Reviewing the risk of internal phosphorus loading in lakes of the Windermere catchment

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Cumbrian Lakes Research Forum.
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UK Centre for Ecology & Hydrology

What is internal nutrient loading?

- Fractions of sediment P which are recycled back into water column
- Often enhanced when hypolimnion anoxic when a lake is stratified
- Other factors – macrophytes, FE:P ratios and wind also important
- Shallow eutrophic lakes particularly at risk
- Prolong recovery of lakes once external catchment inputs have been addressed

Søndergaard et al., 2001 & 2003

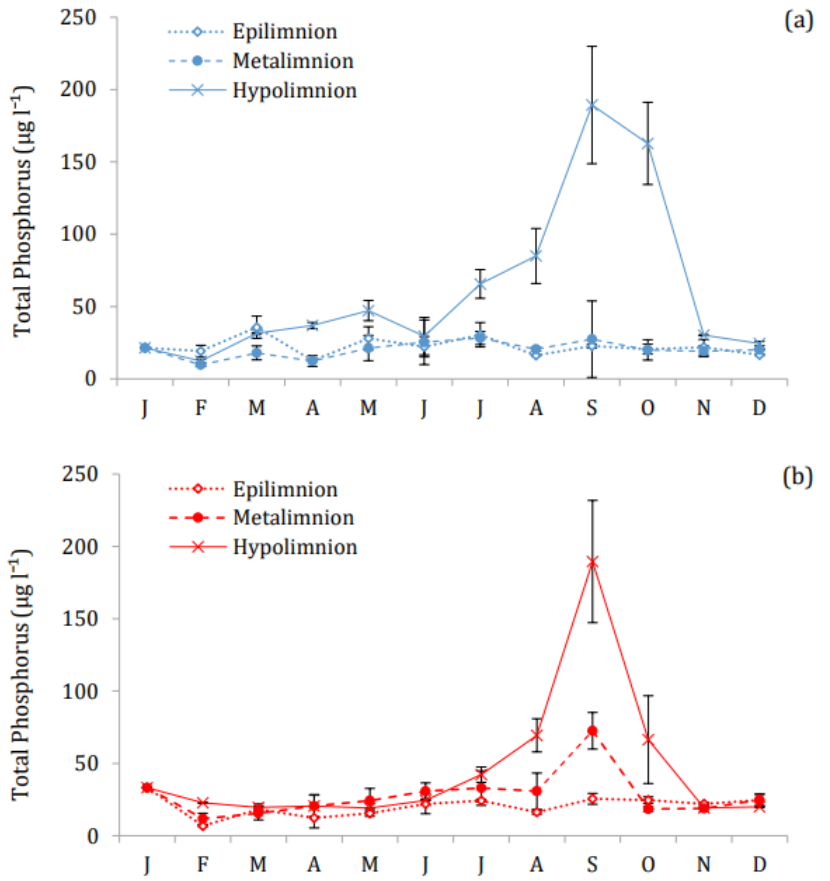
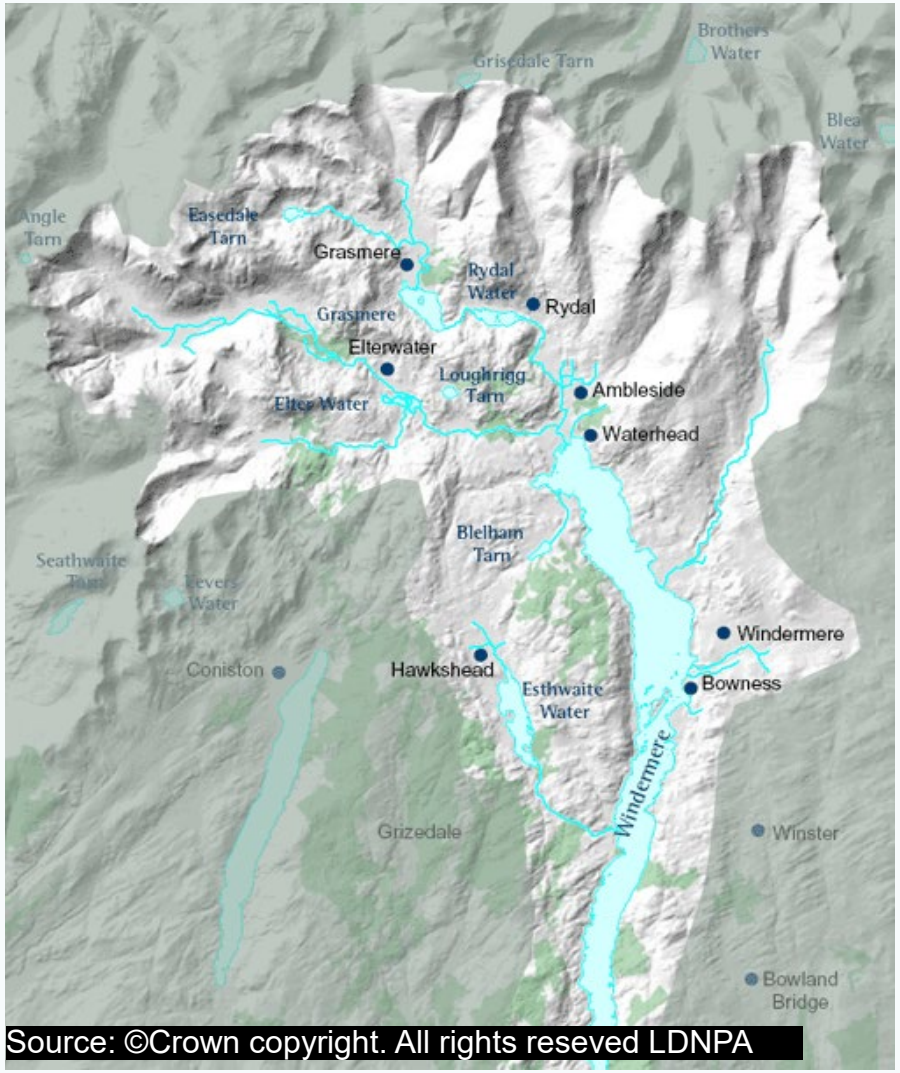


Figure 4.5: Monthly volume-weighted mean total phosphorus concentration of the epilimnion (< 5 m), metalimnion (5 – 10 m), and hypolimnion (> 10 m) throughout 2014: (a) Northern control site, and (b) central impact site. Error bars represent the standard deviation of the volume-weighted mean.

Anderson, A. M. (2018). Lake remediation by top-down and bottom-up management: An ecosystem-scale experiment in the English Lake District. Lancaster University (United Kingdom).

Rationale – why review internal loading in Windermere?

Source: savewindermere.com



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Question

“What is the evidence for sediment phosphorus enrichment or internal phosphorus loading in the eight lakes of the Windermere catchment?”

Web of Science, Google Scholar, NORA, UKCEH, PhD theses

Search terms

What: sediment phosphorus OR internal loading OR internal phosphorus loading OR internal phosphorus recycling OR internal phosphorus release OR nutrient enrichment.
Where: Blelham Tarn OR Elterwater OR Esthwaite Water OR Grasmere OR Loughrigg Tarn OR Rydal Water OR Windermere OR Leven catchment.
When: 1980 - 2023.

Three lines of evidence

1. Occurrence of stratification and hypolimnetic anoxia
2. Evidence of sediment P enrichment
3. Estimates and quantifications of internal P loads

Results

Systematic review findings plus historic oxygen, nutrient, temperature depth profiles

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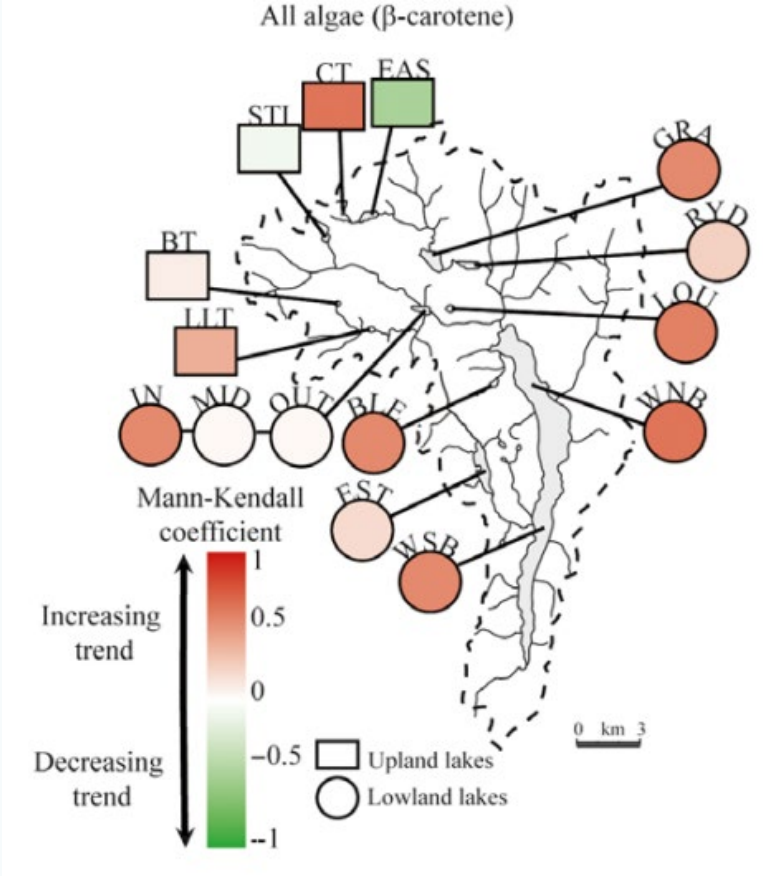
Disproportionate number of publications across catchment. No retrievable publications: Loughrigg Tarn & Rydal Water

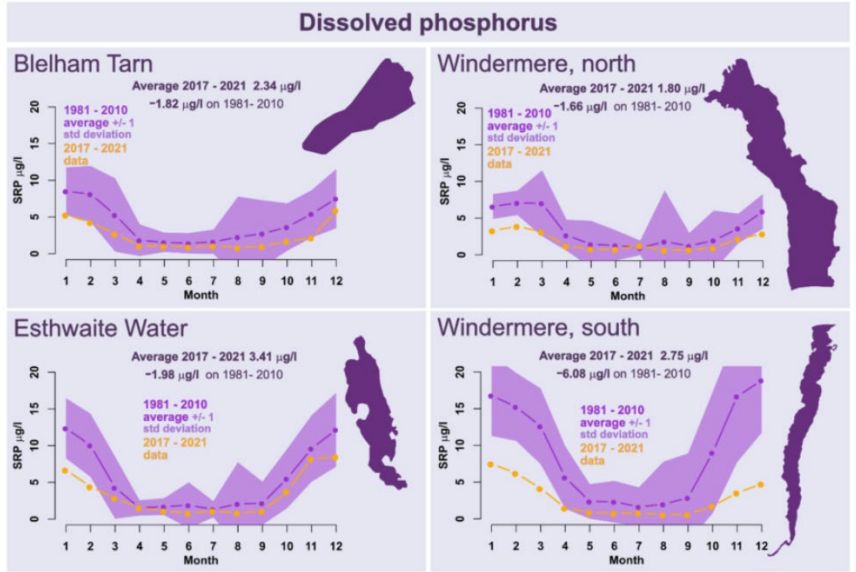
Lake	No. of records retrieved from WoS	No. of records selected for further review	No. of records retrieved from Google Scholar	No. of records selected for further review	No. of records retrieved from NORA	No. of records selected for further review	No. of records retrieved from UKCEH Library Archive	No. of records selected for further review	No. of records where copies not available	No. of UKCEH PhD Theses	Total no. of records for lake
Elterwater	3	3	0	0	1	1	3	3	1	**1**	**7**
Esthwaite Water	11	5	2	0	9	1	39	16	2	**1**	**21**
Grasmere	2	0	0	0	6	6	26	6	3		**9**
North and South Basin of Windermere	7	2	2	1	62	8	252	29	6		**34**
Blelham Tarn	3	1	0	0	3	1	26	5	2	**1**	**6**

All basins have evidence for external P inputs

Historic & contemporary evidence of eutrophication from palaeolimnology & monitoring.



Moorhouse et al., (2018). Global Change Biology, *24*(9), 4009-4022.



[UKCEH: The state of lakes in the Windermere catchment – a long-term view | UK Centre for Ecology & Hydrology (ceh.ac.uk)]

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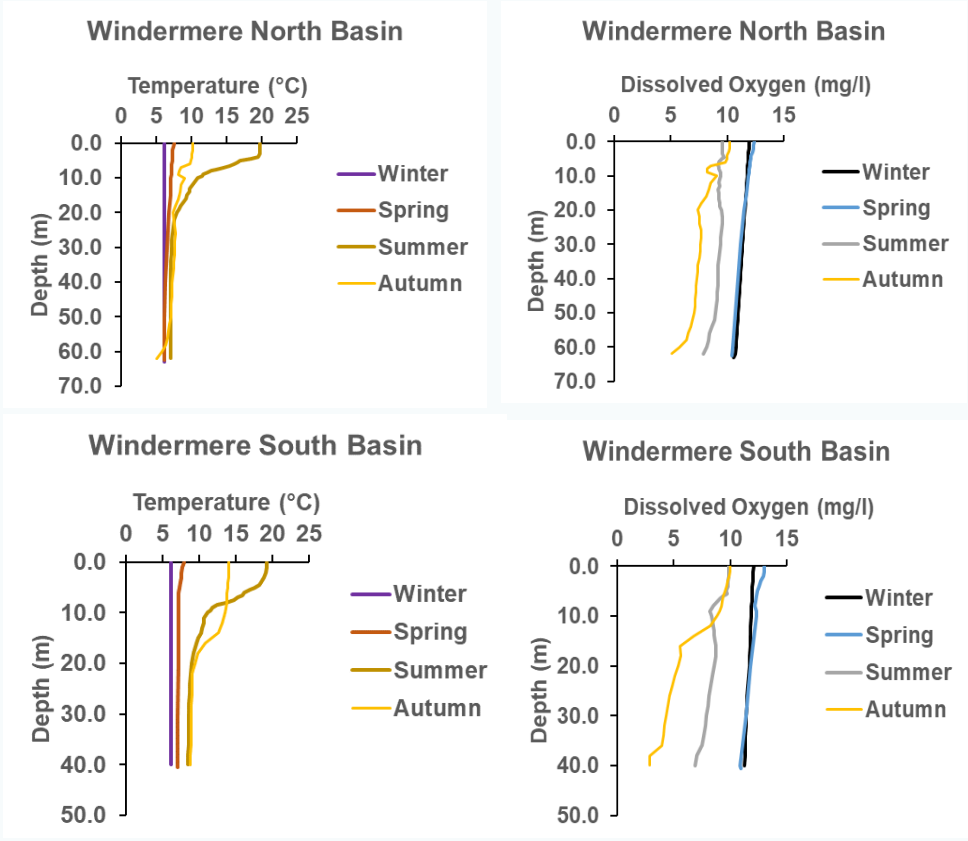
1. Occurrence of stratification and hypolimnetic anoxia

South Basin Windermere – recovery from anoxia following tertiary treatment.

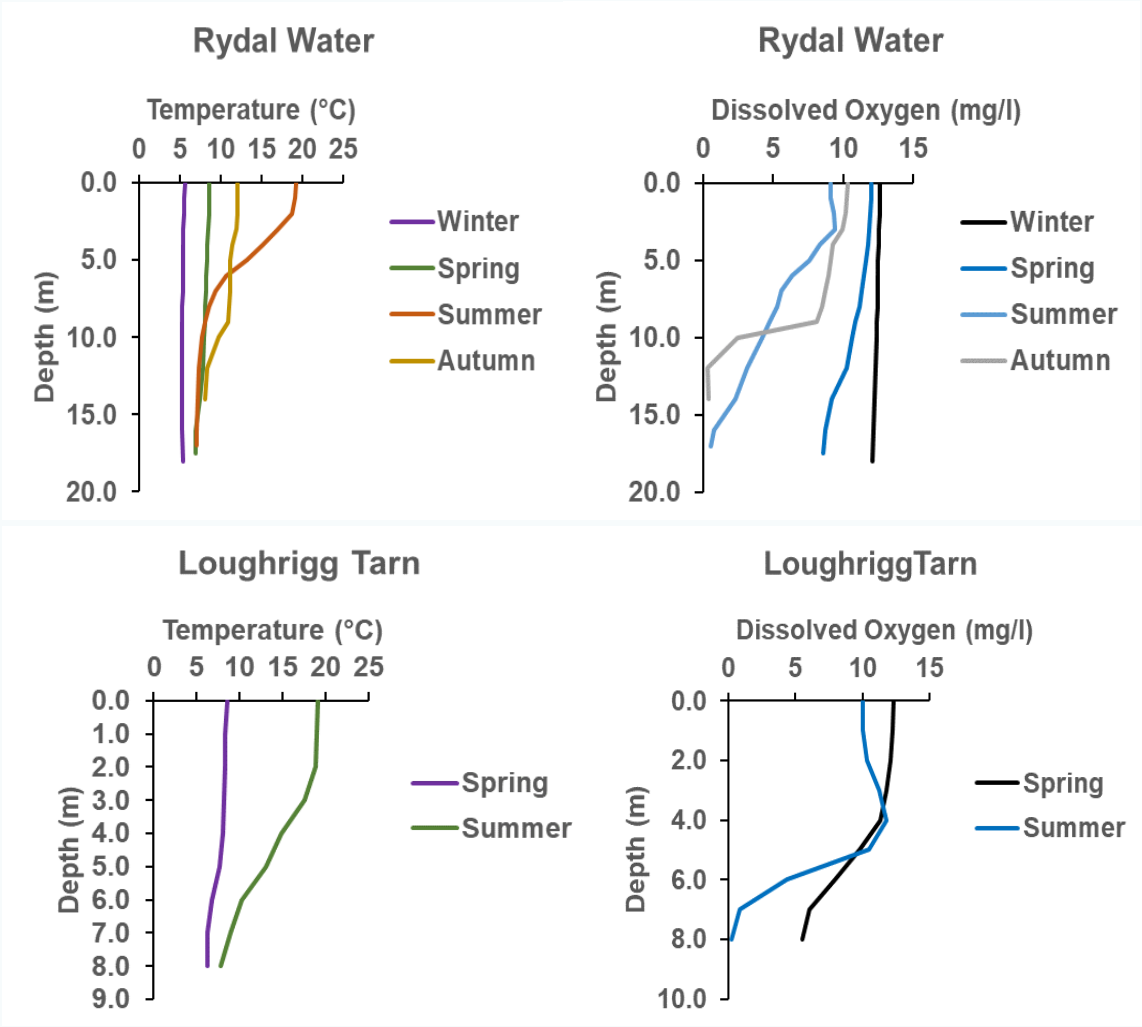
Both North and South basins experience low oxygen at depth when stratified.



UKCEH Lakes Tour 2021

1. Occurrence of stratification and hypolimnetic anoxia

All shallower basins undergo seasonal anoxia when stratified: Blelham Tarn, Esthwaite Water, Elterwater,Grasmere, Loughrigg Tarn and Rydal Water.



UKCEH Lakes Tour 2021

2. Evidence of sediment P enrichment

Only Elterwater, Esthwaite and Windermere basins had quantifiable sediment P measurements.

- Windermere, sediments collected 1989/1990 (Corry et al., 1992)
  - **North Basin**, sites >10m = **1577.7** µg g-1 DW mean AEP.
  - **South Basin** at sites >10m = **1849.6** µg g-1 DW mean AEP.
- **Esthwaite Water**, central basin, sediments collected 2014 (Anderson, 2018)
  - Mean TP = **3034** µg g-1 DW
  - Mean AEP = **2628** µg g-1 DW
- **Elterwater, inner basin**, sediments collected 2014, (Mackay et al., 2015). Values from middle and outer basins but inner has largest concentrations
  - Mean TP = **exceeded 5000** µg g−1 DW
  - Mean AEP= **~3900** µg g−1 DW

3. Estimates and quantification of internal P loads

- Esthwaite Water = a direct quantification of external & internal P budgets. Internal P loading = **~14%** of the annual P load to the lake (Anderson et al., 2018).

Esthwaite Water, UKCEH lakes monitoring. H. Moorhouse

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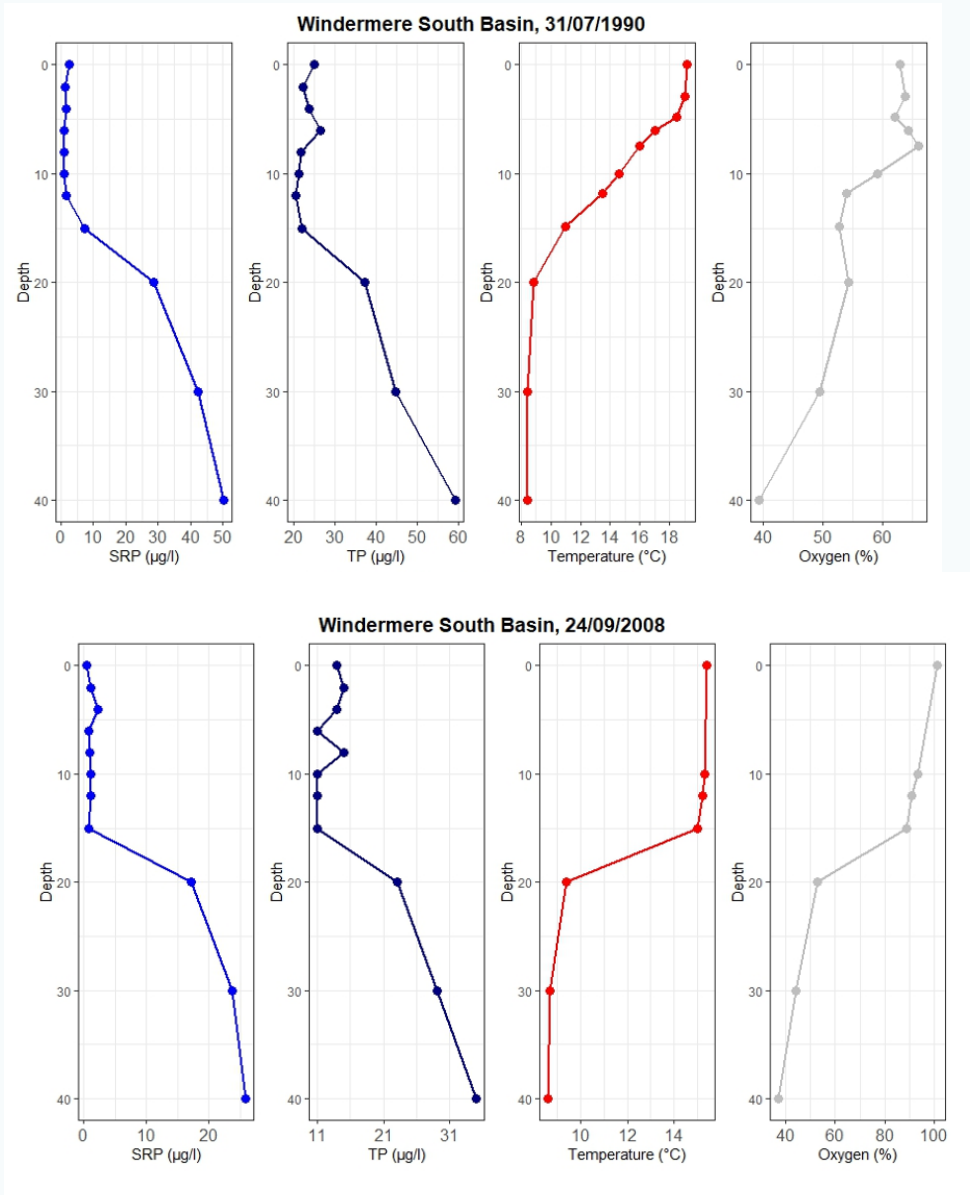
- Elevated hypolimnetic P concentrations = Blelham Tarn, Elterwater, Esthwaite Water, Grasmere, Windermere basins.
- But water column P not routinely monitored. Windermere = 2008. Blelham Tarn, Elterwater and Esthwaite = ~2014 by UKCEH PhD students.
- No data = Loughrigg Tarn & Rydal Water.



UKCEH long-term lakes monitoring programme

Conclusions & Recommendations

- External catchment P loads still dominant. Need quantifying and addressing.
- For accurate assessments = mass-balance calculations.
- Routine oxygen-depth profiles. Currently undertaken at Blelham Tarn, Esthwaite Water, Windermere basins (UKCEH).
- Given seasonal anoxia, shallow depth, eutrophic histories, no data = sediment TP/AEP assessments at Blelham Tarn, Grasmere, Loughrigg Tarn and Rydal Water
- Elterwater inner basin = sediment P indicates internal loading contribution could be highest in the catchment

Thank You

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