A Changing Windermere

March 2025

Acknowledgement

'A Changing Windermere' has been produced by the Love Windermere Partnership utilising the 'State of Windermere Report 2024'.

The State of Windermere report and Windermere Integrated Science Plan (WISP) were commissioned by the Environment Agency in December 2022 and produced by the Freshwater Biological Association.

These documents provide a compilation of existing data from Environment Agency, UK Centre for Ecology and Hydrology and other sources into an evidence base 'State of Windermere' and a recommendations piece 'Windermere Integrated Science Plan' (WISP).

These reports can be found on the Science and Insights pages of the Love Windermere website Science and Insights – Love Windermere .

Introduction

'A Changing Windermere' report summarises the pressures and impacts exerted on Windermere by catchment-based activities and climate change. The report is intended to highlight the challenges presented to all parties involved in the future management of the lake and its catchments.

This report was written by the Love Windermere Partnership under guidance from Dr Ben Surridge at Lancaster University and has been reviewed by UK Centre for Ecology and Hydrology and the Environment Agency's Chief Scientist Group. It is intended to provide additional detail behind the postcard, poster and social media posts summarising some of the key statements.

We have used data and research collated by the Freshwater Biological Association to inform a 'State of Windermere' report commissioned by the Environment Agency on behalf of Love Windermere Partnership together with additional sources of information. References can be used to explore the source data.

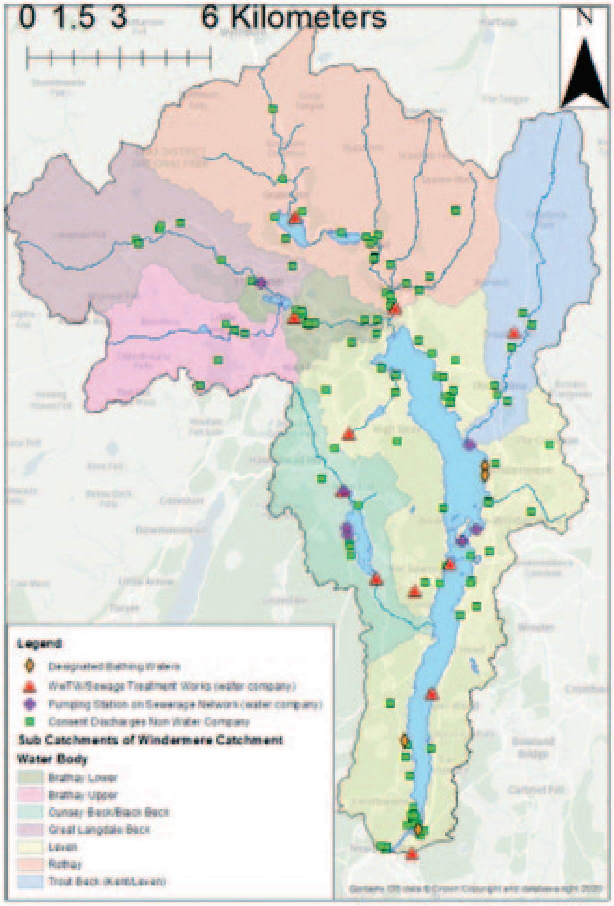


Figure 1: Map of the Windermere catchment and main sub-catchment waterbodies. United Utilities wastewater treatment works (WwTW) and pumping stations (PS) are shown together with private (non-water company) permitted wastewater discharges. The location of designated bathing waters are also shown.

Background

Windermere is England's largest lake and the best-known lake in the Lake District, forming a significant part of the Lake District National Park brand and UNESCO World Heritage Site Status. It appeals to local and international visitors interested in the scenery, landscape, and water-based or water-adjacent activities. The catchment is home to 14,000-17,500 residents, and up to 7 million additional people visit each year[1].

Windermere is a narrow, ribbon-shaped lake with two distinct basins – North and South, separated by a shallow sill at the ferry crossing just south of Belle Isle.

Property	North Basin	South Basin	Lake Total
Catchment area (km^2)	187	63	250
Lake Area (km^2)	8.1	6.7	14.8
Volume (m^3 x 106)	201.8	112.7	314.5
Max. depth (m)	64	42	64
Mean depth (m)	25.1	16.8	21.3
Mean retention time (days)	180	100	280

Table 1: Summary of Windermere's key characteristics

Windermere is officially a 'mere' meaning shallow lake. Windermere is used throughout this report to refer to the lake, not to the town.

The two basins are classified as separate waterbodies under the Water Framework Directive[2] and vary in their dimensions, geology, hydrology, chemistry, and biology (Table 1[3]). To the north, the underlying geology is hard volcanic rocks; to the south, softer slates, shales and sandstones are separated by a band of limestone[4].

The Windermere catchment (Fig. 1) sits within the wider Leven catchment and refers to the area from which the lake receives water and material, including runoff of nutrients, sediments, and other pollutants. The catchment can be further divided into sub-catchments that name the major inflows to Windermere. The North Basin is fed by the River Rothay sub-catchment (Grasmere and Rydal Water), the River Brathay Upper and Lower sub-catchments (Elterwater and Langdale), Great Langdale sub-catchment, Troutbeck sub-catchment, Blelham Beck (Blelham Tarn) and Mill Beck. The South Basin receives water from the North Basin, Wilfin Beck and the Cunsey Beck sub-catchment, which includes Esthwaite Water. All water eventually leaves Windermere via the River Leven, which flows from Newby Bridge to Morecambe Bay.

Windermere is a designated County Wildlife Site[5]. The catchment contains over 20 Sites of Special Scientific Interest (SSSI), one Special Area of Conservation (SAC) and one Ramsar Site at Esthwaite Water. The River Leven is one of the principal salmon rivers in England and Wales and there are important spawning grounds in the catchment for salmon and sea trout which require clean water and high-quality habitat to flourish. Windermere itself provides habitat for Arctic charr, brown trout, and European eel. Otters are present throughout the Windermere catchment. They are considered a priority species under the Natural Environment and Rural Communities Act (2006) and are protected under the Wildlife and Countryside Act 1981 and the Conservation of Habitats and Species Regulations 2017. Windermere is a source of drinking water with an associated Drinking Water Protection Area. The water company United Utilities abstract water to supply people across the Northwest.

Environment Agency staff taking water samples

Monitoring of Windermere

There is a long history of scientists monitoring Windermere's water and the plants and animals that live in it. This data has been collected since the 1930s by organisations such as the Freshwater Biological Association, the UK Centre for Ecology and Hydrology and its predecessors and the Environment Agency.

In England, water quality is formally classified across a range of parameters for the Water Framework Directive[6] including nutrient concentrations, dissolved oxygen and a selection of plants and animals. The Bathing Water Directive[7] requires water sampling and analysis for bacteria at specific 'designated' locations of which Windermere has four (Fig. 1).

A wide range of science professionals and an increasing number of Citizen Scientists are continually expanding our collective understanding of current water quality and how that might change alongside the effects of climate change. This evidence base and future research are essential for informing future lake management and monitoring the effects of environmental change and restorative action[8].

This extent of interest and monitoring gives us data that we can use to understand the current water quality of Windermere and trends and patterns over time. For instance, nutrient enrichment of Windermere has been occurring for almost 200 years[9] and when combined with increasing water temperatures recorded over the last 70 years, has resulted in increasing frequency of potentially harmful algal blooms[10].

Many organisations are working to improve the lake's condition, through practical conservation of species and restoration of habitat, regulation of activities, education, advice and guidance, and improvements to wastewater treatment.

However, given climate change impacts which will be described later, future interventions will likely need to go much further to deliver significant benefits for Windermere. This highlights how everyone can play their part in helping the environment through effective partnership and collaboration.

Lake Water Quality

Windermere water quality can be considered under a range of parameters which can be grouped as nutrient inputs, bacteria or faecal inputs, algae and harmful algal blooms, fish and indicators of biodiversity including invasive non-native species and climate change factors such as water temperature.

Statutory water quality

The Environment Agency has a duty to report water quality under the Water Framework Directive (WFD) and the Bathing Water Directive (BWD).

> **The WFD classification has a 5 point system from High to Bad Status, representing increasing levels of deviation from natural conditions. Good or better is a pass, everything else fails. Good status is a "slight change from natural conditions". One of the rules of the WFD classification is the so called 'One out, all out' rule: if one element fails, the relevant component overall and the overall waterbody status, will fail too.**

The ecological status of Windermere under the Water Framework Directive in 2022 was Moderate (limited by results for aquatic plants and algae (macrophytes and phytobenthos) and total nitrogen in the North Basin and aquatic plants and algae (macrophytes, phytobenthos, phytoplankton) and dissolved oxygen in the South Basin).

The four Bathing Waters at Rayrigg Meadow, Millerground, Lakeside YMCA and Fellfoot (Fig. 1) designated under the Bathing Water Directive have achieved an 'Excellent' classification since 2015.

Nutrients

Nutrients such as phosphorus (P) and nitrogen (N) are essential for all life on earth. P alongside N can regulate the growth of algae and aquatic plants, but if present at high concentrations they can cause problems such as algal blooms.

> **Total phosphorus refers to the combined total of all forms of P including dissolved 'soluble' orthophosphate together with that in particulate form.**

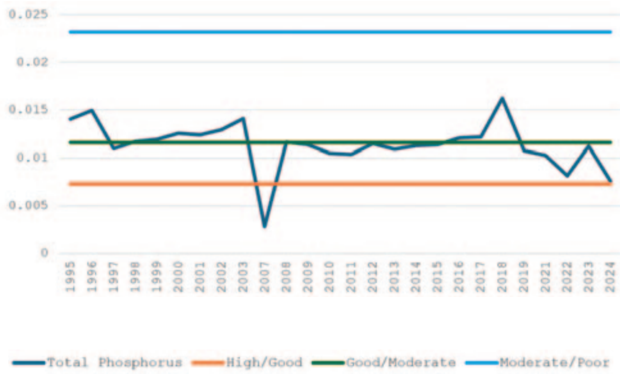
Phosphorus in Windermere

Primary sources of P to the lake include wastewater and agricultural runoff. Some P may also be released from nutrient enriched lakebed sediments, which have accumulated historic nutrient inputs through a process known as internal loading[11].

The latest WFD classification (2022) for total phosphorus in the North and South basin is Good.

The concentration of P in Windermere increased between 1945 and 1991 due to wastewater from increasing visitor numbers[12] and the introduction of P based detergents used widely in society. Following improvements to wastewater treatment in the early 1990s and legislation to limit P in domestic detergents in 2014, concentrations of P in the lake fell and the trend shows they have been relatively stable for the last 15 years (Fig. 2).

Phosphorus - Windermere North Basin



Phosphorus - Windermere South Basin

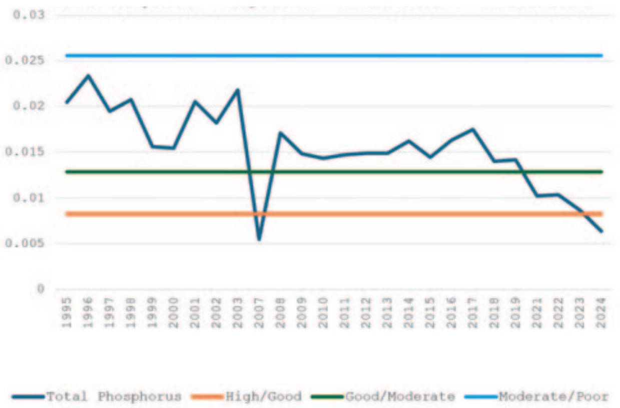


Figure 2: EA monitoring results for Total P in North and South Basins of Windermere.

Nitrogen in Windermere

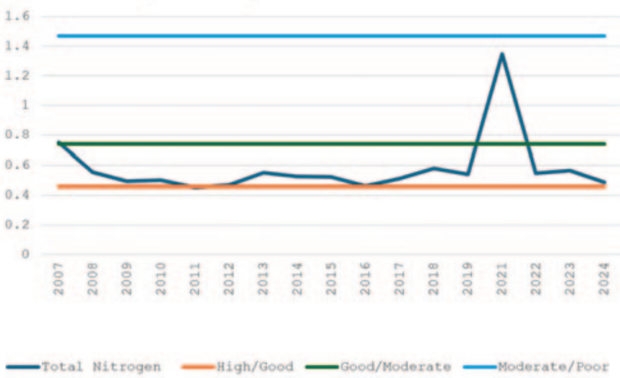
Sources of nitrogen impacting the lake include wastewater, fertilisers, animal waste and atmospheric deposition.

The latest Water Framework Directive (WFD) total nitrogen classification (2022) for the South Basin is Good and Moderate for the North Basin.

> **Total nitrogen refers to the combined forms of nitrogen; nitrite, nitrate and ammonia together with all other organic compounds that contain nitrogen including that in particulate form held in soils and sediment.**

Environment Agency (EA) data show total N concentrations increased between 2004 and 2007 in the South Basin but the trend shows they have since remained relatively stable and consistent with Water Framework Directive (WFD) Good status (Fig.3). Equivalent records for the North Basin began in 2007 and have remained generally stable except for 2021, where one exceptionally high sample result, taken in a particularly cold April and mirrored by sample results elsewhere (Coniston Water), affected the overall classification. The last estimate of the total average load of dissolved inorganic nitrogen to the lake was 294,000kg yr1 (with 80% coming from the inflowing streams) in 2009[13]. The inputs of Nitrogen include atmospheric deposition, and the sources are therefore hard to quantify.

Nitrogen - Windermere North Basin



Nitrogen - Windermere South Basin

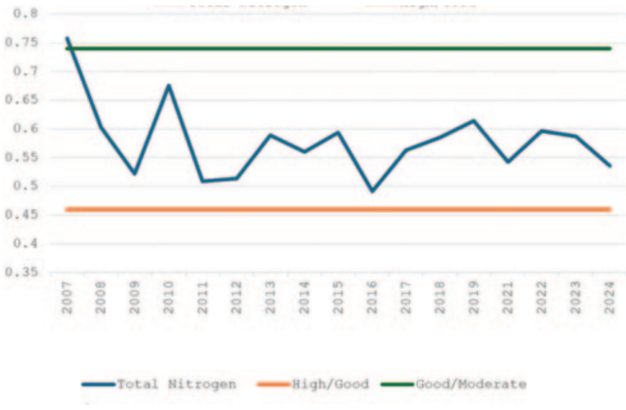


Figure 3: EA monitoring results for Total N in North and South Basins of Windermere.

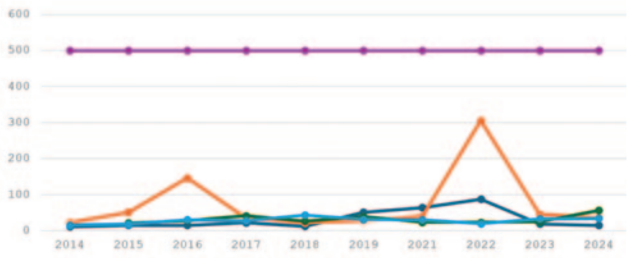
Bacteria

Bacteria such as Escherichia coli (E.coli) and Intestinal Enterococci (IE) are present in human, animal and bird faeces and enter the lake via agricultural runoff, wastewater discharges, and directly from wildlife. The Environment Agency monitors bacterial concentrations in Windermere throughout the summer period (May to September) at four sites designated under the Bathing Water Directive (Figure 1). This equates to 20 samples during the season. Classification of bathing water quality is calculated based on 4 years' worth of data (80 samples) assessed against a 95 percentile target, which means 95% of samples or 19 of 20 must reach the required standard.

The standard for 'excellent status' is 500 No/100ml for E.coli and 200 CFU/0.1l for IE.

The results (Fig.4) of these samples taken at the four designated bathing waters at Rayrigg Meadow, Millerground, Lakeside YMCA and Fellfoot (Fig. 1) on Windermere have consistently rated 'Excellent' under the Bathing Water Directive Classifications since 2015.

E-Coli No/100ml



IE CFU/0.11

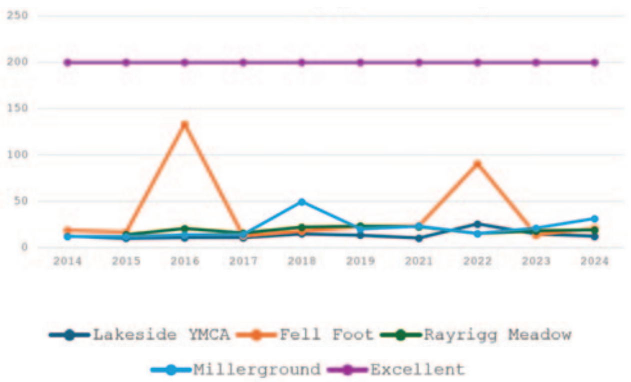


Figure 4: Environment Agency (Bathing Water Directive) sample results for annual 95th percentiles for Escherichia coli. (E Coli) and intestinal enterococci (IE). Based on annual data collected May - September.

Data from the Big Windermere Survey[14] (2022-2023) carried out at over 90 sites around the Windermere catchment showed that concentrations of bacteria in Windermere were highest in summer before decreasing in autumn and continuing to decline in winter and spring. Annual averages for two key types of bacteria were lower in the South Basin than in the North Basin (Table 2).

		Annual mean (cfu mL^{-100})	Range (cfu mL^{-100})
North Basin	Escherichia coli	122.8	1-3000
	intestinal enterococci	65.2	1-1100
South Basin	Escherichia coli	86.8	1-1300
	intestinal enterococci	55.8	1-2100

Table 2: Annual mean bacterial concentrations taken from the Big Windermere Survey results 2022-23

(Cfu refers to colony forming units – the measure of bacterial concentration used in water quality monitoring)

Algae and cyanobacteria

The populations of algae and cyanobacteria (that can produce harmful toxins) in the lake varies seasonally and from year to year in response to the availability of nutrients and weather conditions, which influence the lake temperature and physical structure. The amount, or biomass, of algae in lake water can be indicated by measuring the concentration of the main (green) pigment algae and cyanobacteria use in photosynthesis called chlorophyll-a. Concentrations of chlorophyll-a increased in both basins of Windermere up to the early 1990s, when a reduction and associated reduction in total phosphorus concentrations within the lake were observed following improvements to wastewater treatment[15]. However, concentrations were then noted to rise again to ~5 mg m-3 in the North Basin and ~8 mg m-3 in the South Basin by 2007[16]. Annual mean concentrations of chlorophyll-a in Windermere's North Basin have remained stable since peaking in 2010, whereas the South Basin has increased slightly since 2010.

The long term UKCEH data shows that the annual mean chlorophyll-a concentrations for both basins of Windermere are consistent with a mesotrophic or moderately productive lake and have been consistently lower than those of the more nutrient enriched (productive) lakes (Blelham Tarn, Elterwater and Esthwaite Water) in the catchment[18].

While chlorophyll-a concentration change over decades, they also vary over the course of a year with peaks in spring and summer (Fig. 5).

Reports of Blue Green Algae (BGA) made to the EA by the public (Fig.6) have progressively increased over the last 20 years. This may be due to increasing occurrence of BGA but it may also be due to a greater level of interest and awareness in the public resulting in more reports. There may therefore be some bias in the data.

Algal biomass

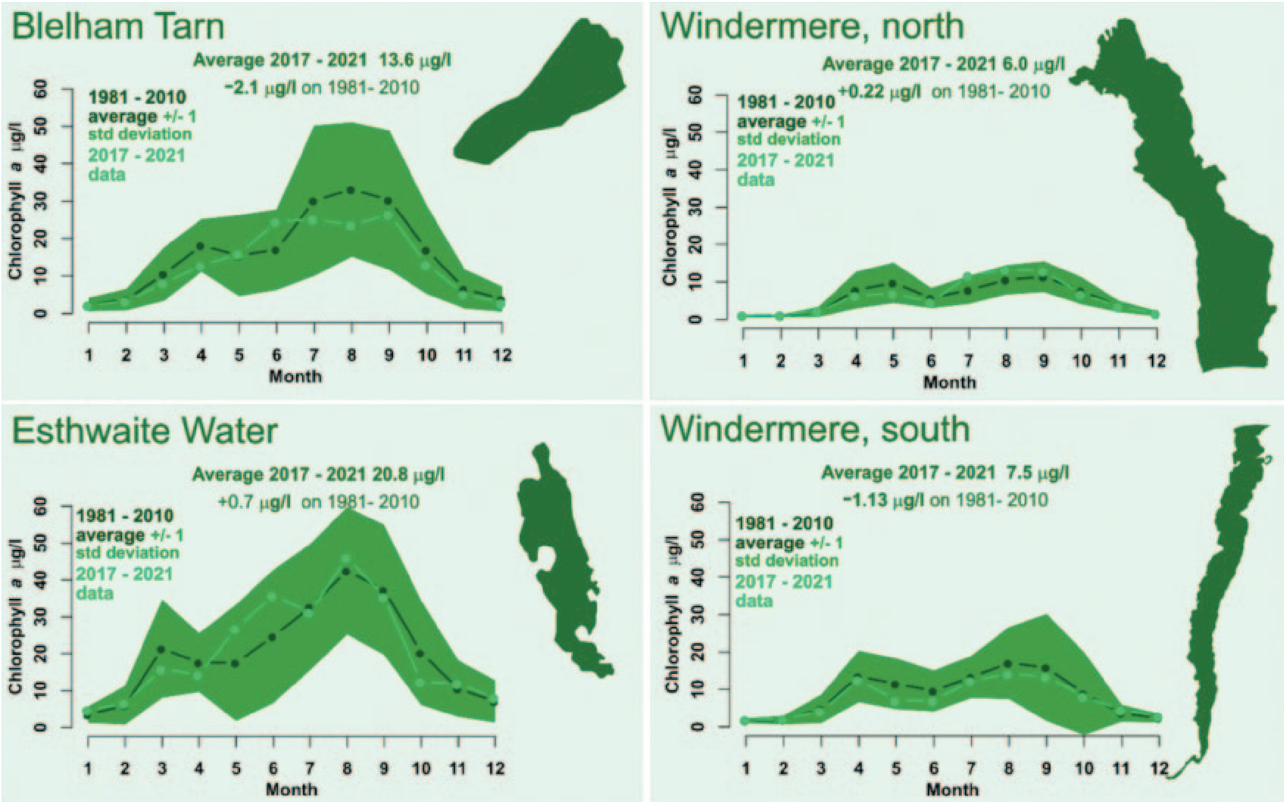


Figure 5: Long-term changes in chlorophyll a concentration in Blelham Tarn, Esthwaite Water and Windermere. Figure reproduced with permission from UKCEH blog 'The state of lakes in the Windermere catchment – a long-term view'. A concentration of 1 µg L^{-1} is equivalent to 1 mg m^{-3}.

Windermere Confirmed Algal Blooms

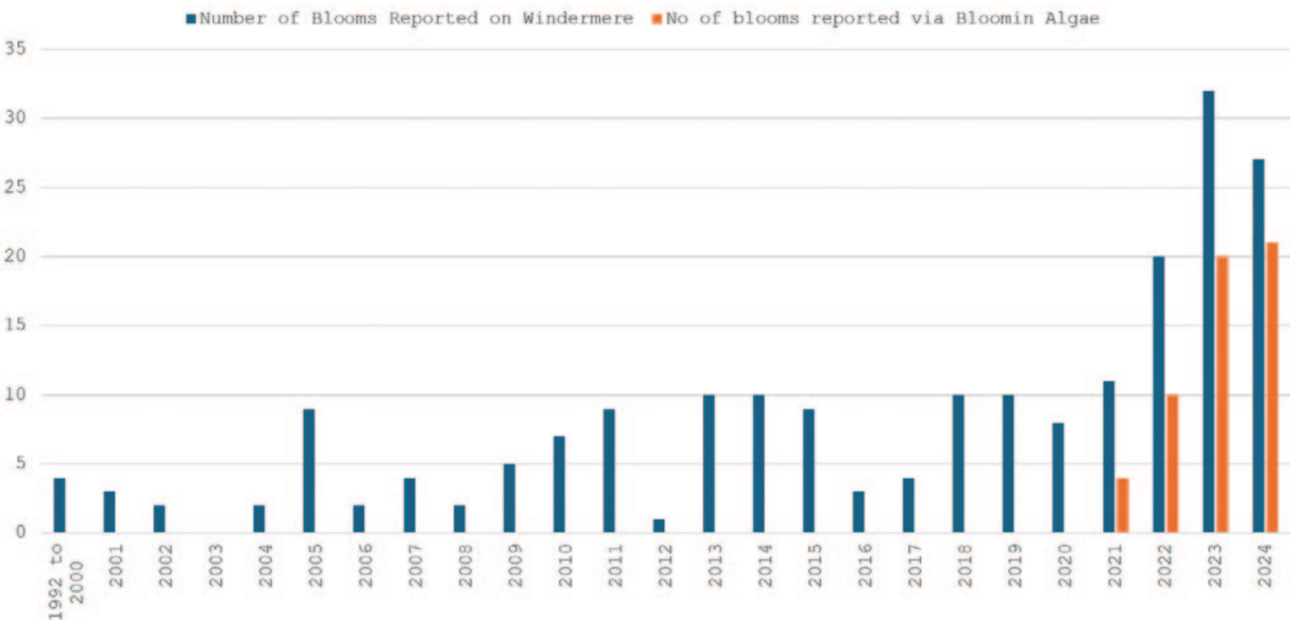


Figure 6: Algal blooms reported to the Environment Agency and via the CEH Bloomin Algae App 200-2024.

Fish and biodiversity

Fish communities are an important indicator of overall water quality. A summary of the known fish species in Windermere were reported by the UKCEH Lakes Tour in 2015 and included Arctic Charr, brown trout, Atlantic salmon, pike, perch, eel, three spined stickleback and European bullhead amongst others. These species were all detected by eDNA data collected in 2015/16[19]. The populations of these fish species are changing due to increasing lake water temperature and from predation by non-native species or those better suited to the warming conditions[20]. Coarse fish, including bream, carp, roach, rudd, ruffe and tench, are thought to have been introduced to Windermere, with many of their populations increasing due to the changing environment favouring them. These species likely have been introduced as live bait by anglers [21] or from other lakes and rivers in the catchment, or illegally introduced for recreational fishing. The types of fish in the lake and their population size play two important roles in the lake ecosystem. Roach and ruffe affect other fish species in Windermere, for example, by outcompeting Arctic charr through eating their eggs (ruffe) and competing for the same food sources, such as the zooplankton. Additional pressure on zooplankton populations from fish may impact their ability to control algae, their main food source, leaving algae populations free to grow further[22].

Birds and mammals

Alongside the fish communities in Windermere, the presence of other wildlife adds to our understanding of the overall biodiversity of the area. In addition to the eDNA survey for fish, in 2015, a survey looking at non-fish data, identified otter, moorhen, cormorant and various duck and geese species as present. Other surveys by the Wetland Bird Survey have recorded over 60 species of bird in the catchment[23].

Impacts on Windermere water quality

Climate change

Climate refers to long-term prevailing weather conditions. Regional influences, including the Gulf Stream, North Atlantic Oscillation (NAO), and the El Nino Southern Oscillation (ENSO), can affect the Lake District's weather and climate[24] on varying timescales Changing weather patterns and long-term shifts in temperature and rainfall, as a result of human-induced climate change, have been shown to impact both the chemistry and biology of lakes worldwide, including in the Windermere catchment[25].

Lakes, including Windermere, are particularly sensitive to climate impacts such as water temperature increases and changes in rainfall patterns, because they can combine with other pressures such as nutrient enrichment, invasive and non-native species, and habitat degradation[26].

Temperature

Lake surface water temperature has been monitored by UK CEH and their predecessor organisations since the 1940s. It is an important characteristic of a lake ecosystem affecting lake processes including: growth rates of algae, thermal stratification patterns, and dissolved oxygen availability.

UKCEH data show that surface water temperatures in Windermere have increased by 1.7°C in the last 70 years, with an average increase of 0.02°C per year between 1945-2003[27], When comparing the periods 1961-1990 and 1991-2005, surface waters have warmed by an average of 1.1°C[28]. This trend (Fig. 7) is expected to continue or accelerate in the future.

Surface temperature

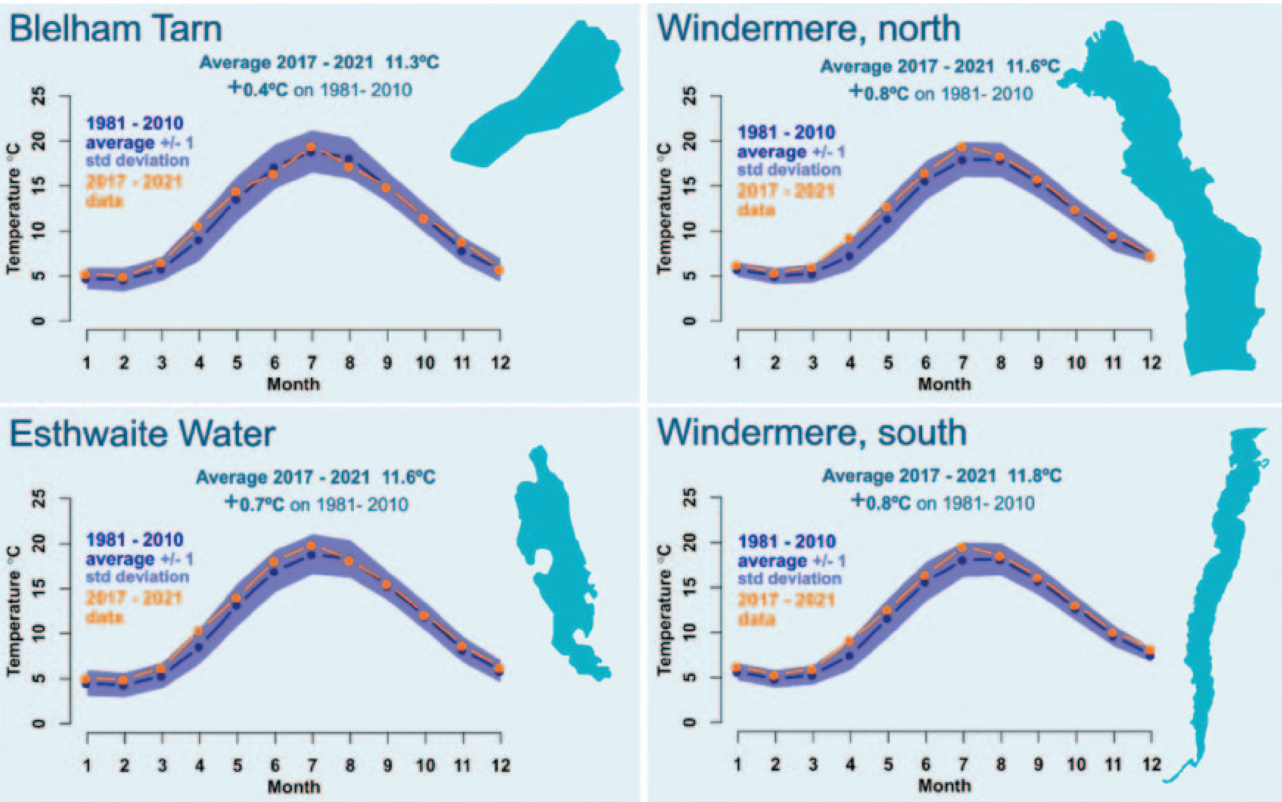


Figure 7: Long-term changes in surface water temperature in Blelham Tarn, Esthwaite Water and Windermere. Figure reproduced with permission from UKCEH blog 'The state of lakes in the Windermere catchment – a long-term view'.

Impact of water temperature on lake structure

Lake stratification occurs when lakes form distinct layers of water with different temperatures and densities. Typically, in summer, the surface layer is warmer and lighter than the cooler, deeper waters, preventing mixing between the two. During this period, decomposition of organic matter at the lakebed can reduce oxygen levels in the water, and limited mixing can constrain the opportunity for replenishment of oxygen from the surface waters. This can lead to low oxygen conditions in deeper waters or 'anoxia', which can threaten aquatic life. The longer, warmer summers driven by climate change mean the duration of thermal stratification in both basins of Windermere[29], is increasing, extending the period for which these anoxic conditions persist. In addition, one of the impacts of reduced oxygen near the lakebed is to cause chemical and biological changes that result in the release of nutrients stored in the bed sediments into the water column[30]. These then become available to support algal growth, even if other nutrient inputs from the catchment are reduced. How much this process contributes to lake water nutrient concentrations varies between lakes and is hard to study in nature so is often uncertain.

Impact of water temperature on algae and cyanobacteria

Temperature regulates the growth rate of organisms such as algae. Algae are a diverse group of organisms, with a preference for a range of environmental conditions. When combined with nutrients, higher lake temperatures have contributed to increases in the abundance of algae and subsequently the frequency and severity of algal blooms that result when these plants grow excessively. Warmer water temperatures can cause these blooms to occur earlier in the season, last longer and become dominated by cyanobacteria (blue green algae)[31]. The physiological adaptations of the cyanobacteria group enable them to outcompete many other algae in warmer waters. There is a great deal of interest in algal blooms on Windermere, especially those dominated by cyanobacteria, as they can produce cyanotoxins that are harmful to people and animals.

In addition, algae, like all living things, grow, feed, and die, and as they do so, they add to the organic material in lake sediments. As this material is broken down, the organisms responsible for its decomposition consume oxygen, reducing the amount available near the bottom of the lake. As climate change may lead to more intense thermal stratification and an increase in algal bloom events, the subsequent increase in decomposition in deep waters lacking oxygen replenishment for longer periods of the summer may exacerbate the anoxia that drives the release of nutrients from lakebed sediments, as discussed above.

Impacts of water temperature on fisheries

Changes to water temperatures have also altered how suitable Lake Windermere is for various plants and animals, including the iconic Arctic charr, which is vulnerable as a cold-water species [32].

Arctic charr, is a UK Biodiversity Action Plan (UK BAP) species. Windermere is at the southern edge of its habitat range, making them particularly vulnerable to environmental change, specifically lake temperature increases from climate change[33]. In the 1980s and 1990s, Arctic charr were seen to move from deep waters due to oxygen depletion to shallower and therefore warmer parts of the lake, less suitable for their success. [In the 1980s and 1990s, Arctic charr habitat in the south basin of Lake Windermere began to shrink due to low oxygen levels in the colder, deeper water associated with eutrophication.] In addition, the spawning grounds required by Artic charr are reducing due to the fine sediments accumulating from land runoff and the decay of algae[34]. The overall mean temperature of Windermere 1961-1990 was 10.4°C rising to 11.5°C in 1991-2005[35]. Arctic charr egg survival rate is affected above 8.5°C, and female ovulation inhibited at 11°C, leaving a poor outlook for Arctic charr[36].

While some fish species (Arctic charr) suffer with increasing temperatures, others such as roach and other coarse fish thrive because their biology allows them to tolerate warmer temperatures, putting additional pressure on Arctic charr through competition[37] and altering the balance between zooplankton and algae described previously.

Rainfall

The Lake District experiences the highest annual rainfall in England, which varies significantly across the region and between seasons.

Annual mean rainfall for the Level catchment is over 2m. There have been notable dry and wet periods over the last 200 years and when comparing the wet 1990s with the dry 1880s there has been a notable decline in summer precipitation (-9%) offset by increases across spring (+24%), autumn (+11%), and particularly winter (+37%). This pattern has been more obvious since the 1960s[38]. December 2015 was the wettest (and one of the warmest) December's in the last 200 years.

Intense, heavy rainfall can increase the run-off of sediment, nutrients, bacteria, and other contaminants into the lake [39]. If rainfall frequency and intensity increase with climate change, the run-off from soils, slopes and fells together with further erosion of footpaths could worsen[40]. Intense, heavy rainfall also increases the likelihood of sewers becoming overwhelmed and subsequent operation of storm overflows. It is generally understood that during heavy rainfall periods, raw wastewater is diluted when spills occur, however, in still waters such as lakes, the time it takes for water to pass through the lake (retention) means nutrients and other pollutants from raw wastewater discharges may remain in the lake for longer[41] than is the case for most rivers.

That said, there has also been limited evidence of increased rainfall reducing nutrient concentrations through dilution and flushing in smaller lakes within the catchment, while decreased summer rainfall can also exacerbate issues associated with stratification, nutrient enrichment, algal growth, and sediment resuspension due to increased water retention times[42].

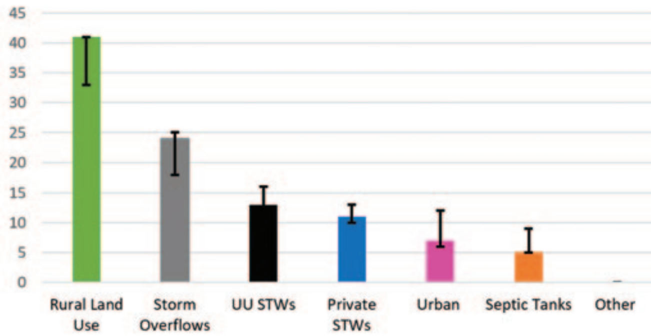
Climate change will continue to drive change in Windermere, both directly through increasing water temperatures, stratification and changing rainfall impacting the retention time of the lake and by interacting with other drivers (e.g. nutrients, invasive non-native species). Expected and ongoing changes, such as extended periods of dry and wet weather, will affect water quantity and quality, with most water courses projected to experience declines in water quality[43]. This highlights the need for continuing research and management action to keep up with a constantly shifting baseline[44], given the potential short- and long-term consequences for both people and the environment.

Nutrient pollution

An investigation in 2023 by the Environment Agency using the Source Apportionment Geographical Information System (SAGIS)[45] modelled the proportion of the total amount of P coming from different sources into Windermere. It identified that 52% of total P in the North Basin is associated with point sources (i.e. private and public wastewater discharges), whereas 48% is related to diffuse sources (i.e. land use and septic tanks). In the South Basin, 59% of total P is associated with point sources and 41% with diffuse sources (Fig. 8). The model was run following completion of Asset Management Plan[46] (AMP 6) in 2020, and the data used in the model is summarised in the report.

SAGIS has only been run for P, not N, at this time.

Total Phosphorus Source Apportionment (%) - Windermere North Basin, post 2020



Total Phosphorus Source Apportionment (%) - Windermere South Basin, post 2020

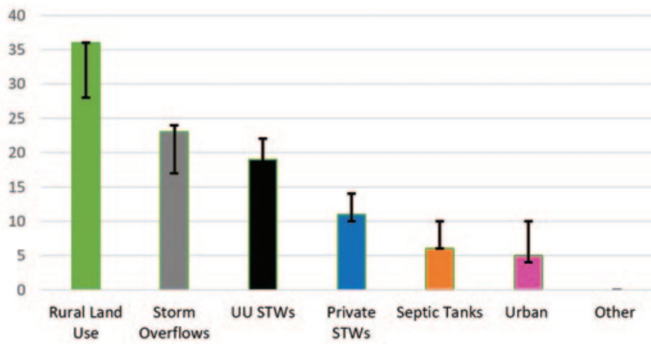


Figure 8: EA total phosphorus SAGIS results for the North and South Basin.

People

Windermere's sediments can be used to understand changes in the catchment since the lake formation 14,000 years ago. Impacts have increased more recently from changes in land management, the growth in tourism and recreation and expansion of settlements[47]. These have contributed to the water quality seen today.

Human activity throughout the Windermere catchment, combined with our changing climate, continues to put pressure on the environment.

Resident population

Westmorland and Furness Council estimate the Windermere catchment's resident population to be between 14,000 and 17,500 individuals. Windermere attracts a significantly higher number of visitors.

Visitor population

In 2021, the Environment Agency collaborated with Cumbria Tourism and Global Tourism Solutions to identify a suitable catchment area (Fig. 9) around Windermere for modelling visitor activity around the lake[48]. This area is like the water catchment shown in Fig. 1, but is slightly extended to the west, east and southeast. Analysis undertaken through this work showed that this catchment hosted 7 million visitors in 2019, typically peaking during the summer school holiday months of July, August and September, although visitor numbers remain elevated from April to October. The visitor population contributes £753 million in economic impact, including 9,315 full-time equivalent positions. Those 7 million visitors a year, when spread equally throughout the year, equate to 19,178 additional people daily in the Windermere catchment, more than doubling the resident population.

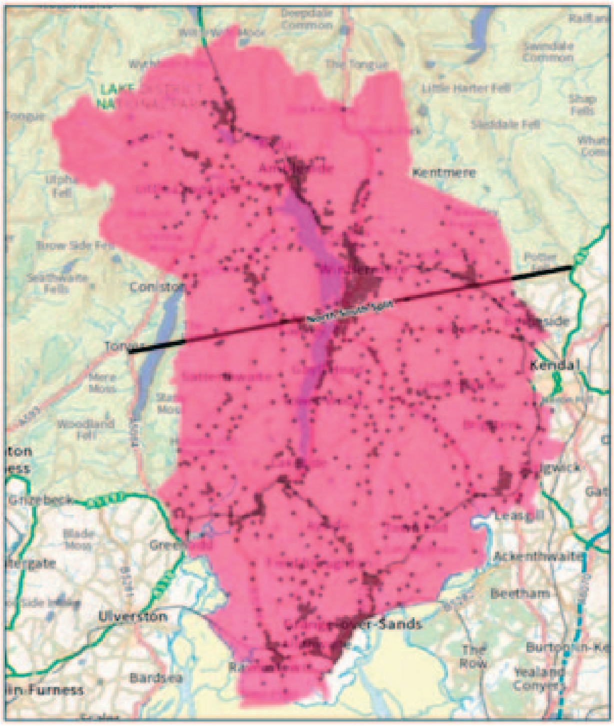


Figure 9: Windermere Catchment area appropriate for the purposes of modelling visitor economy activity in the area around the lake.

Year	Cumbria Total Visitor Numbers	Lake District National Park Visitor Numbers	Value to Cumbria	Value to Lake District National Park
2012	37.97m	14.84m	£3.14bn	£1.49bn
2019	47.90m	19.89m (Windermere Catchment 7 million)	£4.38bn	£2.15bn
2020	24.08m	9.77m (likely due to coronavirus pandemic)	£2.33bn	£1.08bn
2022	41.38m	17.83m	£4.67bn	£2.35bn
2023	42.42m	17.83m	£4.65bn	£2.30bn

Table 3: Scarborough Tourism Economic Activity Monitor (STEAM) data

Cumbria and the Lake District National Park received 42 million visitors in 2023, bringing £4.65 billion to the local economy and providing 45,882 full-time equivalent jobs. In addition to providing employment and being of economic importance, the visitor economy has a broader and significant role to play in supporting vibrant communities. This includes driving regeneration, supporting public transport and schools, underpinning a resilient supply chain, and maintaining culture, arts, and heritage assets.

Tourism now underpins the economy of the central Lake District.

A survey[49] undertaken by Cumbria Tourism in 2020, asking why people visit showed that while only 16% came to spend time on the water, 79% came for the physical scenery and landscape, highlighting the intrinsic value of lakes within the Lake District landscape.

Little is known about the direct and indirect impacts of recreational lake users on the environment beyond pressure on wastewater treatment activities. Well used and walked areas can lead to footpath erosion, and lake margins may be affected by walkers and other water recreation uses, for example, boats can damage lake shore reedbeds and other habitat that in themselves help remove nutrients from the lake's water. The National Trust monitored the shore at Harrowslack and areas around Blea Tarn during peak season weekends in 2024 and noted an increased amount of litter and use of the area for camping and campervanning. These activities can cause pollution through lack of drainage facilities and toilets for human waste, as well as the impacts litter can have on wildlife and lake health. On the days monitored, almost 90 hours was spent by National Trust Rangers litter picking at Harrowslack and Blea Tarn.

Wastewater

Infrastructure

Approximately 2,000 pieces of wastewater infrastructure, referred to as assets, are permitted to discharge wastewater into the Windermere catchment, excess nutrients not absorbed by plants or through natural degradation ultimately reach the lake. Assets include household septic tanks, privately owned and operated package treatment plants, such as those used by non-household activities like hotels or campsites, Wastewater Treatment Works (WwTWs) and storm overflows operated by United Utilities (UU). Wastewater, which includes sewage and used (grey) water, contains the nutrients phosphorus and nitrogen, which can contribute to algal blooms, as well as bacteria and other contaminants such as pharmaceuticals.

There was a notable acceleration of nutrient inputs in the 1960s due to the growing human population and the centralisation of wastewater treatment[50], which was followed by significant reductions in nutrients in the 1990s.

Around 60% of the total P input to Windermere is from wastewater from water company and non-water company discharges.

Water company wastewater treatment

UU has 10 WwTWs and 6 storm overflows (see Fig. 1), in the Windermere catchment. Three storm overflows are located at the WwTWs in Grasmere, Ambleside and Near Sawrey. Three further storm overflows are located at wastewater pumping stations in Elterwater, Hawkshead and at Glebe Road in Bowness in Windermere. There is one additional emergency discharge point at Esthwaite Lodge. Where treated or 'storm overflow' wastewater is discharged into lakes and rivers, it is done so by permission under a 'permit' issued by the Environment Agency. The level to which treatment is set is based on factors such as the volumes discharged and the environment it is being released into. Limits are reviewed by the Environment Agency when required. These permitted sites are inspected and sampled by the Environment Agency to assess compliance; the raw data are publicly available here (Open WIMS data).

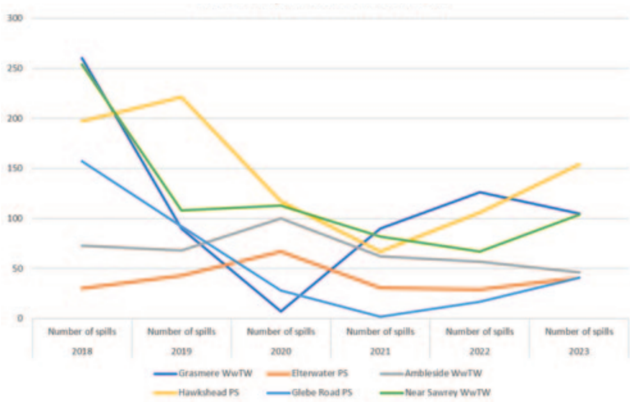
Water company storm overflows

In dry weather conditions, sewers across the Northwest, carry wastewater away for treatment, and are typically no more than 16% full[51]. When it rains, this 'dry weather flow' of 16% is combined with rainwater. This is because a large proportion of the sewer pipework across the Northwest is combined, so there are no separate pipes for surface water run-off and wastewater from homes or businesses. During heavy rain, when sewers are full of additional rainwater, and storage tanks at treatment works have been fully utilised, storm overflows are designed to act as a pressure relief valve to prevent wastewater backing up via toilets, drains and blown manholes on roads and fields, flooding homes and businesses. They allow rainwater mixed with wastewater, to be discharged to a river or lake by a permit issued by the Environment Agency.

If a storm overflow discharges outside of periods of heavy rain, this is termed a 'dry weather spill'. These discharges contain higher levels of bacteria and nutrients along with other elements than treated sewage discharges. In such situations, they may cause harm to the environment. It is the Environment Agency's role to investigate the reasons for these occurrences, whether a breach of permit conditions has occurred and to appropriate compliance and enforcement if a breach is believed to have happened.

Storm Overflows are monitored with Event Duration Monitors (EDM), which record the number and duration of spills (Fig. 10). Each sensor captures data signals every 15 minutes.

Number of spills from storm overflows



Duration of spills from storm overflows

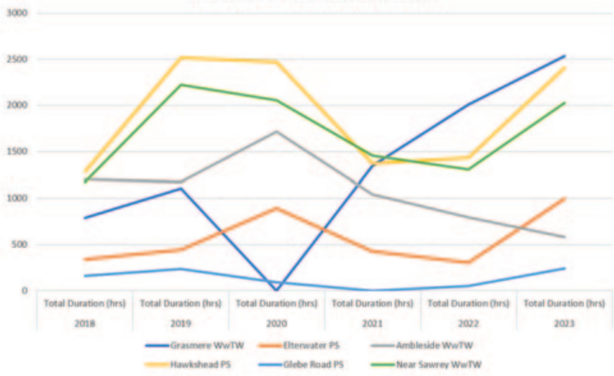


Figure 10: EDM Data 2018 – 2023, No. of spills and duration of spills.

The data is reviewed and shared with the Environment Agency. These describe when a flow is operating but does not provide information about the content or amount of the overflow water.

Water companies are required by law to submit data on overflow discharges to the Environment Agency. An annual report of this data is available Event Duration Monitoring - Storm Overflows - Annual Returns.

A live view of storm overflows can also be found here: www.unitedutilities.com/better-rivers/storm-overflow-map/ Storm overflow map | United Utilities - Better Rivers.

United Utilities investment

Over the last 24 years, UU has invested more than £75 million upgrading wastewater treatment sites (WwTW), pumping stations and sewers in the Windermere catchment. Investment follows Environment Agency requirements that standards should be tightened, and permit limits changed at specific locations. Currently, 6 of the 10 WwTWs (Ambleside, Grasmere, Hawkshead, Langdale, Outgate and Windermere) have a permit limit for Total Phosphorus, ranging from 0.25mg/l - 2mg/l of total phosphorus[52]. The former, which is set at Windermere, is defined as the technically achievable limit – the best standard of treatment available. In general, the standard achieved from primary and secondary wastewater treatment delivers an average Total Phosphorus concentration of 6mg/l for all domestic wastewaters. It is the addition of specific phosphorus removal techniques that lead to this lower level of total P concentration.

Need a sentence or 2 to explain what a Total P standard is – so far not defined and yet mentioned later – I don't have the words but this is probably where it needs to go

As part of UU's next phase of investment, in the period between 2025 and 2030, UU has been approved to invest a further £200 million, which means sites operated by UU will have total phosphorus standards added to all WwTWs at a minimum of 'high' phosphorus removal of 0.5mg/l or the technical achievable limit (TAL) of 0.25mg/l alongside other tighter permit conditions (Table 4). These limits will come into effect as those improvements are completed over the next five years.

UU's planned £200 million investment in AMP 8 between 2025 and 2030 will include reducing spills at all storm overflows to an average of 10 per annum or less in the same timeframe.

United Utilities Site WwTW	Phosphorus	Other
Ambleside	Technically achievable limit (TAL)	Spill frequency reduction and screening
Far Sawrey	High standard of P removal	Improvements to BOD, ammonia and suspended solids (SS)
Ferry House	High standard of P removal	
Grasmere	TAL for P removal	
Hawkshead	TAL for P removal	Improvements to BOD, ammonia and SS
Langdale	TAL for P removal	Improvements to ammonia
Near Sawrey	High standard for P removal	Improvements to ammonia
Outgate	High standard for P removal	
Troutbeck	High standard for P removal	Improvements to BOD, ammonia and SS

Table 4: Phosphorus standards set for completion (2025-203 investment period) at United Utilities sites in the Windermere catchment.

Non-UU permitted sites

In addition to UU sites, many private properties and businesses are some distance from mains sewers and manage their own wastewater. There are 89 permits held by private individuals or companies managing their wastewater treatment in the Windermere catchment and a further 10 just downstream of Newby Bridge at the outflow of Windermere. The Environment Agency regulates these sites against the conditions set out in their permit. The total combined permitted discharge volume from these sites is equivalent to the permitted discharge from Ambleside WwTW – 1800m3/day. Permit limits for phosphorus removal are generally only applied to larger volume discharges such as those from water company operated sites. These sites therefore typically don't include phosphorus removal in the treatment processes prior to discharge to the environment.

In addition, there are an estimated 1,800-2,000 smaller private sewage treatment facilities that are subject to General Binding Rules (GBR)[53] – GBR applies to small wastewater discharges from septic tanks or small treatment plants. Operation under GBR requires the ability to meet a list of criteria, including location, operating standards and maintenance. Septic tanks offer a basic level of wastewater treatment via a two-step process; the settlement and 'treatment' of solids by bacteria within the tank, then bacteria in the soils of the 'soakaway or drainage field'. Septic tanks are considered a 'diffuse' source of phosphorus because the discharge is often to land via soakaway/drainage field rather than a point discharge to water. It should be noted that some septic tank drainage fields are situated near lakes and rivers, in areas where the natural 'water table' is high, or on steep gradients or shallow soils where the discharge to water courses may be more direct. In addition, over time, drainage fields can become saturated from continuous discharge, this can reduce their ability to support naturally occurring bacteria that help break down any remaining waste.

Land cover and change

The landscape of the Lake District and Windermere catchment has changed and evolved since the retreat of glaciers 17,000 and 10,000 years ago, and Windermere, along with the other lakes, is a legacy of that time.

In more recent history, since the occupation by people around 12,000 to 5,000 BC, lake sediment records evidence agriculture, forestry and deforestation, industry including mining and fisheries, urbanisation, transport and tourism[54].

In the 6th to 8th centuries, agricultural ploughing, and sheep, cattle and pig grazing expanded, leading to soil loss, which accumulated in lake sediments. In the 12th and 13th centuries, the wool industry and associated deforestation increased, and valley floors were drained to increase grain production. Charcoal production for iron smelting and gunpowder manufacture led to greater woodland management, which continued here into the 20th century. In the late 18th century, reforestation attempts were made along the west shore, including non-native larch. Exotic trees continued to be introduced in the 1800s on larger properties and estates. Between the 18th and 19th centuries, there was a shift from arable to livestock farming, and drystone walls were constructed. Land cover changed from temporary grassland and woodland to permanent grass and rough grazing, with land primarily being used for pastoral sheep farming between 1866 and 1988[55]. Arable farming represented 7.6% of land use in 1870, declining to less than 3% thereafter, with further declines since 1961[56].

Beef and dairy cattle farming largely occur in the lowland south, with higher ground used for sheep production. Poor catchment soils support mixed woodland (sessile oak and ash) with deforested areas dominated by bracken, lowland wetland, and fields. Higher ground supports moorland vegetation with bogs developing in areas of poor drainage. About 10% of land is used for woodlands and commercial forestry operations, with coniferous trees planted from the 1960s to the 1980s.

This is a national scale data product and should be viewed with some caution when used to represent local catchment scale habitats.

There are low concentrations of heavy metals such as copper, lead, zinc and cadmium in Windermere today, but we know that these contaminants have been deposited as a result of human activity in the past. Algae may have absorbed these heavy metals and then as the algae decompose, the heavy metals became incorporated within lakebed sediments[58].

Land cover in the Windermere catchment 2020

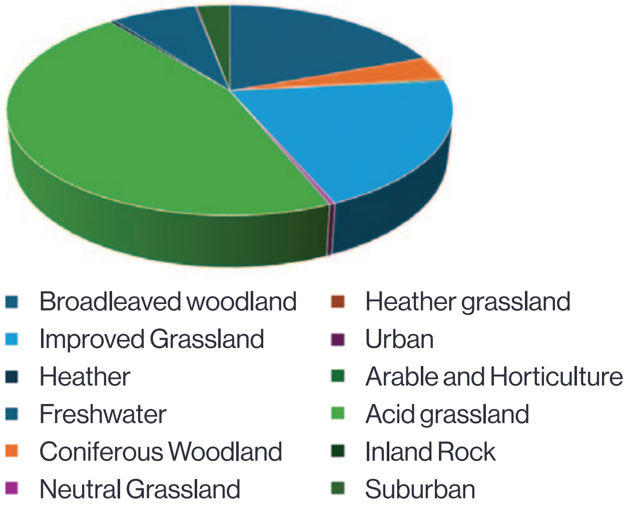


Figure 11: Land cover map 2020[57], shows land use cover in the catchment.

Land management

While modern land-use practices, like wastewater treatment practices, increasingly adopt methods that reduce their impact on water quality, historic practices in land use still contribute to the issues we see today. Soil testing and nutrient management plans help to ensure the use of fertiliser is kept to a minimum, avoiding additional nutrient contributions. Soils can be managed to reduce erosion and the further accumulation of sediments which affect the spawning grounds of important fish species such as Arctic charr. Management practices can also help ensure that new or old nutrients are held within the soils and kept on the land where they can be utilised by plants.

Some land-use and management approaches within a catchment can help reduce further inputs of nutrients and sediments to the lake and can help restore important habitat to balance the lake ecosystem.

Riparian or river/lakeside woodland exists in the catchment and this type of land-use can play an important role in intercepting nutrients and sediment and regulating the water temperatures critical to aquatic plants and animals; however, current coverage can't be determined from either the 2007 or 2020 Land Use Cover maps. In addition, the Cumbria Local Nature Recovery Strategy pilot map shows 655.68ha of wetland habitat (not open water) in the catchment, wetland habitats support a wide range of species but also act to slow the flow of water during intense rainfall events. Tree planting, wetlands and peat restoration have additional benefits of mitigating climate change through their carbon capture.

Comforted or discouraged?

Windermere water quality has been studied by many scientists working for different organisations over several decades. The recent upsurge in people who volunteer as Citizen Scientists is adding to our collective understanding of current water quality and how it may change.

Data tells us that we can be confident in:

- Windermere's 4 designated bathing waters have consistently received the highest classification, 'excellent,' under the Bathing Water Directive since 2015.
- Levels of Total Phosphorus have improved notably since the 1990s and have remained relatively stable for the last 15 years. Windermere received 'good' status classifications under Water Framework Directive for Total Phosphorus in 2022.
- Levels of Total Nitrogen are also stable receiving 'good' status for the South Basin.
- Annual mean concentrations of cholophyll-a as an indicator for abundance of algae remain consistently lower in Windermere than other lakes in the Windermere catchment.
- The presence of many species of fish, including those indicating clean water and high-quality habitat, such as the Atlantic salmon and sea trout. The presence of otters further indicates a high-quality environment.

However, we should not be complacent:

- Not all parameters under Water Framework Directive achieve 'good' status for Windermere.
- Total Nitrogen levels for the North Basin are 'moderate' under the Water Framework Directive, and there is more work to be done to better understand the role nitrogen plays in Windermere.
- Climate change is impacting the chemistry and biology of lakes worldwide. Windermere has not escaped this threat with lake temperatures rising by 1.7 °C in the last 70 years.
- Increased temperatures combined with nutrients increase the frequency and duration of algal blooms. Cyanobacteria (the algal group that can produce the harmful cyanotoxins) are better adapted to warmer temperatures and we are likely to see more of this type of bloom in the future.
- Populations of fish species are changing due to competition from those favouring warmer temperatures, and the introduction of non-native species that cause a double impact of outcompeting Arctic charr by eating eggs, but also in grazing on the predator to algae – zooplankton. The iconic Arctic charr in Windermere is already at the most southerly extent of its suitable habitat and temperatures continue to rise.
- Increased frequency of intense heavy rain increases the run-off of sediments, and the nutrients and other contaminants within them, into the lake, adding to nutrient inputs and affecting fish spawning grounds with fine particulate matter. These downpours also put additional pressure on sewer networks, increasing the frequency of storm overflows.
- The 7 million people who come to the Windermere catchment to enjoy its landscape and natural environment more than double the resident population every day of the year, putting pressure on the natural environment, but also bringing £753 million in economic impact and supporting over 9,000 jobs (2019).

Ongoing and planned action

The Love Windermere Partnership are committed to providing accurate information guided by science and data. We are grateful to the science professionals and academics that research lakes monitor this iconic place and there guidance to us in producing this report.

We are also grateful to the people who gave up their time in 2023 to attend the Management Plan development sessions facilitated by Dialogue Matters and earlier 2022 Citizen Panels facilitated by Involve, we are using this feedback together with science and data to inform our Action Plan that will be published later this year. While the Action Plan will give further detail on the work that is being delivered or is planned please be assured we are not waiting for that to do the work that needs doing.

To keep informed please sign up to the Partnership newsletter.

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