Phosphate levels in the River Rothay and Windermere

A citizen science project by Tim Boden
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Another outpouring of national angst about the state of Windermere, August's Big Windermere Survey results showing a significant annual deterioration in lake phosphate levels. Windermere was historically fed by low-nutrient, high-purity, high-clarity mountain streams supporting a unique ecosystem. This is now threatened by human activities – a complex mix of town and off-grid, tourism-based sewage effluent and farming currently apportioned by the Environment Agency as per Figure 1 – leading to excessive nutrients, primarily phosphate but also nitrates, triggering algal blooms that multiply, die, sink and decay causing damaging lake-floor, low-oxygen, eutrophic conditions. Yet the results that have triggered current concerns are but two points in time, each with their own uncertainties. Filling in these gaps is the aim of a citizen science project, undertaken by a team from Ambleside Action for a Future.

Treated Effluent	35%
Storm Overflow	5%
Farming	30%
Off-Grid	30%

Figure 1: EA Phosphorus Allocations

This Ambleside-based project started in March, following a long-established methodology used by Wye Valley citizen science teams, studying the River Rothay, which, together with its tributary Stock Ghyll, runs through Ambleside before discharging into Windermere just after receiving the treated effluent from the Ambleside waste-water treatment works (WwTW), comprising 34% of the flow into Windermere's North Basin (the Brathay is a further 39%). A sampling methodology was constructed to examine all potential local sources of phosphate - sewage works, farming fields, drains and off-grid sites. Weekly samples were taken from the River Rothay and Stock Ghyll, both above and below the WwTW, and phosphate levels analysed using a commercially-available, low-cost tester which can provide results down to a limit of measurement of 40ppb. Urban and rural drains discharging into the river were also tested to determine whether they contained rainwater or were contaminated with phosphate, the latter though either sewer misconnections or leakage of phosphate-dosed tap water.

The testing period lasted until September, covering the tourist peaks of Easter, Bank and school holidays as well as the 32-day drought from late-May to mid-June. The results were striking (Figure 2, measured) – clear peaks in phosphate levels flowing into the lake were identified during both the drought and August holidays, the maximum of 120ppb breaking the Rothay's *Good Quality* Water Framework Directive targets (Figure 3) and directly attributable to sewage outflow. Furthermore, a series of contaminated drains were reported to the Environment Agency for investigation into misconnections or water-main leaks. No evidence of farming-based phosphate pollution was found.

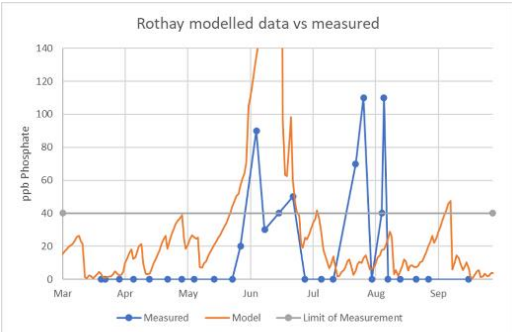

Figure 2: Measured vs Modelled Phosphate levels in the River Rothay downstream of WwTW

High Quality	Good Quality	Moderate Quality
<52ppb	53-109ppb	110+ppb

Figure 3: WFD Phosphorus Targets for the River Rothay

United Utilities has significantly invested in its local treatment of sewage effluent – there was no evidence that they were operating outside the permits awarded by the Environment Agency – however their solution of relying on Lake District rain to dilute phosphorus before entering into the lake clearly fails both when rainfall is low or when normal and tourist numbers high. The result is that pools of phosphate-richer water form at the northern end of the lake.

To investigate their impact, a simple North-Basin-wide hydrodynamic model was constructed, using publicly-available information on daily river flows and lake levels. The model did broadly predict the peaks observed by the testing (Figure 2, model), but not their intensity. Unfortunately, given the extremely limited information published on the treatment work's daily phosphate outputs, discharges could only be roughly estimated from monthly spot data which may explain the unexpected August peaks in measured data.

Once in the lake, this model predicted that pools created in June would migrate slowly southwards, accelerated by the heavier rains in July and August, passing out of the North Basin during September and October. To examine whether in practice this happened, spectral images from the ESA Copernicus satellite programme were used to analyse lake algal concentrations. Given the limiting role of phosphate in stimulating algal growth, researchers estimate phosphate levels from algae on a lake-by-lake basis, baselining each analysis from simultaneous physical measurements. By linking results from the last four Big Windermere surveys to satellite pictures taken at roughly the same time, phosphate profiles of the lake were determined over both time and distance down the lake.

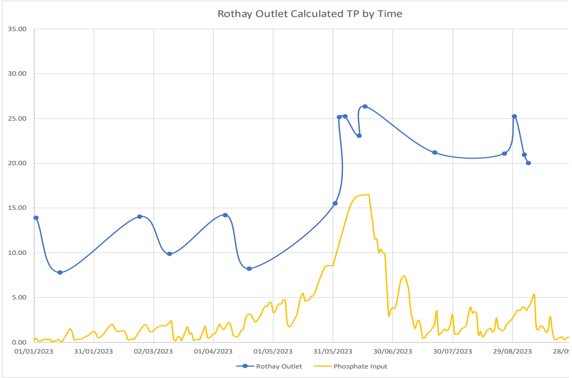

Figure 4: Modelled vs Calculated Phosphate Measurements for the Rothay outflow

The first clear result (Figure 4) was that in-lake phosphate levels calculated near the Rothay outlet were considerably higher than modelled input – even in winter when tourist numbers were low and heavy rain expected to flush out any summer pollution. In-line with published Windermere Survey results, this strongly suggests that the lake is retaining higher historical levels of phosphate, potentially though its sediment. There was a clear congruent peak in June, linked to a similar magnitude and timing of rise in the modelled input of the pooled effluent, indicating an impact from the Ambleside WwTW output.

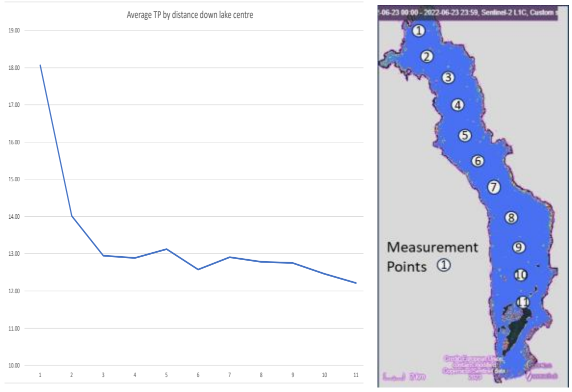

Figure 5: Variations in phosphate levels down Windermere's North Basin centreline

The next finding (Figure 5) was that phosphate levels at Waterhead (1,2) were significantly higher than down-lake, suggesting a dependency on either historical phosphate input or high levels of tourism. The slight increase opposite Brockhole (3-5) may relate to discharges from its cluster of off-grid tourist sites and hotels. Beyond there, given that diffuse flow input to the North Basin (excluding the Brathay and Rothay) is 27% of the outflow, yet diffuse phosphate inputs (Figure 2, Farming and Off-Grid) represent 60%, phosphate levels would be expected to increase. The actual observed slow decline may indicate simple dilution with diffuse phosphate levels overstated or be related to removal of phosphate by algal blooms.

Unfortunately, any signal from the phosphate-rich water heading down-lake was swamped by high background levels of phosphate; instead, consistent peaks and troughs appeared along the lake length (Figure 6), suggesting that lake-wide factors trigger the phosphate changes. Certainly, troughs align with high lake flow rates and peaks with low flow, corresponding to better weather, increased tourism and higher levels of sunshine. Mechanisms for this are unclear.

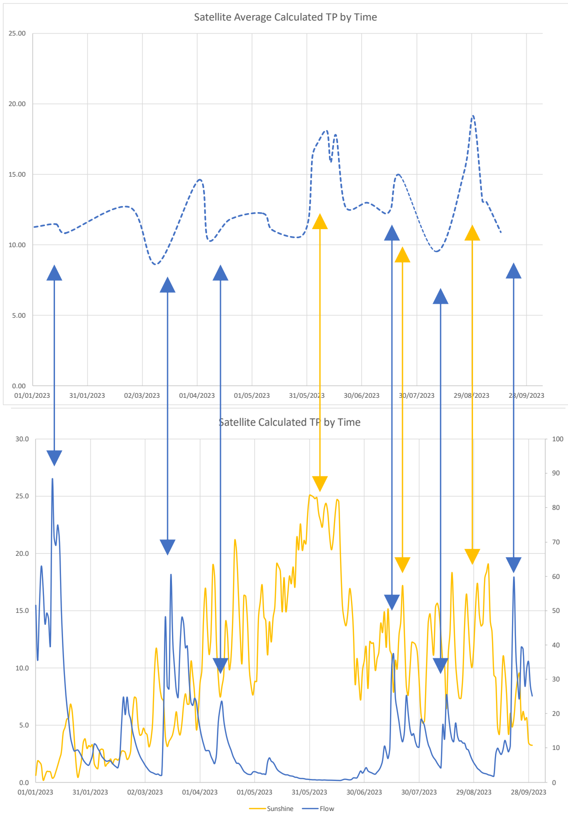

Figure 6: Average phosphate levels over the lake length showing linkage to climatic events

In summary, the study demonstrates that whilst annual levels of sewage outflow by United Utilities may be within overall permits, seasonal variations in tourist numbers and river flow affect the extent to which discharges are diluted prior to entry into Windermere and create significant rises in local phosphate levels that could trigger algal blooms. Satellite data, baselined by the Big Windermere Survey, finds that, despite major reductions in sewage phosphate outflows over the last few years, levels in the lake are significantly higher than current inputs even out of season, suggesting that historic emissions have been stored in sediment and are being released over time, with greatest concentrations at the North end of the lake. The mechanisms driving this release are not yet understood but appear to be linked to lake-wide climatic events such as high flow and sunshine.

Given the aim of interested parties to protect and restore the Windermere's ecological health, algal blooms, spawned by higher local concentrations of phosphate, are a key threat. Focussing on the timeliness of all phosphate inputs is critical – reducing discharges when tourist numbers are high and rainfall and lake flow low. Such a system-wide approach would not only consider reducing discharges from public treatment works, but also help private owners to improve their plant which as a norm do not remove phosphate from their discharges. It would also consider best practice in farming to mitigate seasonal discharges as well as public information aimed at reducing the unnecessary use of phosphate-dosed tapwater both inside and outside the home and 'slow-the-flow' activities aiming to capture storm-based, both urban and rural run-off before slowly releasing retained water. Repairing the health of Windermere will not be a speedy process, requiring the gradual reduction of stubborn background levels of retained phosphate by reducing inputs and flushing through cleaner water, but immediate action to reduce the scale of blooms is a necessary first step.