Lake Water Quality Report: Lough Arrow

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(Roden & Murphy. 2013).

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1.0 Introduction

This report summarises data obtained from a monitoring programme of surface water quality in Lough Arrow over a three year period. This environmental monitoring was carried out by IT Sligo personnel for the purposes of the Interreg VA programmes Collaborative Actions for the Natura Network (CANN) project. This project launched in June 2018 and its purpose is to meet the obligations of the "Recovery of protected habitats & priority species" under the "Environment" priority of the Interreg VA programme, primarily, improving the conservation condition of selected protected habitats under the Natura network. L. Arrow is a site of interest under the project as it is a designated Special Area of Conservation under the European Union's Habitats Directive (92/43/EEC). The Lough contains a representative example of the Annex I habitat: "Hard oligo-mesotrophic waters with benthic vegetation of Chara *spp*. (3140)" and water quality parameters inform the condition assessment of the lakes feature of interest.

1.1 Site description and location

Lough Arrow is a limestone lake situated 24 kilometres south-east of Sligo town, County Sligo with coordinates of 54º03'36.7" North and 8º19'39.1" West. The lake occurs on the borders and within the counties of Sligo and Roscommon.

The lake is 1,458 hectares in size with an average depth of 9 metres (maximum 33 metres) (National Parks and Wildlife Service. 2015). In contrast to the lakes considerable size, it, has a small catchment (6,255 hectares) and it is primarily replenished by springs located on the lakebed (Inland Fisheries Ireland. 2015). Lough Arrow is considered to be unique in comparison to other Irish lakes as a result of this hydrological characteristic (National Parks and Wildlife Service. 2013). An overview of the lake is illustrated in Figure 1.

Figure 1. Lough Arrow location and overview.

2.0 Methodology

2.1 Sampling strategy

The sampling programme commenced in July 2018 and was completed in October 2020. Data was obtained from six surface water sites which were sampled monthly from July to October in 2018 and May to October in both 2019 and 2020. Sampling by IT Sligo was completed to compliment routine Water Framework Directive (2000/60/EC) sampling carried out by the Environmental Protection Agency (EPA) and sample collection by IT Sligo on a particular date was dependent on statutory monitoring (see Table 2). Overall, six sites were monitored on L. Arrow, five of which were EPA routine sites and one site solely by IT Sligo personnel which was of interest to the project team due to its close proximity to an urbanised area. The location and coordinates of these sites are given in Figure 2 and Table 1.

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Table 1. L. Arrow surface water quality sampling sites coordinates.

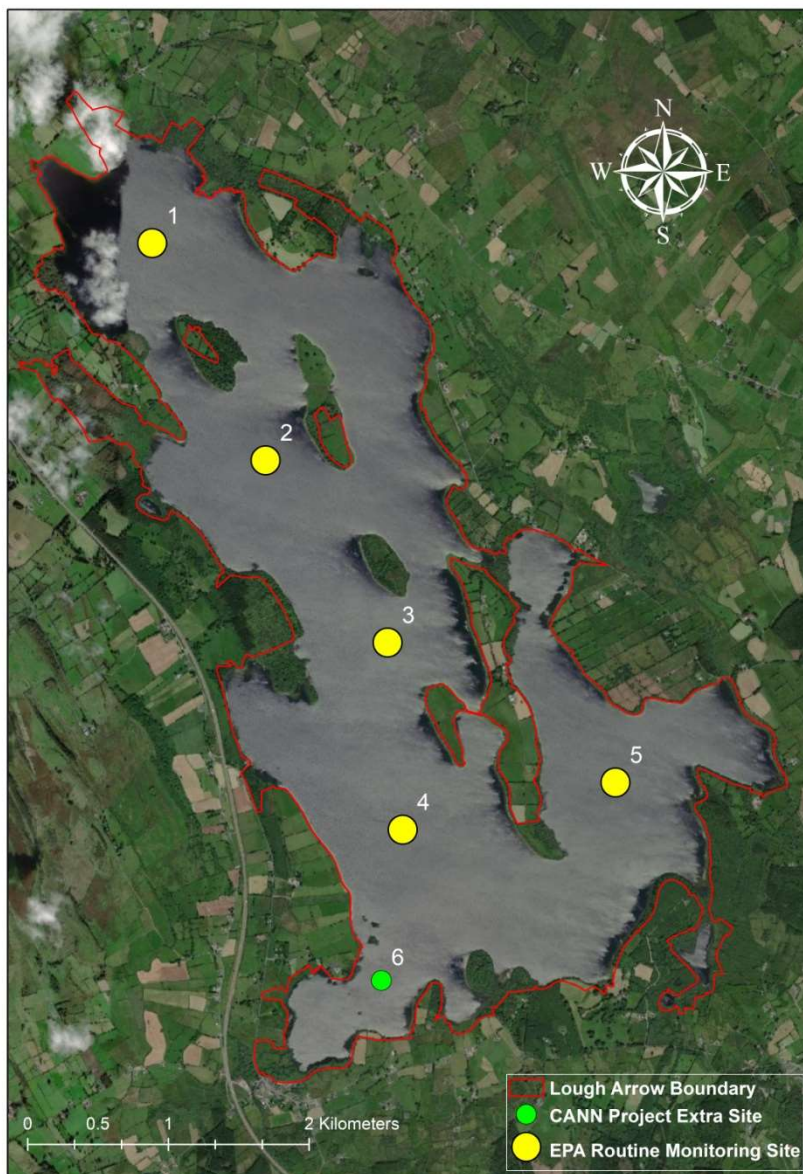| Site number	EPA Monitoring Site	Coordinates	
		Lat	Long
1	Yes	54.08105135	-8.34716014
2	Yes	54.06721545	-8.334732
3	Yes	54.05560841	-8.32138724
4	Yes	54.04367332	-8.31964667
5	Yes	54.04674195	-8.29658774
6	No	54.034023	-8.3219026

Figure 2. Lough Arrow's EPA and CANN project team sampling sites.

Table 2. Sampling dates and corresponding sites sampled by IT Sligo and EPA personnel.

Sampling date	Site sampled					
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
18/07/2018	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel
28/8/18	EPA personnel	EPA personnel	EPA personnel	EPA personnel	EPA personnel	IT Sligo Personnel
20/9/19	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel
15/10/18	EPA personnel	EPA personnel	EPA personnel	EPA personnel	EPA personnel	IT Sligo Personnel
14/5/19	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel
19/6/19	EPA personnel	EPA personnel	EPA personnel	EPA personnel	EPA personnel	IT Sligo Personnel
8/7/19	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel
21/8/19	EPA personnel	EPA personnel	EPA personnel	EPA personnel	EPA personnel	IT Sligo Personnel
9/9/19	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel	IT Sligo Personnel
22/10/19	EPA personnel	EPA personnel	EPA personnel	EPA personnel	EPA personnel	IT Sligo Personnel
20/5/20	EPA personnel	EPA personnel	EPA personnel	EPA personnel	EPA personnel	IT Sligo Personnel
24/6/20	EPA personnel	EPA personnel	EPA personnel	EPA personnel	EPA personnel	IT Sligo Personnel
29/7/20	EPA personnel	EPA personnel	EPA personnel	EPA personnel	EPA personnel	IT Sligo Personnel
25/8/20	EPA personnel	EPA personnel	EPA personnel	EPA personnel	EPA personnel	IT Sligo Personnel
28/9/20	EPA personnel	EPA personnel	EPA personnel	EPA personnel	EPA personnel	IT Sligo Personnel
21/10/20	EPA personnel	EPA personnel	EPA personnel	EPA personnel	EPA personnel	IT Sligo Personnel

2.2 Field sampling

Sampling sites were located on each sampling occasion using a Garmin® GPS 12. At each sampling site a YSI pro professional plus multiquatro probe was utilised to obtain PH, oxygen, temperature and conductivity surface readings during both the 2018 and 2019 sampling seasons. EPA standard one litre sampling containers were used to collect a surface

water sample at each individual site on all sampling occasions throughout the three year monitoring programme.

2.3 Sample processing

Laboratory processing of samples collected by IT Sligo Personnel in 2019 and 2020 were analysed at the EPA laboratories in Castlebar, County Mayo where each sample collected was analysed using standard EPA protocols. Samples were transported directly from L. Arrow to the laboratory for further processing immediately after sampling had taken place. IT Sligo personnel carried laboratory processing for samples collected in 2018.

The Environmental Protection Agencies (2017) standard protocol EPA W23 Chlorophyll was utilised to determine chlorophyll concentration. It was individually extracted from stored filters by boiling it in 15mls of 94.6% concentration of methanol. The absorbance of each extracted sample was measured using a HACH DR 3900 spectrophotometer at 665 and 750nm wavelengths. The concentration was then determined from inputting the measured absorbances and sample volume into the standard equation utilised in the EPA standard protocols manual.

Nutrient concentrations in the environmental samples collected were determined utilising a HACH DR3900 spectrophotometer. 50 ml of stored water from each individual sample was defrosted and a number of HACH cuvette reagent kits designed for use with DR3900 spectrophotometer were utilised to determine concentrations of target nutrients. Nitrate NO_3-N was tested utilising HACH LCK339 cuvette reagent kit with a measurement range of 0.23 - 13.5 mg/L. Ammonium NH_4-N concentrations were determined utilising HACH LCK304 cuvette reagent kit with a measurement range of 0.015 - 2 mg/L. Phosphate PO_4-P determination was obtained through the utilisation of the HACH LCK349 cuvette kit with a

measurement range of 0.05 to 1.5 mg/L. All procedures for nutrient determination followed manufacturer's guidelines.

2.4 Data Treatment

IBM SPSS 26 software was utilised to carry out statistical analysis on the data collected over the three year period to determine significant yearly differences in the parameters recorded. Additionally, significant differences in parameters of interest between sites over the course of the monitoring programme were delineated.

Data was tested for homoscedasticity and normality to meet the assumptions of the tests applied. Kruskal Wallis and Moods Median tests were used dependant on individual parameters homoscedasticity to determine the significant differences across sampling seasons.

Post hoc Mann-Whitney pairwise multiple comparisons adjusted by Bonferroni correction were utilised to determine differences between each individual treatment pair, where a significant difference was observed. A value of $\alpha = 0.05$ was used to denote significance for all tests.

3.0 Results

Average yearly temperature did not differ significantly over the course of the three year sampling program (P=0.775) with yearly averages of 15.52 ˚C, 15.38 ˚C and 15.11 ˚C for 2018, 2019 and 2020 respectively. Temperature peaked at 19.2 ˚C which was recorded in both July 2018 and 2019. The minimum temperature observed was 10.9 ˚C which occurred in October 2020.

Average conductivity concentrations in the lake increased year on year from 2018-2020 (228.71, 247.18 and 271.13μS/cm). The yearly concentrations recorded were also observed to

be significantly different (P=0) with a significance occurring between concentrations recorded in 2018 and 2020 (P=0).

Oxygen concentration from 2018-2020 ranged from 6.03 to 11 mg/L with the lower value occurring in June 2019; similarly the lowest oxygen saturation occurred in the same time period (59%). The maximum concentration occurred on two occasions (August 2019 and October 2020). Oxygen concentration differed significantly on differing sampling years (P=0). Comparison of concentrations recorded between 2018-2019 showed no difference (P=.876) while both 2018-2020 (P=0.001) and 2019-2020 (0.009) had significant differences.

Lough Arrow's chlorophyll – a concentrations ranged from 0.5 - 6.19 MG/M3 over the course of the three year sampling programme. 2018 had the highest yearly average concentration observed at 3.69 MG/M3. Statistical analysis also determined this year differed significantly from both 2019 (P=0.005) and 2020 (P=0.004) sampling seasons with average concentrations of 2.177 and 2.11 MG/M3 observed for those year's.

The lake's highest yearly average phosphate levels were observed in 2018 (0.068 mg/L). Additionally, 2018 TP concentrations differed significantly from both 2019 (P=0) and 2020 (P=0). Yearly average TP levels were less than 0.05 for both 2019 and 2020.

Ammonium was observed to have a significant difference across sampling years (P=0) with pairwise comparison confirming that each year was significantly different from one another (2018-2019 (P=0)) (2019-2020 (P=0.002)) apart from the 2018-2020 comparison (P=0.273). Despite the observed differences all three years average concentration fell under the measurement range of <0.015 mg/L. Ammonium's maximum value on the lake was 0.034 mg/L which occurred in July 2019.

Nitrate concentration in L. Arrow did not differ significantly over the monitoring program (P=0.435). Furthermore, yearly average concentrations for all sampling years fell below

measurement range for the laboratory processing test applied to detect Nitrate (<0.23 mg/L), However, a maximum value of 0.93 mg/L was recorded in May 2020.

A summary of the statistical analysis for the parameters recorded over the course of the sampling period is detailed in Table 3 and Figure 3.

Table 3. Lake yearly averages of concentrations recorded and statistical comparisons

| Parameter	Yearly Averages			P Value (2018-2020)	P Value pairwise comparisons		
	2018	2019	2020		2018-2019	2018-2020	2019-2020
Chlorophyll – a (MG/M3)	3.69	2.177	2.11	0.001	.005	.004	1
Phosphate P04-P (mg/L)	0.068	<0.01	<0.01	0	0	0	.224
Ammonium NH4-N (mg/L)	<0.015	<0.015	<0.015	0	0	.273	.002
Nitrate NO3-N (mg/L)	<0.23	<0.23	<0.23	.435			
Temperature ˚C	15.52	15.38	15.11	.775			
Oxygen concentration (mg/L)	9.055	8.89	9.86	0	.876	.001	.009
Conductivity (µS/cm)	228.71	247.18	271.13	0	.876	0	.173
PH	8.63	8.77	8.27	0	.167	0	.009
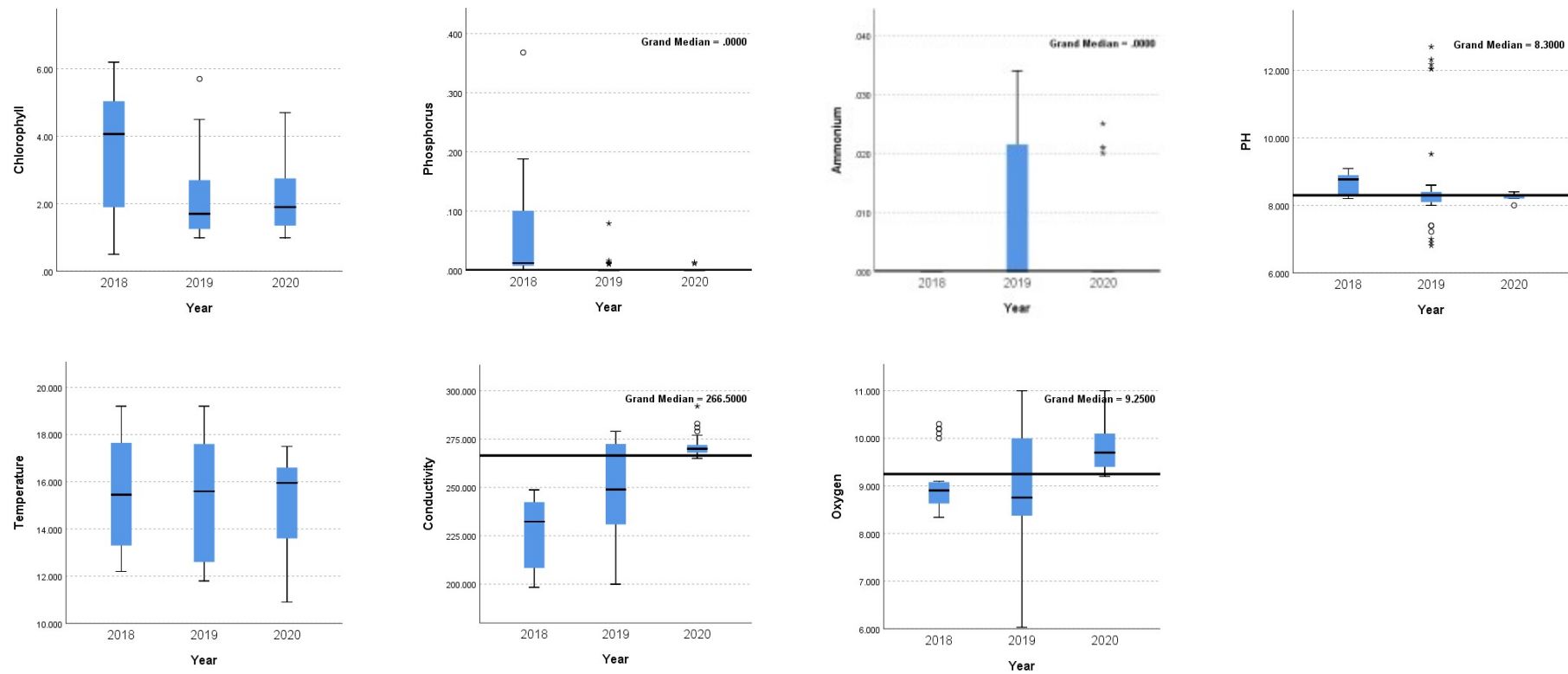
Figure 3. Boxplot of each recorded parameters yearly values .

The analysis of different sampling sites nutrient and phytoplankton conditions over the course of the sampling period found that no significant differences occurred. Nitrogen and ammonium were similar across sampling sites over the three year period with P values of 0.477 and 0.848. Phosphates followed a similar trend with a P value of 0.883 observed. Chlorophyll - a concentrations were also comparable across sites over the course of the monitoring programme (P=0.709).
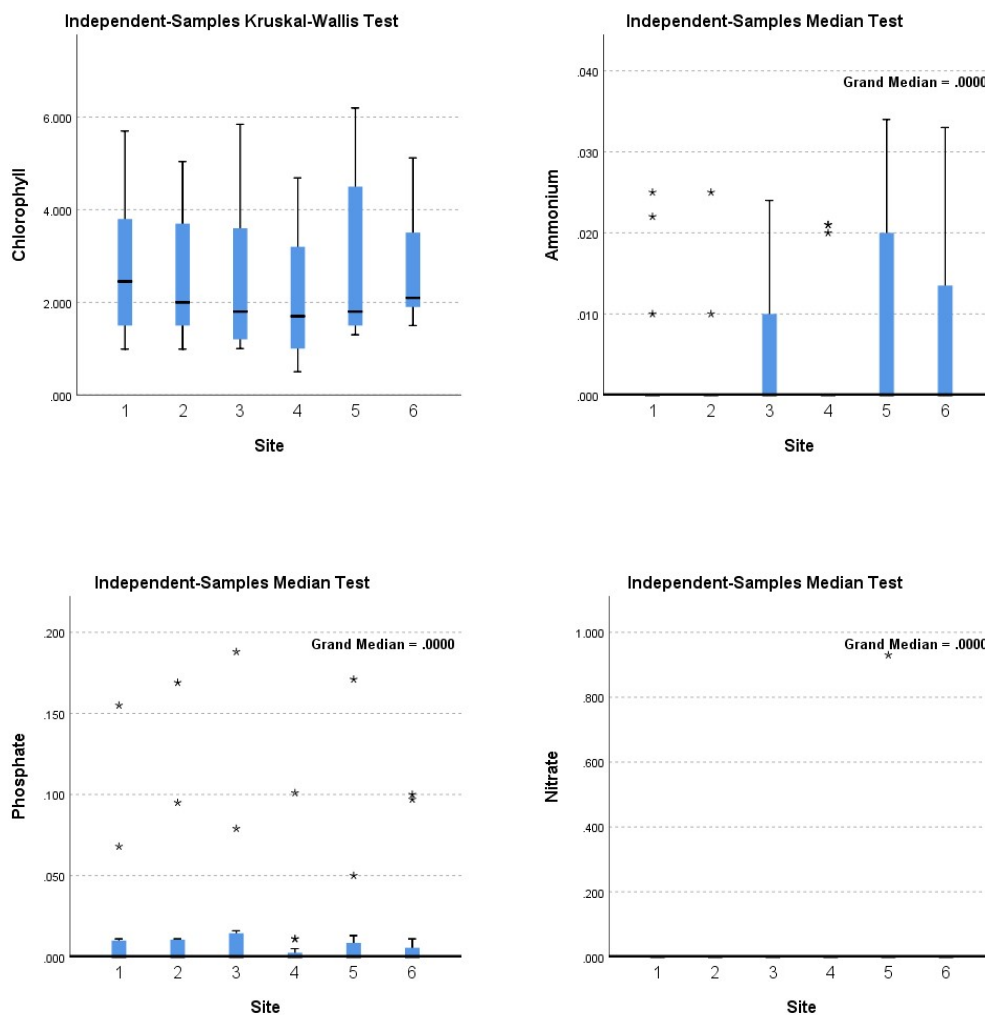

Figure 4. Boxplots of parameters of interest cross site comparison over the course of the monitoring program.

4.0 Discussion

As Lough Arrow is a designated "Hard oligo-mesotrophic waters with benthic vegetation of Chara *spp*. (3140)" Annex I habitat. Its conservation condition is assessed from a standard Article 17 protocol developed by Roden *et al* (2020). Water quality forms part of this assessment with Total Phosphorus (TP) an indicator of habitat quality as declines in euphotic depth, charophyte cover and crust condition are correlated where it occurs in excess of .01 mg/L. Roden & Murphy (2019) assessed the conservation condition of L. Arrow in 2019 utilizing historical EPA water quality data for their assessment. The assessment classified TP as "Unfavourable-Inadequate or Poor" as average concentrations in the lake were 0.0125 mg/L. In comparison, the water quality assessment carried out by IT Sligo's CANN project team identified average TP levels (converted from PO4-P) were 0.022 mg/L in 2018 which classified this parameter of the assessment as "Unfavourable-Bad or Bad".

Table 4. EPA historical water quality data utilised by Roden & Murphy (2019) for Total Phosphorus level classification for the purposes of Article 17 conservation condition assessment.

Year	Total P mg/L
2016	0.0117
2017	0.0128
2018	0.0125
Average	0.0123

The culminated EPA and CANN team data collected in 2019 and 2020 determined the average TP levels were classified as "Favourable" in both those years as it was <0.01 mg/l. This indicates an improvement in nutrient conditions for the purposes of an Article 17 assessment over the course of the monitoring program.

Other nutrient parameters recorded such as Ammonium and Nitrate were consistent throughout the sampling period and average yearly values remained under the measurement range.

Chlorophyll – a is an indicator of phytoplankton growth (O Connor. 2015), is a parameter used for the Article 17 assessment of this Annex I habitat (Roden & Murphy. 2013) as it is associated with nutrient enrichment (O Connor. 2015). Average yearly trends of chlorophyll - a followed a similar pattern as to what was observed for TP concentrations observed decreased year on year from 2018 -2020 indicating improved water quality in the lake.

Site 6, which was the site of interest for the CANN project team due to its close proximity to the lakes only urbanized area was monitored in conjunction with the EPA statutory monitoring locations on the lake to assess if statutory monitoring encompassed all the spatial variation in water quality occurring in the lake.

The cross site analysis of parameters related to nutrient conditions and phytoplankton biomass in the Lough determined that no significant difference were identified between sites indicating current statutory monitoring is sufficient to determine changes in the lakes physico-chemical parameters over the course of a Article 17 reporting period.

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Appendix I: 3140 Annex I habitat condition assessment parameters and thresholds NPWS (Roden & Murphy. 2013).

Parameter	Favourable or Good	Unfavourable-Inadequate or Poor	Unfavourable-Bad or Bad
Area	Stable or increasing	Decrease <10%	Decrease ≥10%
Number of vegetation zones	4 or more*	2–3*	1 or none†
Euphotic depth m	>7	4.5–7	<4.5
crust cover %	>70	70–20	<20
Crust chlorophyll a µg/cm³	<45	>45	undefined
Crust chlorophytes % frequency	<45	>45	undefined
C&K score	>0.6	0.3–0.6	<0.3
Lake level	at or above cyanophyte crust	>50% of cyanophyte crust exposed	*Characurta* visible above water
Total phosphorus (TP) mg/l	<0.01	0.01–0.02	>0.02
Colour Hazen units	<15	15–30	>30
Index(TP* Colour)	<0.1	>0.1<0.5	>0.5