, as well as their rarity, the primary focus of the potential lake level change will concentrate on their potential habitat areas. *Potamogeton x gessnacensis* was primarily recorded as a shallow water plant (depth range of 30-110 cm) and was restricted almost entirely to three embayments (centred on SH6982569685, SH6988569640 & SH6989069850), where it clearly benefited from increased shelter as well as the optimal water depth. Interestingly, a small number of plants were also recorded in deeper water (1.5 – 2.7 m) where they occurred as lone plants and although having laminar leaves, these did not reach the water surface like the shallow water specimens (Figure 3.1 below).

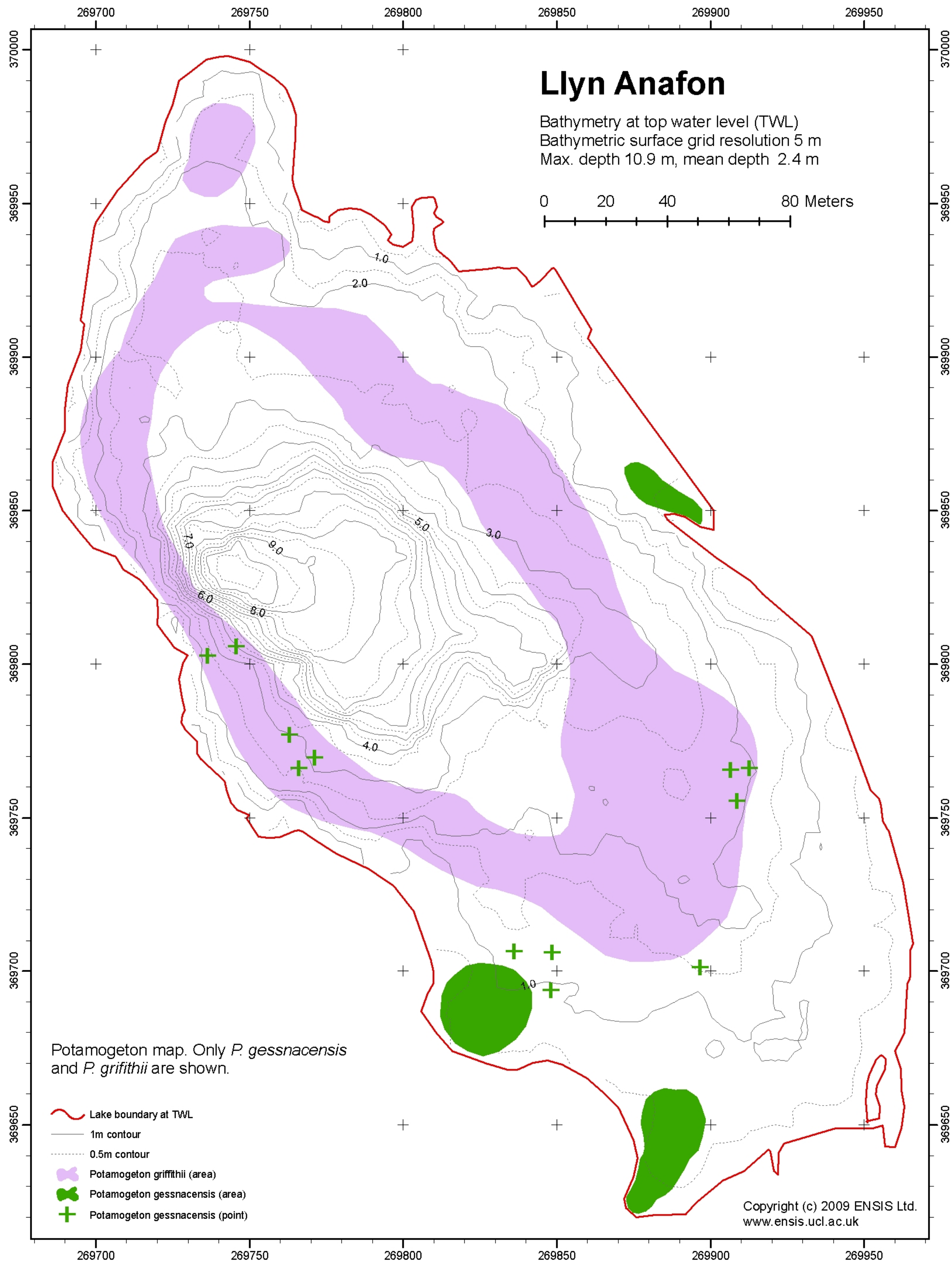
Potamogeton x griffithii was a lot more widespread within the lake, but was recorded only in deeper water areas (1.7 m – 3.9 m) and mainly in quite sparse beds or as single, isolated plants. Plants were generally healthy looking and up to 2.5 m tall in deeper water. Although having an apparent optimal depth between 2.3 m and 3.2 m, there were significant areas of the lake in this depth range where no *P. x griffithii* was recorded (Figure 3.1 below). A few plants were recorded at 1.4 – 1.6 m around the south west of the lake; possibly the shelter afforded from the windward shore allowed them to grow in shallower water.

Other notable species included a small area of *Elatine hexandra* close to the dam at SH6985569885 growing at approximately 100 cm water depth. While *E. hexandra* is a characteristic species of oligotrophic (as well as more nutrient rich sites), it is normally a lowland species and previously recorded at a maximum altitude of 440m in Lake Ferta (C. Kerry, Ireland; Preston *et al.* 2002) and a possible nineteenth century record from 490 m in the Scottish Highlands (Preston & Croft 1997). In Wales, the previously highest recorded population was in Llyn Gynon (SN799646) at 425 m. Llyn Anafon may therefore support the highest population of *Elatine hexandra* known in the UK, thus adding to the local distinctiveness of the lake.

The *Ranunculus* species seen flowering in 2009 near the south-east shore was not possible to identify on site and material collected and examined later appeared intermediate between *R. aquatilis* and *R. peltatus*. A hybrid of these two species does occur naturally (Stace 1997), but it is not possible to confirm the Anafon material to be this without more detailed taxonomic study. With neither parent known to be present within the immediate locality and both very rare above 400 m (Preston *et al.* 2002), this is yet another unusual occurrence at the site.

A small area of *Potamogeton alpinus* was recorded growing in a deep pool at the southern end of the lake at the point where the main inflow enters the site (SH6995569627). Although present at a few sites in Wales, Llyn Anafon is the only protected (SSSI) site where it is recorded and is therefore important for the conservation of the species within Wales.

Figure 3.1: Distribution of *P. x gessnacensis* and *P. x griffithii* in Llyn Anafon



3.2 Water quality

Water quality data for Llyn Anafon have been made available from a joint EA / CCW funded project (Table 3.2, Goldsmith *et al.* in prep). Currently Llyn Anafon has very high water quality and fulfils the Habitats Directive criteria required for this lake type (set out in JNCC 2005). The pH remained stable over the sampling period and although slightly higher than many upland lakes in North Wales is consistent with mixed geology of the catchment which although primarily of base poor igneous geology, has outcrops of more alkaline (feldspar-rich) dolerite and andesite (Preston *et al.* 1998). Catchment land use is restricted to relatively low intensity grazing by sheep and horses which along with its remote location results in very low nutrient inwash and hence low total phosphorus (TP) and nitrogen (TON & TN) concentrations. Moderate amounts of dissolved organic carbon (primarily humic acids), derived from catchment soils and peat, was evident from the slightly elevated measured values as well as the brown tinge of the water.

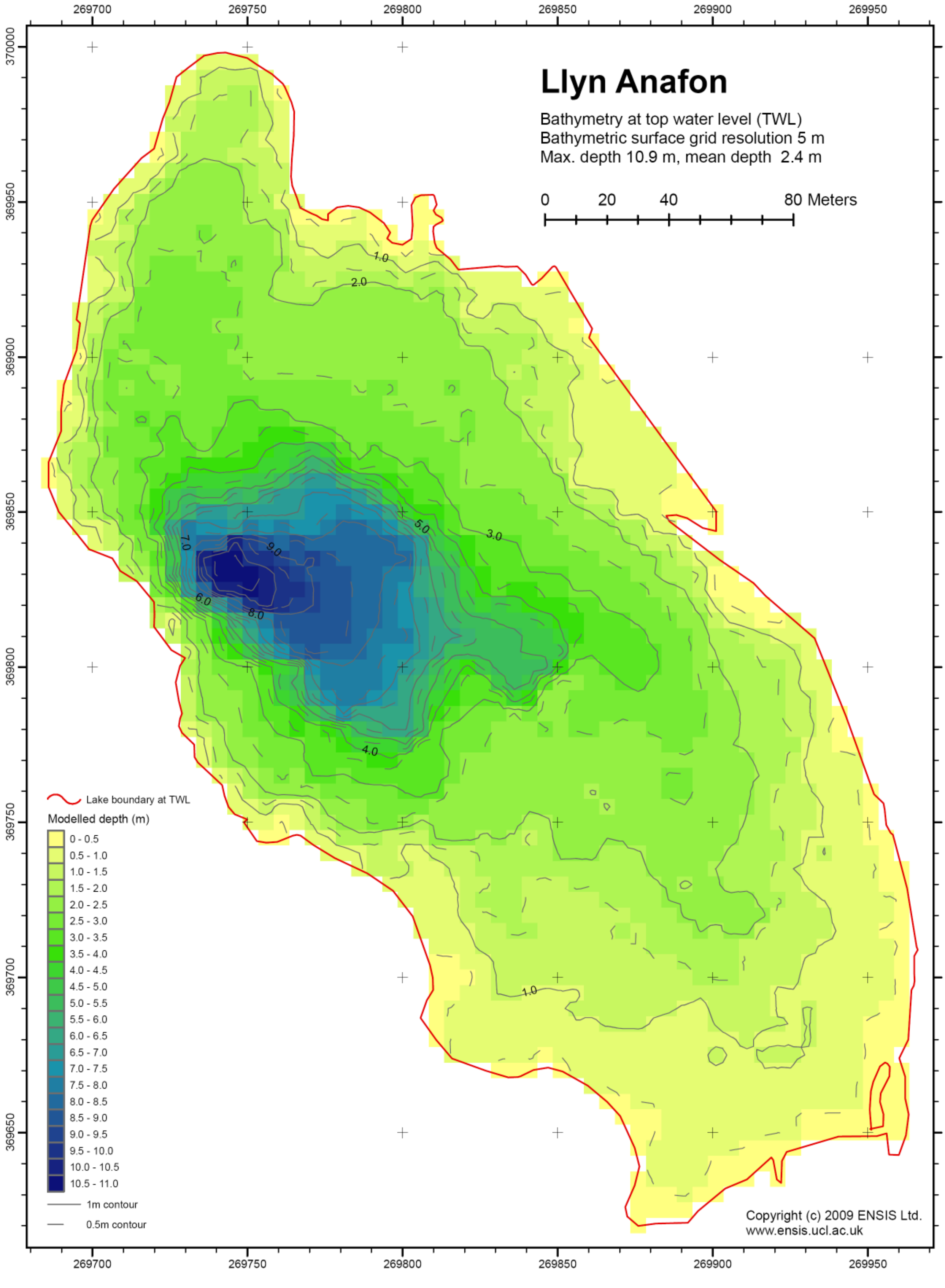
Table 3.2: Quarterly water chemistry data from Llyn Anafon 2008/9 (by permission of EA / CCW; Goldsmith *et al*. in prep)

Analyte \ Date	Apr. '08	Jul. '08	Oct. '08	Jan. '09	Mean
pH	6.84	6.75	6.55	6.77	**6.71**
Conductivity at 20C (μScm^{-1})	39.0	35.0	33.0	30.0	**34.3**
Total Phosphorus as P (μgl^{-1})	5.9	9.1	6.7	5.6	**6.8**
Orthophosphate, reactive as P (μgl^{-1})	1.7	1.5	1.7	<1.0	**1.5**
Nitrogen : Total as N (mgl^{-1})	0.200	0.350	0.270	0.410	**0.308**
Nitrogen : Total Oxidised as N (mgl^{-1})	0.0786	0.0353	0.0438	0.2130	**0.0927**
Alkalinity to pH 4.5 : Grans Plot (mgl^{-1})	4.20	5.90	3.10	2.60	**3.95**
Dissolved Organic Carbon as C (mgl^{-1})	1.74	4.75	4.23	2.27	**3.25**
Chlorophyll, Acetone Extract (μgl^{-1})	0.65	2.60	0.67	1.10	**1.26**
Aluminium : Active (μgl^{-1})	23.10	27.90	53.50	40.60	**36.28**
Aluminium : Total (μgl^{-1})	53.00	120.00	110.00	63.00	**86.50**
Total Suspended solids (mgl^{-1})	0.67	0.10	1.00	0.10	**0.47**
Calcium (mgl^{-1})	2.09	2.64	1.59	1.69	**2.00**
Magnesium (mgl^{-1})	0.74	0.71	0.51	0.52	**0.62**
Potassium (mgl^{-1})	0.30	0.20	0.24	0.42	**0.29**
Sodium (mgl^{-1})	4.33	3.37	3.05	3.12	**3.47**
Iron, Dissolved (μgl^{-1})	14.50	50.60	53.30	30.50	**37.23**
Chloride (mgl^{-1})	8.10	5.20	4.70	5.30	**5.83**
Sulphate as SO_4 (mgl^{-1})	2.34	2.68	1.73	2.13	**2.22**
Silicate, reactive as SiO_2 (mgl^{-1})	2.19	1.53	1.92	2.22	**1.97**

The composition and structure of the aquatic vegetation (including several important indicators of local distinctiveness) coupled with high water quality, should rightly classify the site as being “favourable” under the Common Standards Monitoring (CSM) guidelines for this Habitats Directive feature (JNCC 2005). The current situation with the leaking dam and planned engineering work however, are considered to place this status at significant risk of decline.

3.3 *Bathymetric survey*

Figure 3.2: Bathymetric map of Llyn Anafon at top water level (July 2009).



Although Llyn Anafon has a maximum depth of 10.9 m, the deep area is restricted to a relatively small region towards the north-west shore (Figure 3.1). The mean depth was calculated as 2.4 m and approximately 80 percent of the lake area is shallower than 3.0 m, making good habitat for aquatic plants. The shape of the Anafon basin clearly has implications for water level reductions and Table 3.3 shows the loss in lake area calculated for successive lowering of the lake.

Table 3.3: Calculated loss of surface area for Llyn Anafon at different water levels.

Water level below TWL (m)	Lake area (ha)	Lake area lost (ha)*	Percentage loss of lake area
0.0	5.56	0.00	0.00
0.5	5.16	0.40	7.19
1.0	4.08	1.48	26.60
1.5	3.39	2.17	39.00
2.0	2.86	2.70	48.56
2.5	1.76	3.80	68.33
3.0	1.13	4.43	79.70

* This figure represents the area of exposed lake sediments

In addition to the loss of surface area of the lake, lowering water levels also has implications for the exposure of lake sediment. Over the past 80 years since the construction of the dam, lake sediments have been deposited in the areas that were once above the natural lake shore. In places these appear relatively deep (>50 cm) and have already caused local concern during periods of drawdown due to the dangers of these soft sediments to livestock and potentially the general public. The shallow area around the southern end of the lake would be particularly affected.

3.4 Potential ecological impacts and habitat scenarios

With the application of further GIS to the botanical and bathymetric data it is possible to assess the potential habitat changes brought about by different water level scenarios, dependent on the final choice of engineering solution. A permanent change in the water level will affect the entire aquatic flora, but the distinct zonation exhibited by the two *Potamogeton* hybrids best demonstrates the effects of habitat change and their extreme rarity is ultimately of the greatest conservation interest at the site.

Potamogeton x gessnacensis was assigned a minimum and maximum depth for viable growth based on the survey data (30 – 110 cm) and an optimum range of growth where it was recorded performing best (50 – 80 cm). Similarly, *P. x griffithii* is assigned a viable range (1.7 – 3.9 m) and optimum range (2.3 – 3.2 m). Both species were recorded outside of their assigned depth range, but only as occasional single plants (see Figures 3.3 & 3.9 respectively). The series of maps below (Figures 3.3 – 3.14) and Tables 3.4 and 3.5 show the range of potential area of depth habitat for each of the two *Potamogeton* hybrids for successive water level reduction scenarios.

Table 3.4: Habitat availability for *P. x gessnacensis* in Llyn Anafon under different water level scenarios.

Water level below TWL (m)	Area of viable range (ha)	Area of optimum range (ha)	Area of viable range (%)	Area of optimum range (%)	Map figure (below)
0.0	1.46	0.71	26.19*	12.67	Figure 3.3
0.5	1.18	0.35	21.20	6.33	Figure 3.4
1.0	1.04	0.32	18.69	5.75	Figure 3.5
1.5	1.47	0.51	26.37	9.07	Figure 3.6
2.0	1.30	0.41	23.27	7.32	Figure 3.7
2.5	0.52	0.21	9.39	3.77	
3.0	0.19	0.06	3.41	1.12	Figure 3.8

* Nb. Actual observed range is less than 2.5% of the lake area

Table 3.5: Habitat availability for *P. x griffithii* in Llyn Anafon under different water level scenarios.

Water level below TWL (m)	Area of viable range (ha)	Area of optimum range (ha)	Area of viable range (%)	Area of optimum range (%)	Map figure (below)
0.0	2.40	1.38	43.17*	24.84	Figure 3.9
0.5	1.83	0.54	32.93	9.75	Figure 3.10
1.0	0.88	0.21	15.77	3.68	Figure 3.11
1.5	0.47	0.15	8.45	2.74	Figure 3.12
2.0	0.34	0.16	6.06	2.83	Figure 3.13
2.5	0.30	0.13	5.30	2.29	
3.0	0.28	0.08	5.08	1.35	Figure 3.14

* Nb. Plants were observed growing at approximately 75% of the viable depth habitat

Figure 3.3: Potential depth habitat range for *Potamogeton x gessnacensis* at TWL showing current distribution of the species (July 2009)

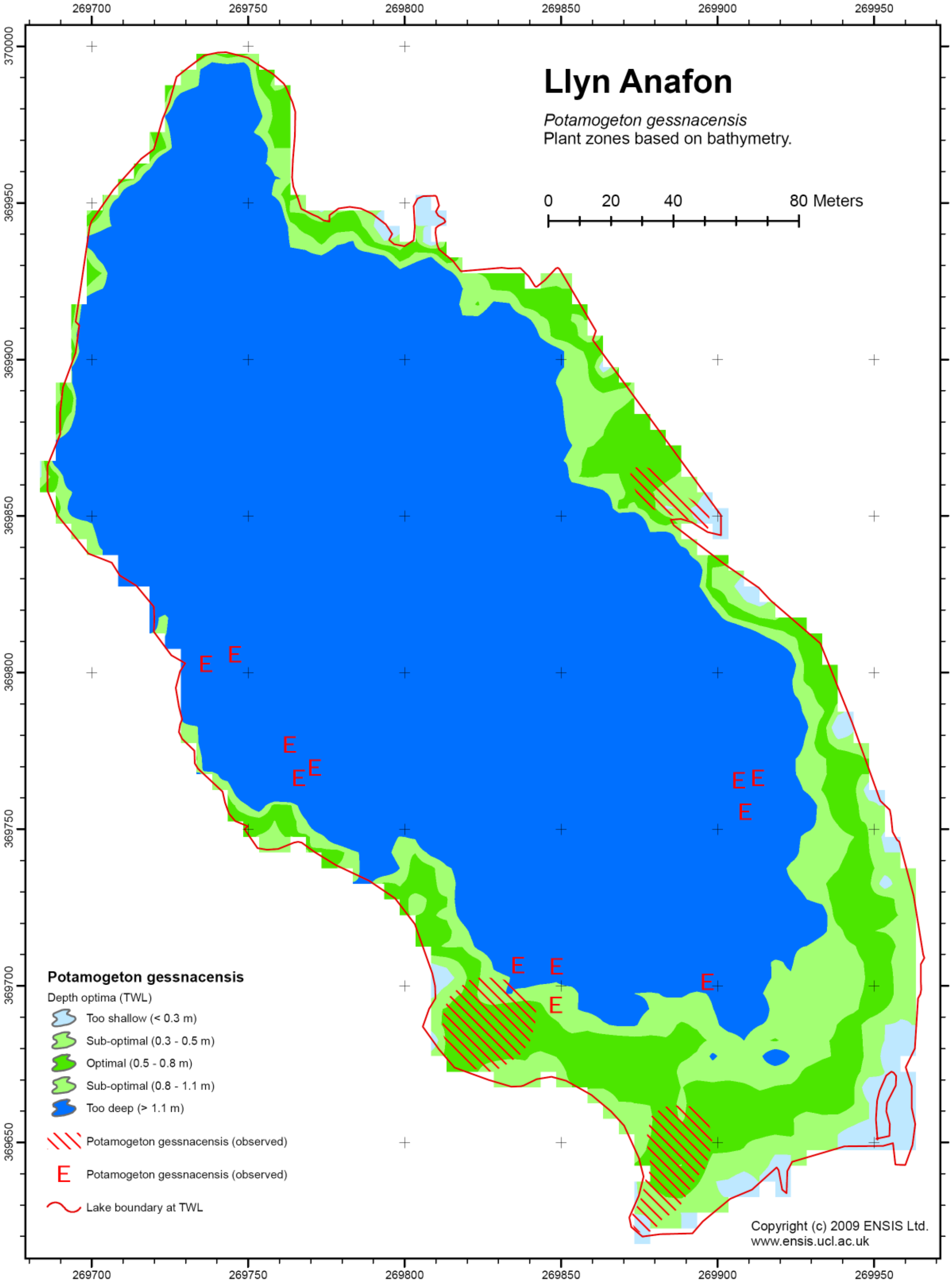


Figure 3.4: Potential depth habitat range for *P. x gessnacensis*: 0.5 m drawdown scenario

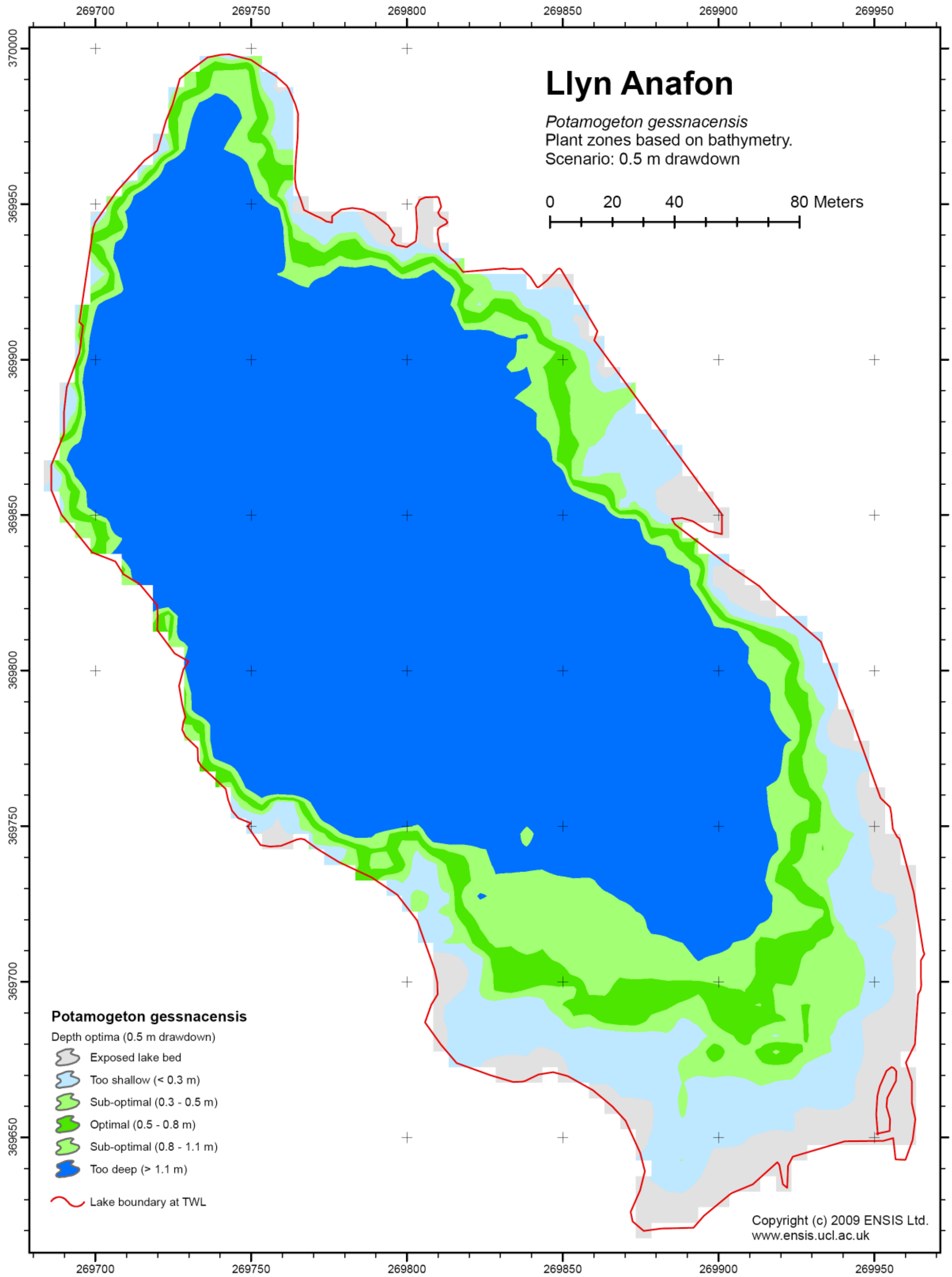


Figure 3.5: Potential depth habitat range for *P. x gessnacensis*: 1.0 m drawdown scenario

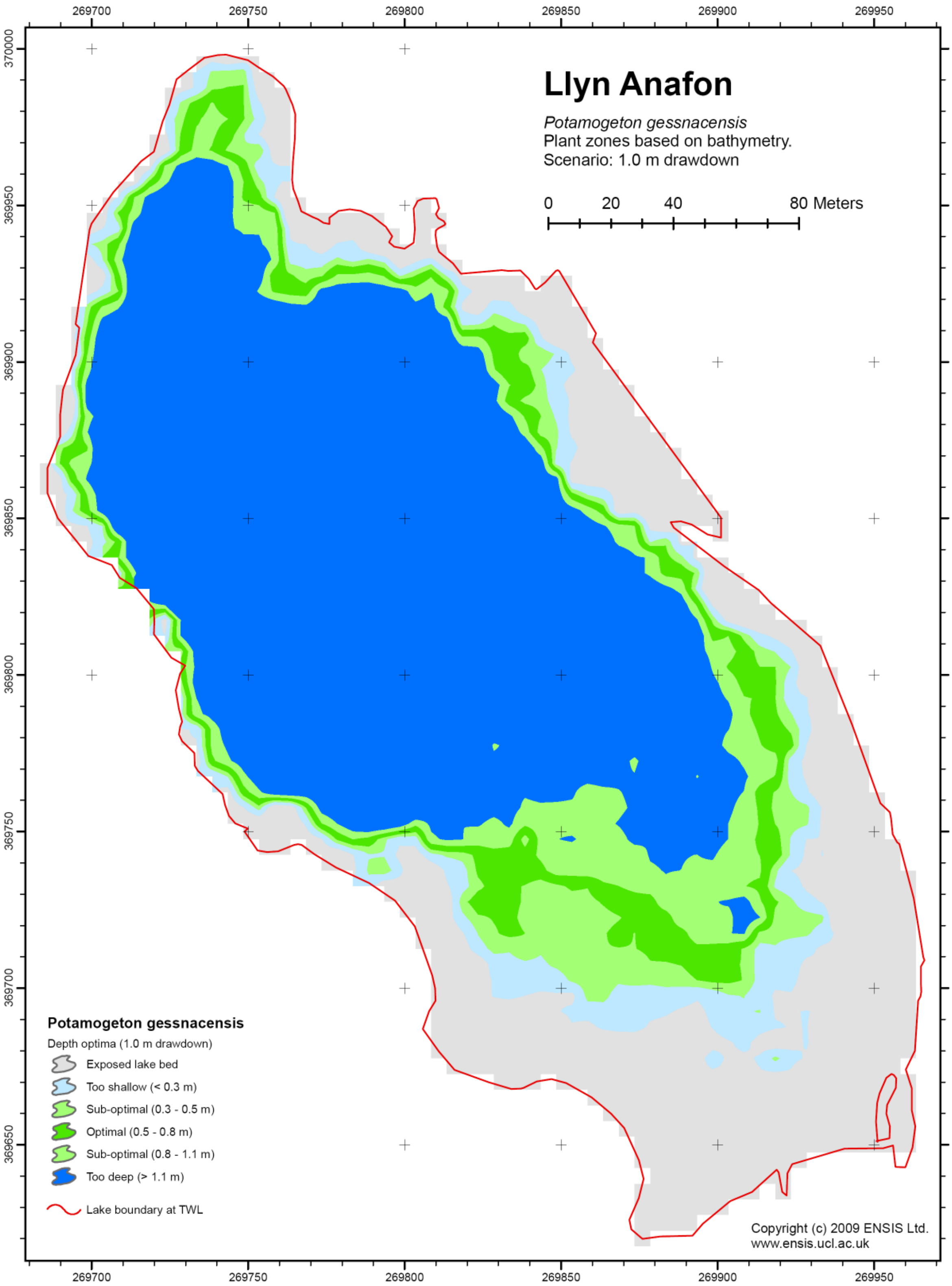


Figure 3.6: Potential depth habitat range for *P. x gessnacensis*: 1.5 m drawdown scenario

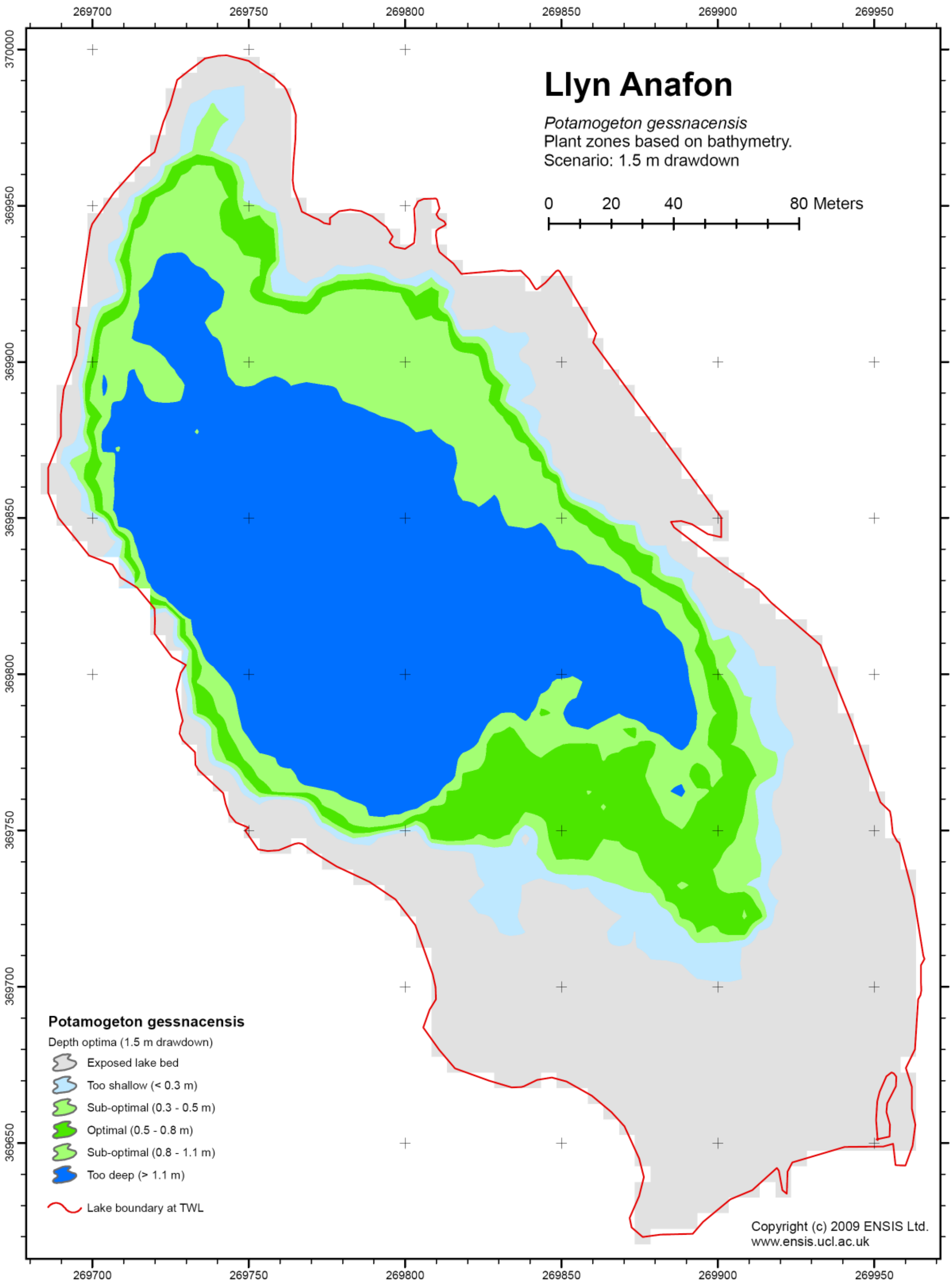


Figure 3.7: Potential depth habitat range for *P. x gessnacensis*: 2.0 m drawdown scenario

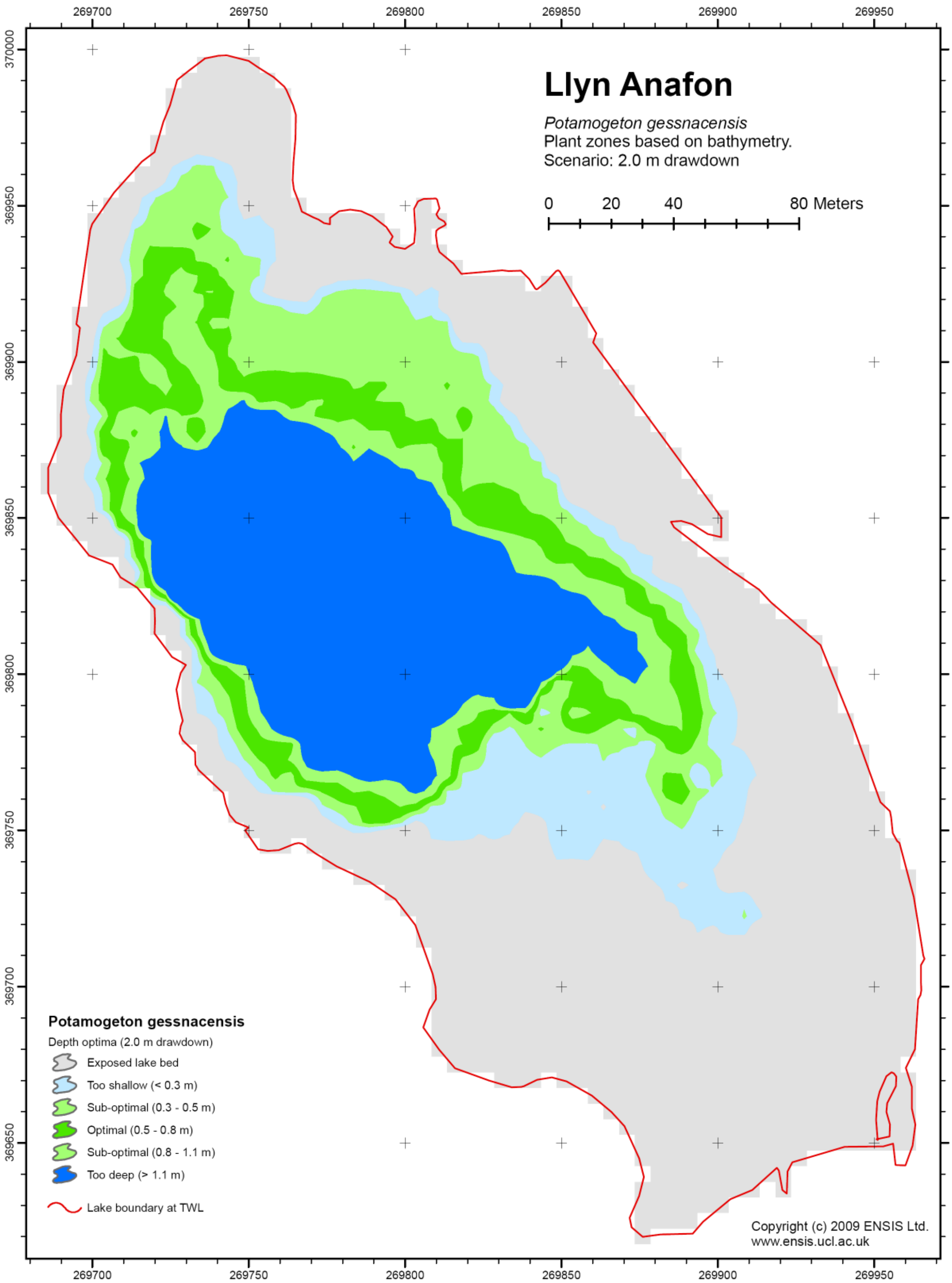


Figure 3.8: Potential depth habitat range for *P. x gessnacensis*: 3.0 m drawdown scenario

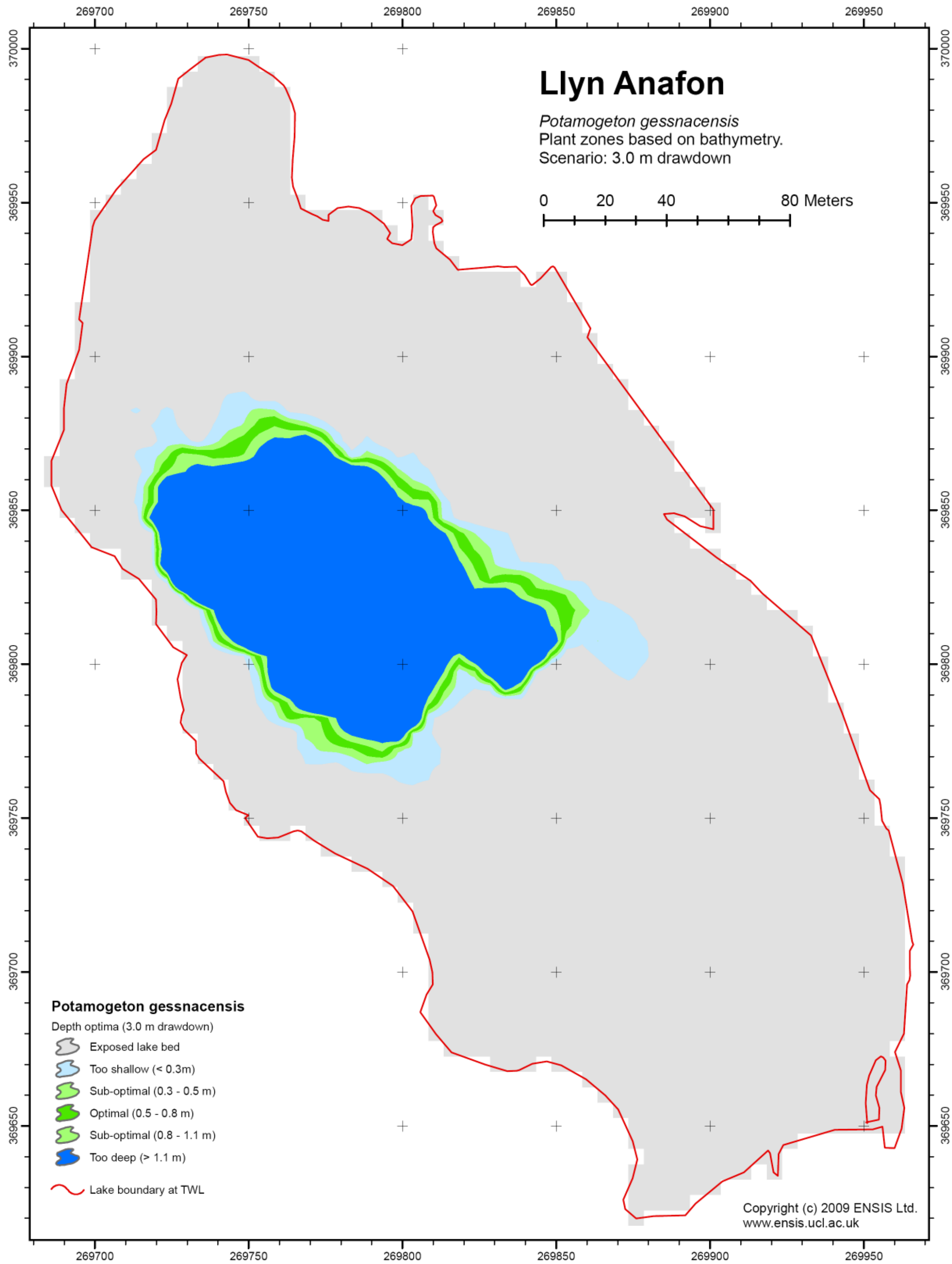


Figure 3.9: Potential depth habitat range for *Potamogeton x griffithii* at TWL showing current distribution of the species (July 2009)

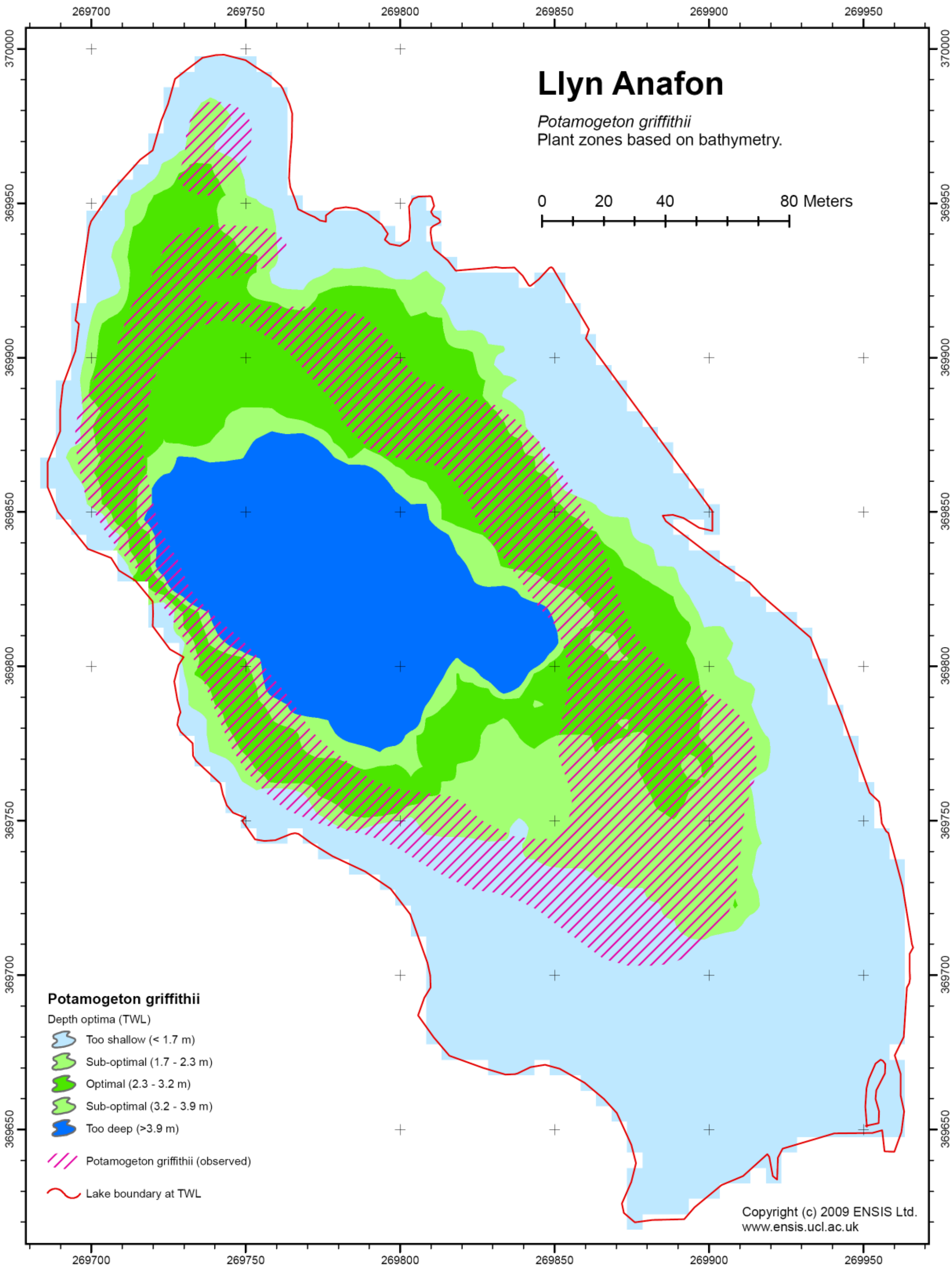


Figure 3.10: Potential depth habitat range for *P. x griffithii*: 0.5 m drawdown scenario

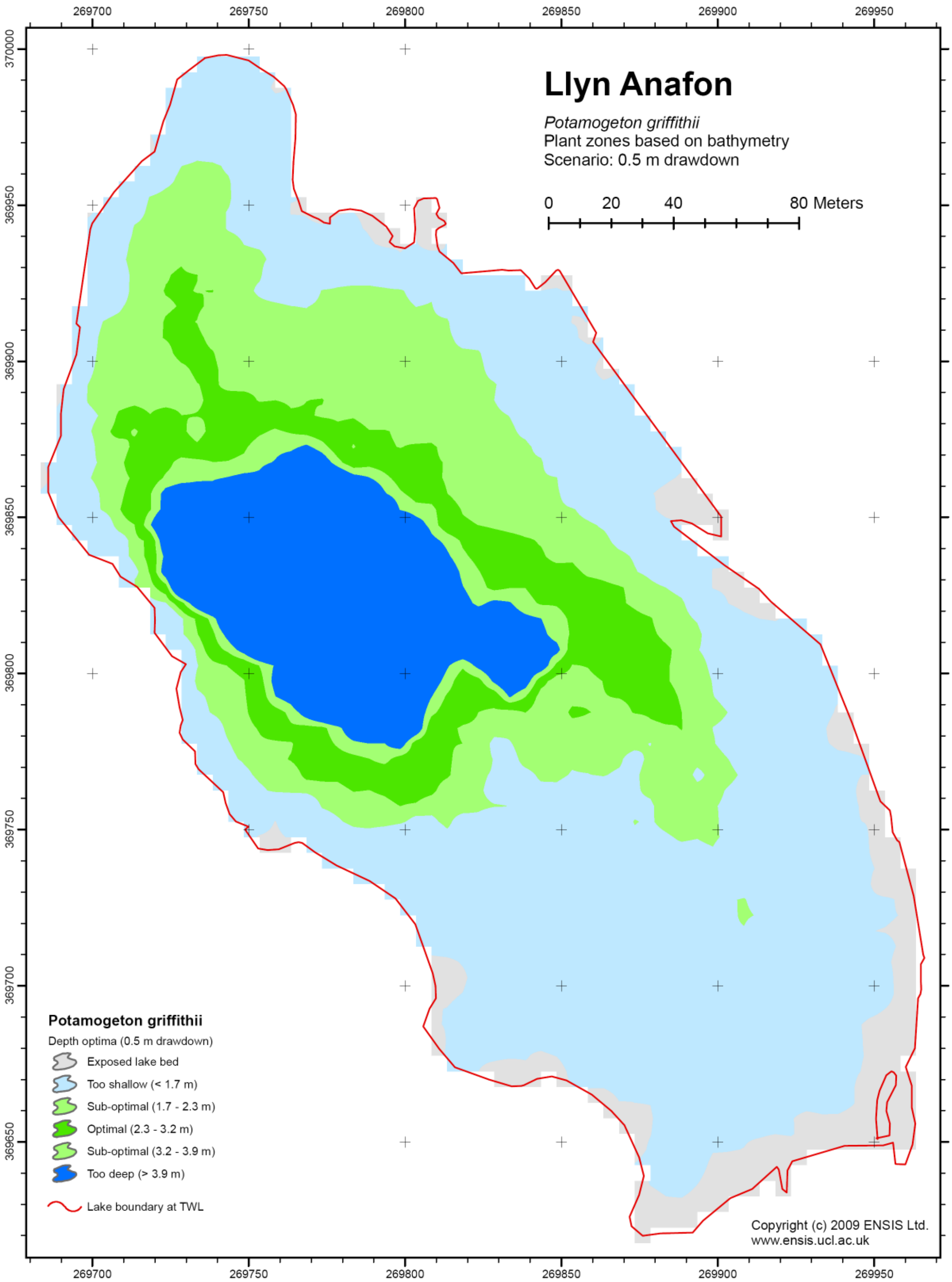


Figure 3.11: Potential depth habitat range for *P. x griffithii*: 1.0 m drawdown scenario

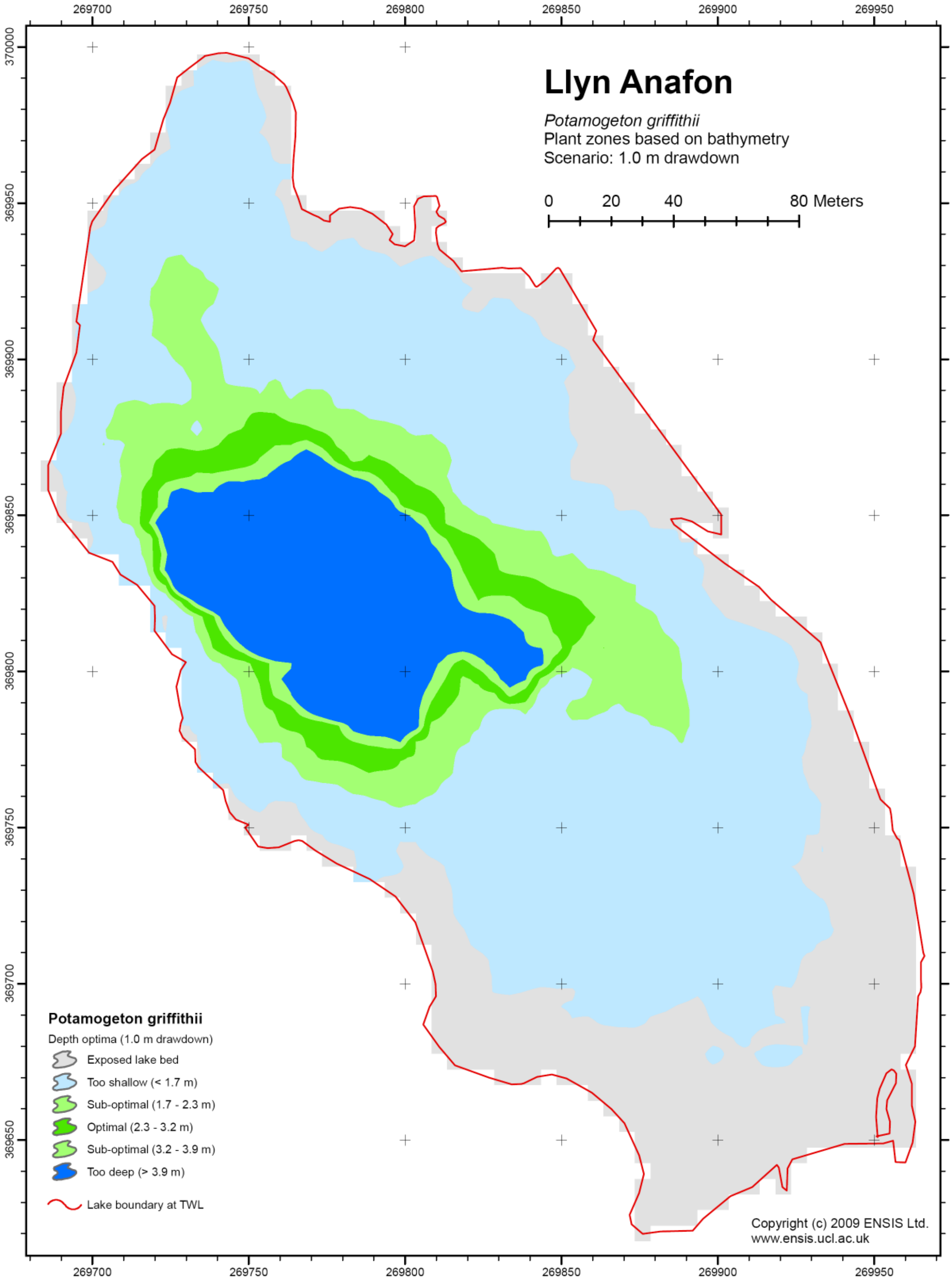


Figure 3.12: Potential depth habitat range for *P. x griffithii*: 1.5 m drawdown scenario

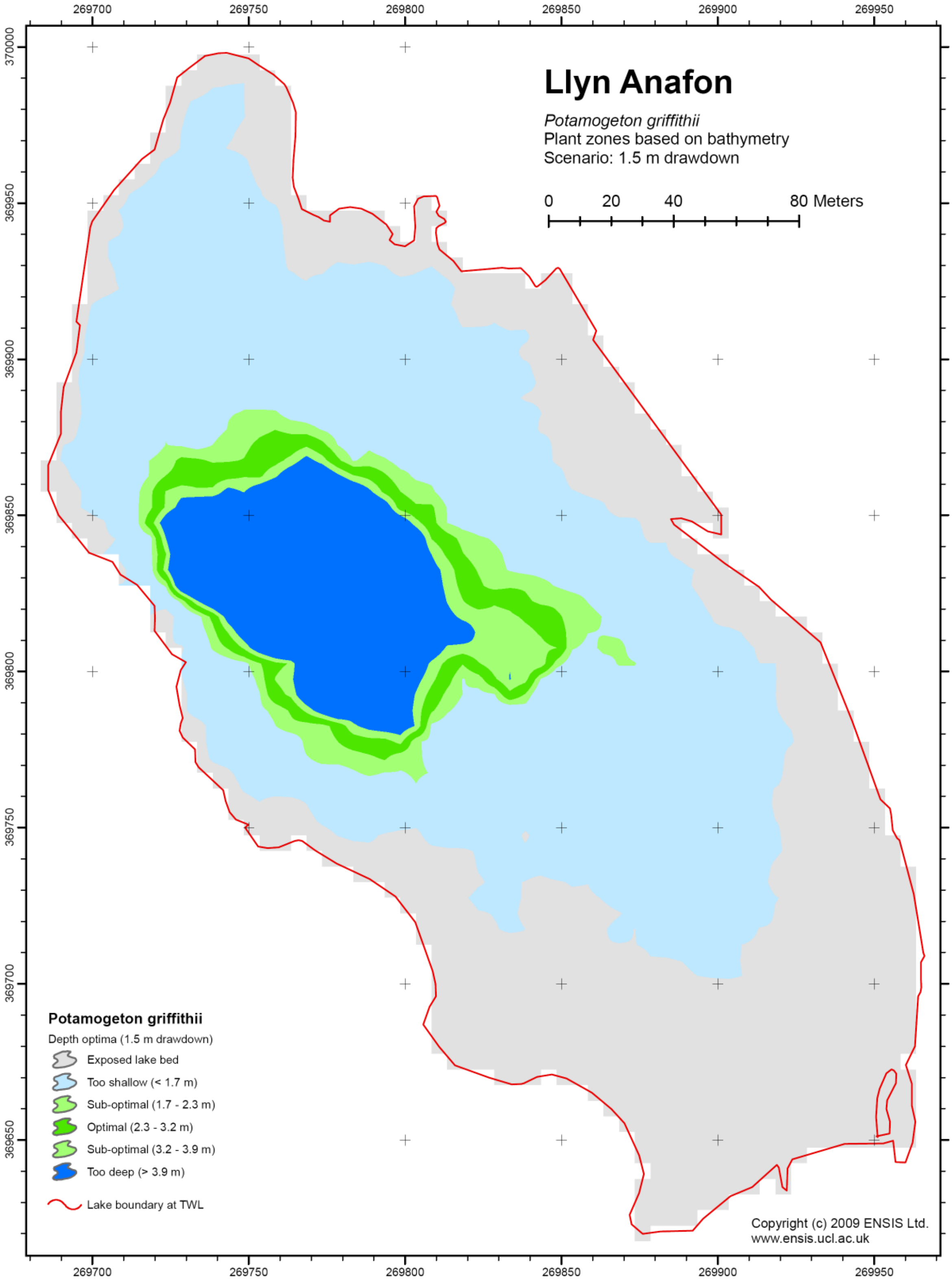


Figure 3.13: Potential depth habitat range for *P. x griffithii*: 2.0 m drawdown scenario

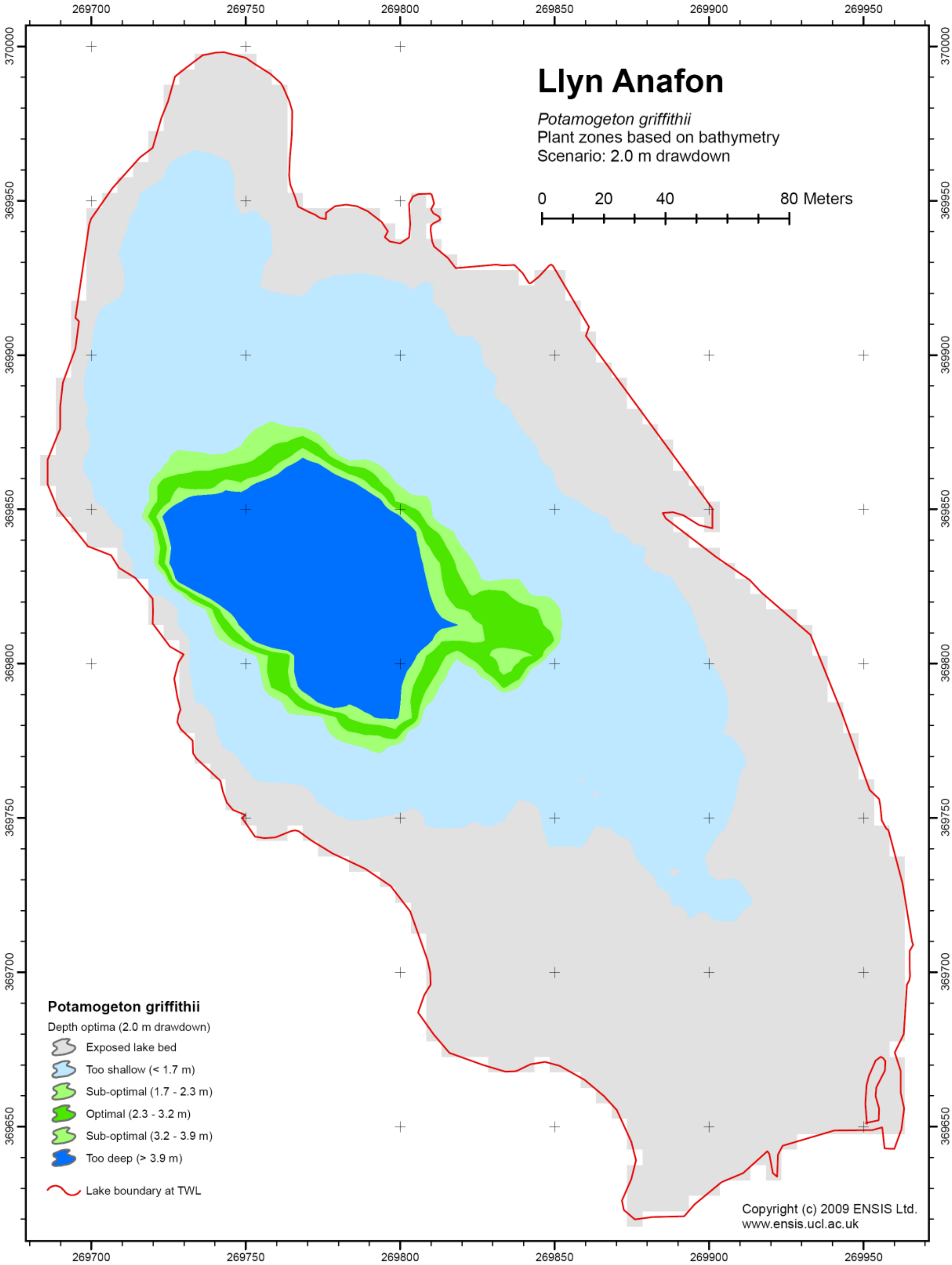
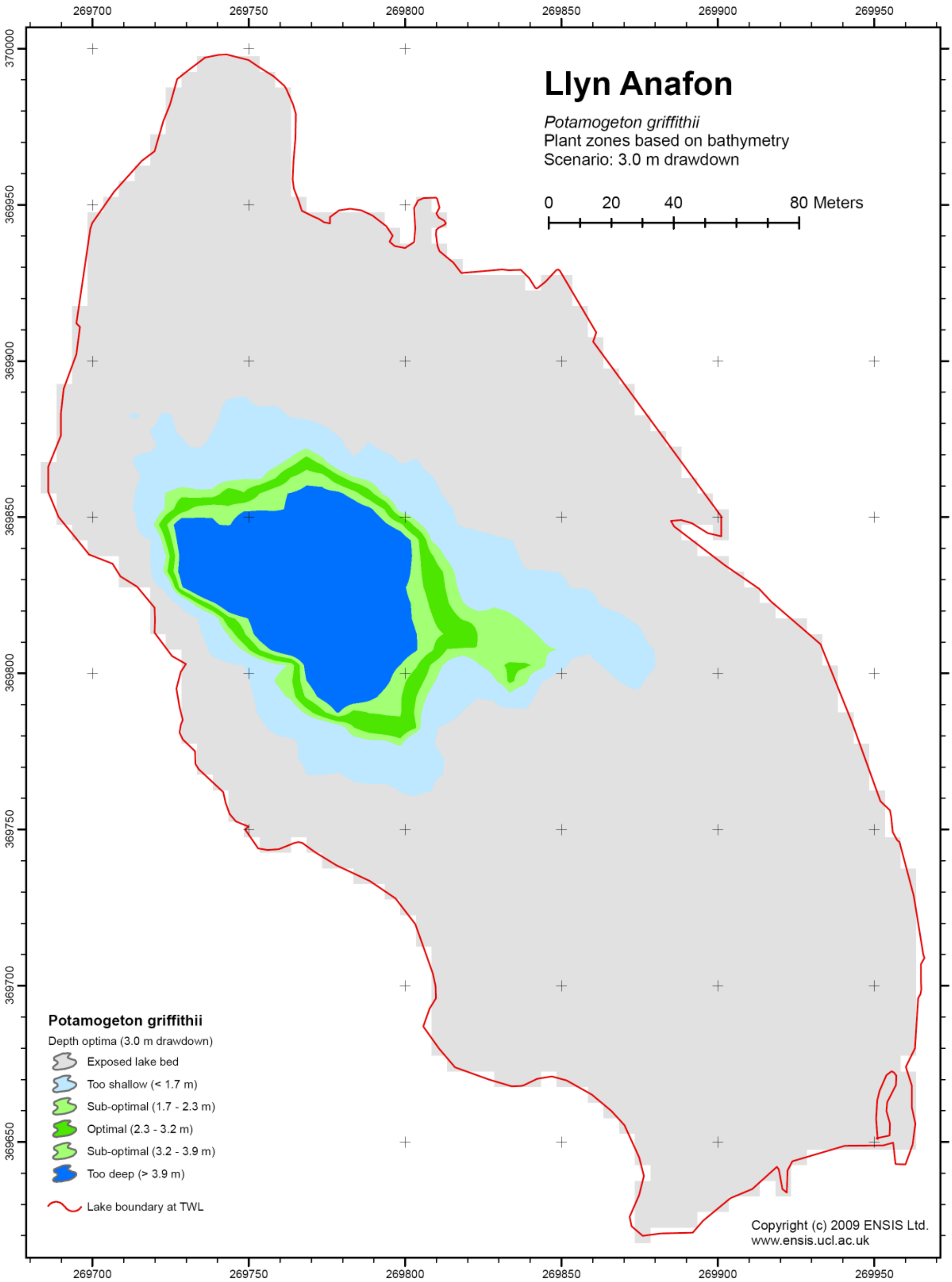


Figure 3.14: Potential depth habitat range for *P. x griffithii*: 3.0 m drawdown scenario



4 Discussion

4.1 Site condition

The current status of Llyn Anafon is considered to be “favourable” with respect to both its exceptionally good water quality and its species rich, characteristic and distinctive aquatic flora. The long established occurrence of two exceptionally rare *Potamogeton* hybrids makes the site particularly important within the SAC, and thus any potential damage to these species or their habitat requires close scrutiny. In addition the site holds the only SSSI record for *Potamogeton alpinus* in Wales, has a potentially very rare *Ranunculus* (subgenus *Batrachium*) hybrid and has the highest recorded occurrence of *Elatine hexandra* in the UK. These additional features of local distinctiveness greatly enhance the value of the site for conservation within the Habitats Directive site type, i.e. “Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*” (EU Habitat Code: H3010).

Recent changes to the hydrological regime brought about by efforts to reduce the stress on the dam have seriously compromised the favourable status of the Llyn Anafon. Without regular on-site control of the scour valve by Welsh Water, water levels have fluctuated between TWL and approximately 1.5 m below TWL since 2005 (CCW 2005). In addition to the impacts on the lake habitat brought about by reducing the depth and surface area of the lake, this has also placed the site at significant risk of sediment re-suspension and disrupted the normal shoreline: these are considered as serious negative impacts for this habitat feature and place the site at risk of losing favourable status under standard guidelines (JNCC 2005). Furthermore, the longer term impacts of this excessive fluctuation of water levels are considered to place some of the distinctive elements of the lake flora at a significant risk of extinction.

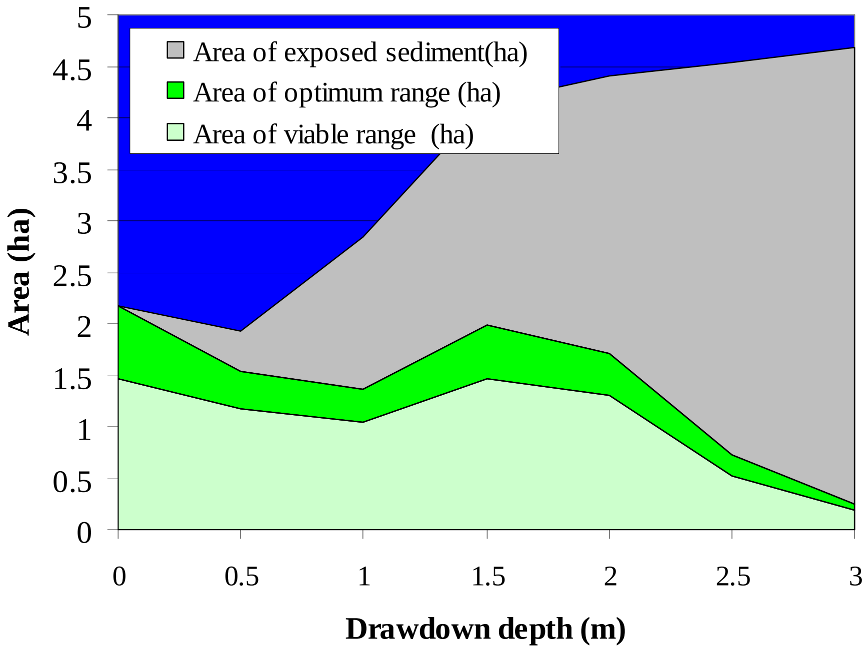
The immediate recommendation is that water levels are stabilised and ideally at TWL. If TWL is considered as being unsafe, it is advised that efforts are made to maintain a water level no more than 0.5 m below TWL, rather than the 1.0 m advised in the Reservoirs Act inspection report (Mott MacDonald 2006). As shown in Figures 3.4 & 3.10, a 0.5 m decrease in TWL will allow the shallow water species to remain submerged, at least in part. A 1.0 m decrease will result in the loss of the majority of the current habitat for at least two of the distinctive elements of the flora (*P. x gessnacensis* and *Ranunculus* sp).

4.2 Long-term habitat change

It is understood that a number of different engineering options have been considered for the Anafon dam, ranging from a full repair of the dam to maintain TWL, through to removal of the dam to reinstate the original outflow and hence level of the lake. Full repair is likely to present impractical logistic issues due to the remote location of the site and need for heavy plant to undertake such a major project. To reinstate the original outflow (c. 1.5 m below TWL) would result in a large expanse of lake sediments being exposed (2.17 ha) and significantly alter the habitat that has developed over the course of the last 80 years since the dam was constructed (Figures 3.6 & 3.12). An immediate drop of 1.5 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.

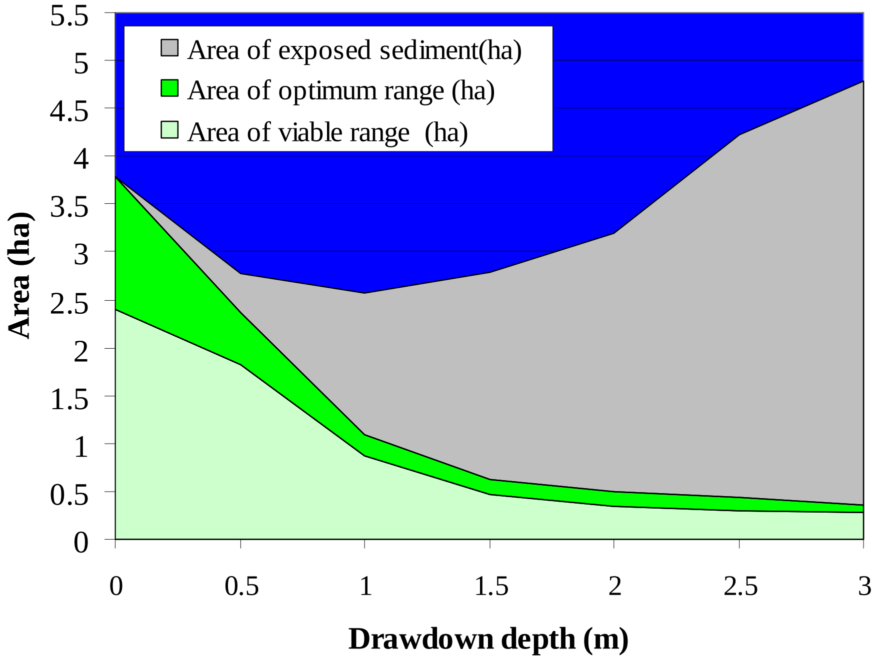
In terms of the *Potamogeton* hybrids, it is clear from the maps above and Figure 4.1 that the habitat availability for *P. x gessnacensis* does not vary greatly unless the drawdown exceeds 2.0 m. Interestingly, under the 1.5 m drawdown scenario, which equates to the original pre-dam lake level, the viable range is equal to the current TWL range, although the optimum range is slightly reduced. At 0.5 and 1.0 m drawdown there is a reduction in available depth habitat, but the greatest area remains in the south-western region of the lake where the prevailing fetch is lowest and hence conditions should be most favourable. Below 2.0 m the availability of suitable depth habitat is significantly reduced. It should be noted that beyond a 0.5 m drawdown the area of exposed sediments increases dramatically. A water level drop from 0.5 m to 1.0 m will leave almost a four-fold increase in the area of exposed sediments in the lake.

Figure 4.1: *P. x gessnacensis*: potential habitat availability under different depth scenarios



The situation is less encouraging for the deeper water species, *P. x griffithii*. There is a significant decrease in the viable habitat, even with only a 0.5 m drop in water level (Figure 4.2). The 1.0 m drawdown scenario results in a loss of nearly two thirds of the viable depth habitat and even greater loss of the optimum depth range for this species. Currently at TWL almost 25% of the lake area is within the optimum depth range for *P. x griffithii*, this falls to 9.8% of the lake area if the water level is lowered by 0.5 m and to only 3.7% if lowered by 1.0 m. *P. x griffithii* was first recorded in Llyn Anafon prior to the dam construction however, when the available habitat was even less (Figure 3.12), suggesting the raising of the water level may even have been responsible for the recent conservation of this rare hybrid at the site.

Figure 4.2: ***P. x griffithii*****: potential habitat availability under different depth scenarios**



In addition to the rare *Potamogeton* hybrids, other species at immediate risk from any loss of depth habitat are the *Ranunculus* recorded only from shallow water (< 1.0 m) near the south-eastern shore and *Elatine hexandra*, which was only recorded from a small area of shallow water (1.0 m) near the dam. The status of *Lobelia dortmanna* is also uncertain at the site and any change in habitat may therefore place this characteristic species at risk at the site.

Rapid changes in water depth are generally short lived in natural lakes and therefore many plant species have developed mechanisms to overcome short periods of increased inundation or desiccation. Indeed, some species, for example *Littorella uniflora*, can take advantage of periods of lower water in summer to flower and set seed. The sort of rapid and permanent shift in depth habitat that a major lowering of the dam would achieve would be beyond natural variability and it is doubtful that some species would cope. This is particularly poignant for the rare hybrids (including the *Ranunculus*) which do not set seed and thus rely entirely on vegetative propagation from viable material. The prolonged desiccation of an entire population with no seed bank could result in a rapid extinction.

4.3 Sediment exposure

Recent efforts to maintain Llyn Anafon below TWL have resulted in problems caused by the periodic exposure of large areas of soft sediments. This is most acute around the southern end of the lake where TWL depths are relatively low (Figure 3.2) and sediment depths generally between 30-80 cm. The problem is compounded by some of the shallow areas, particularly around the south-west side, being comprised of waterlogged peat which offers little more resistance than the sediments overlaying it. While the immediate concerns have been for the safety of livestock (and potentially people) wandering on to the exposed sediments and becoming trapped, there are also ecological implications for the site of the long term exposure of sediments.

A 1.0 m drop in water level will expose over 25 % of the current TWL lake area, with much of this area consisting of fine lake sediments built up over the past 80 years, 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 affect the lake and its biota and for how long after exposure are impossible to predict, but periods of increased turbidity and possibly also increased water colour due to DOC release from exposed peat are considered likely. Any increase in turbidity and / or colour 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 onto 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 can most effectively be mitigated by lowering the water level in several stages rather than a single drop (see recommendations below).

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 as well as promoting growths of filamentous or planktonic algae, to the detriment of higher plants in the lake. Minimising the re-suspension of sediments is considered the only effective means of preventing these negative impacts. The effects of nutrient release can be minimised by slowing down the erosion of sediments. A gradual drop in water level will facilitate slower release and the relatively high turnover of Llyn Anafon should increase the rate of flushing of nutrients from the site.

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.

4.4 Engineering options

The importance of the habitat and species therein at Llyn Anafon requires that every effort is made to ensure its full protection. The current status of the site with respect to its exceptional aquatic flora and high water quality leads to the conclusion that the best course of action is to prevent any further disruption at the site and maintain the water at current TWL. It is recognised however that this situation may not be tenable within the guidelines of the Reservoirs Act and in light of the problems associated with the dam leakage and safety (Mott MacDonald 2006). If remedial work is therefore to be undertaken on the dam, this needs to be conducted in a manner most acceptable to the conservation concerns at the site and with the least possible disruption to the habitat.

Of the options proposed by Mott MacDonald the initial proposal to cut a 1.0 x 1.0 m slot in the spillway was not favoured by CCW and is not considered appropriate by the authors. While it would maintain water levels at approximately 80 cm below current TWL under normal flow conditions, the restricted outflow would result in a rapid increase in water level during higher flow periods and thus regular water level fluctuations of approximately 1.0 m. Although many aquatic plants can cope with water level changes, such regular periods of variation are not considered favourable, particularly for the natural development of marginal plants and the re-development of a natural shoreline.

Four engineering proposals have been put forward for the maintaining the water level at current TWL:

- injecting grout into the dam wall
- laying a membrane on to the upstream side of the dam wall
- the insertion of sheet piling into the dam core
- the installation of a clay core to the dam.

The injection of grouting has been attempted in the past and has failed, any further attempts are considered to be not only technically very complicated, but also to have potential environmental impacts as well as being expensive and requiring a long period of drawdown of up to 3.0 m. Similarly, the installation of an upstream membrane on the dam wall would also require long periods of drawdown and the expense and technical complexity of the work makes it a very unattractive solution. Sheet piling was identified as a potentially more cost effective option, but initial ground investigations have identified poor suitability in the dam core and thus its success cannot be guaranteed. The installation of a clay core in the dam is therefore a more feasible option, but this requires a significant increase in engineering effort and cost and is likely to require at least two seasons work to complete, both requiring significant periods of drawdown and increased environmental impact. In light of these difficulties it is the opinion of the engineers that a satisfactory repair to the dam would not be achievable without disproportionate expense and potential environmental damage.

Removal of the entire mid section of the dam to reinstate the original outflow has also been proposed. This would lower the water level by approximately 1.5 m and reduce the current TWL surface area of the lake by 39 %. In addition to the extra impacts caused by sediment exposure, this option is not considered favourable due to the significant reduction in the viable depth habitat that would be left for *Potamogeton x griffithii*; a 5 fold decrease. While this is likely to have been the original habitat occupied by *P. x griffithii,* the extreme rarity of the plant warrants the highest practical protection of habitat achievable and therefore a lowering of less than 1.5 m would be preferable. The building of the dam at Llyn Anafon has altered the lake significantly over the past 80 years and while the primary purpose of the dam was to supply water, the raised water level also benefited the aquatic flora at the site by creating a larger area of shallow water habitat. While it can be argued that the removal of the dam would return the site to its natural state, the loss of habitat and associated changes within the lake basin would compromise the favourable condition of the site and therefore complete removal is not considered an acceptable option.

The most favourable intermediate engineering solution between repairing the dam and removal is to lower the water level by cutting a 1.0 m deep slot into the spillway of approximately the same width as the original outflow (8.0 m). The current spillway is 24 m wide. This option will lower water levels by approximately 0.8 - 1.0 m under normal flow conditions, but allow a much greater volume of water to escape during periods of high flow and therefore avoid the regular fluxes in water level predicted under the narrow slot option. This option would however result in a 26.6 % loss in lake surface area and place the current population of *P. x gessnacensis* outside its viable depth range. Furthermore, a significant proportion of suitable depth habitat would be lost for *P. x griffithii*, with only about one third the area currently available to this species compared to current TWL.

If the water level is to be permanently lowered, this would be most favourably achieved slowly, over a number of years in order to facilitate the natural redistribution of the flora within the lake. If done in relatively small increments it should avoid the need for any species translocation within the lake and would also allow for the period of transition to be monitored and hence allow for intervention if negative impacts were observed. A slow drawdown would also help to reduce the negative impacts of sediment re-suspension by limiting the amount of sediment released on each successive lowering, rather than exposing all the sediment to erosion at once. The dilution effects brought about by high rainfall and relatively high lake turnover should help to buffer any negative effects of increased nutrients and DOC within the lake.

All of the proposed engineering works will require a period of significant water lowering (approximately 2.0 m) in order to undertake the work. This will affect not only all three beds of *P. x gessnacensis*, but also a number of the characteristic and distinctive species found at the site. In order to minimise the impact on the aquatic plant communities, it is recommended that that any engineering work is conducted towards the end of the growing season, but before the onset of hard frosts which would further damage exposed plants. Ideally we would recommend the work is conducted between mid-September and mid-November, with the time taken for works being kept to an absolute minimum.

5 Recommendations

It is the opinion of the authors that Llyn Anafon and the habitats and species therein are best protected by maintaining the dam and water level at its current TWL height and ensuring the existing habitats are preserved into the foreseeable future. It is recognised however that the repair of the dam would be logistically and financially demanding and would also result in considerable environmental disturbance and potential damage to habitats in and around the lake. Because of this, the following recommendations are based on the partial lowering option whereby a 1.0 m deep x 8.0 m wide channel is to be cut into the spillway to lower the water level by a maximum of 1.0 m. Once completed, a temporary weir should be installed to allow a three stage lowering of the water with the first stage being set at 50 cm below current TWL (to coincide with the proposed temporary lowering), the second stage at 75 cm below TWL and the final stage involving complete removal of the weir leaving water levels permanently at 1.0 m below TWL. It is recommended that each incremental stage is left for 2 years to allow natural movements of species within the lake and to minimise the impacts of sediment re-suspension.

It is stressed here that any engineering works carried out on the site (and indeed the current drawdown policy) immediately compromises the integrity of the site condition under the Habitats Directive guidelines (JNCC 2005) and therefore places it “at risk”. Features of the site such as its extent, its natural shoreline, its hydrology and its natural sedimentation will be directly impacted and it is therefore considered imperative that these features are monitored along with water quality (nutrients, DOC and sediment loads) and the characteristic and distinctive species. This monitoring should be implemented prior to any works being conducted and continued throughout the transitional period and at set intervals thereafter in line with the routine monitoring within the Eryri SAC. Quarterly monitoring of water quality and physical features and annual monitoring of the biology should be conducted as a minimum requirement during the 5 year transitional phase. If during the monitoring a decline is observed in the site condition it is recommended that the water level lowering is reviewed and if necessary further steps are taken to mitigate against further decline.

5.1 Summary of recommendations

Prior to engineering works

- Maintain current water level at TWL, or no lower than 50 cm below TWL
- Ensure regular checks (minimum of weekly) are made on water levels.
- Set up a structured monitoring programme for water quality and habitat features and species within and around the lake.
- Survey Afon Anafon (invertebrates and bryophytes) to gain baseline biological data.

During engineering works

- Work should be carried out between mid September and mid November.
- Drawdown should be no lower than 2.0 m (less if possible).
- The time take to complete works should be kept to a minimum.
- Temporary fencing is advised around the lake to prevent livestock and people straying into areas of exposed sediments.

- Undertake additional species and habitat assessments to assess any direct impacts of works.
- Install a three stage temporary weir allowing a lowering of 50 cm from current TWL

Following engineering works

- Monitor water quality and habitats in the lake at quarterly intervals
- Monitor the characteristic and distinctive species at the site annually
- Re-survey the biota in Afon Anafon to assess impacts. If negative impacts are observed, implement an annual monitoring programme to assess if recovering / declining.
- If after two years the site remains favourable with respect to water quality and biology remove the second stage of the weir to achieve a 75 cm drop in water level
- If after a further two years the site remains favourable remove the third stage of the weir to achieve a 100 cm drop in water level
- Continue monitoring water quality, habitats and featured species for a further year.

Plate 2. Bathymetric survey

6 References

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

CCW (T. Hatton-Ellis) 2005. *Llyn Anafon Site Visit: 8th June 2005*. Unpublished site visit notes, CCW, Bangor.

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 L* 206 , pp7 - 50

Goldsmith, *et al.* in prep. *Lake Macrophyte and Habitat Surveys for Water Framework Directive Status Classification and Site Condition Assessment 2007-2009*. Environment Agency Contract 20457.

Joint Nature Conservation Committee (JNCC) (2005a). *Common Standards Monitoring Guidance for Standing Waters Version March 2005*. JNCC Report, JNCC, Peterborough. (Amended S. Watt 2006. *Changes to Characteristic Species in the Standing Waters CSM Guidance*)

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.*

Poff, N. L. & Hart, D.D. 2002. How dams vary and why it matters for the emerging science of dam removal. *BioScience,* **52:**659-68

Preston, C. D, Pearman, D. A. & Dines, T. A. 2002. *New Atlas of the British & Irish Flora: An Atlas of the Vascular Plants of Britain, Ireland, the Isle of Man and the Channel Islands*. Oxford University Press, Oxford. 910pp.

Preston, C. D., Bailey, J. P. & Hollingsworth, P. M. 1998. A reassessment of the hybrid *Potamogeton x gessnacensis* G. Fisch. (*P. natans x P. polygonifolius, Potamogetonaceae*) in Britain. *Watsonia,* **22**: 61-68.

Preston, C. D. & Croft, J. M. 1997. *Aquatic Plants in Britain and Ireland*. Harley Books, Colchester. 365pp.

Shuman, J. R. 1995. Environmental considerations for assessing dam removal alternatives for river restoration. *Regulated Rivers: Research & Management.* **11:**249-61.

Stace, C. A. 1997 *New Flora of the British Isles*. 2nd Ed. Cambridge University Press, Cambridge, UK.

Plate 3. Macrophyte survey

Plate 4. Hybrid (?) Water-crowsfoot – *Ranunculus* sp. (*Batrachium*)

Plate 5. Llyn Anafon catchment

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