Scottish Natural Heritage
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Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Reducing other pressures: reversing a legacy of water pollution at Loch Leven national nature reserve

Our freshwater systems are subject to a wide range of pressures from both human activity and climate change, depending on where they are located. Perhaps there is no better example of a freshwater loch that is subject to a wide range of pressures than Loch Leven. A National Nature Reserve (NNR) located mid-way between Edinburgh and Perth in the central Lowlands of Scotland, Loch Leven is surrounded by towns, villages, arable farming and industry. As a result of competing demands on its freshwater resource, it has long battled with water pollution. Climate change impacts can exacerbate the effects of pollution, and where this occurs, management of water quality becomes even more important.

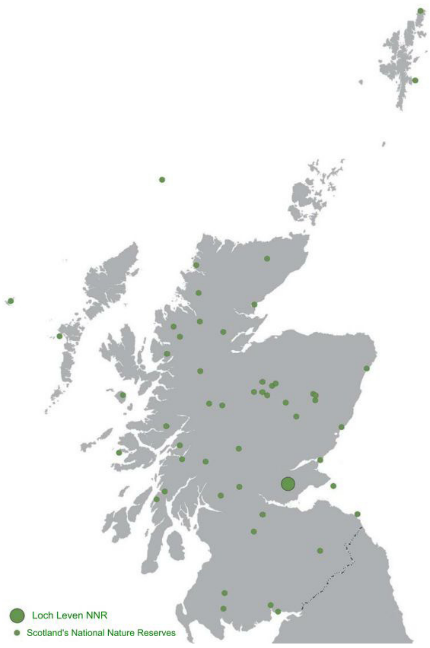
Although we can do things to try to reduce or mitigate climate change, it is already affecting our freshwater habitats. Therefore, we must look at how we help our most vulnerable freshwater habitats to adapt to the effects of climate change. One option is to try to reduce the wide-ranging 'human' pressures causing poor water quality in the first place. Here we explore how improved land management around Loch Leven has improved the water quality and resilience of the loch to future pressures we may not be able to control.

1. The climate risk: multiple pressures on our standing freshwaters

Loch Leven National Nature Reserve is home to the largest eutrophic or 'nutrient rich' freshwater body in lowland Scotland (Map 1). Loch Leven's nutrient rich waters support abundant food sources making it attractive to a wealth of birds, and earning it both National and International conservation designations.

The day-to-day management of the loch is shared between Scottish Natural Heritage, who manage most of the Nature Reserve (including 1300ha of loch and islands) and Kinross Estate who manage the fishing and shooting. The RSPB, Perth and Kinross Council and Historic Environment Scotland manage specific areas and amenities, and the River Leven Trustees are responsible for managing the loch's water levels.

Climate change has been identified as one of several interacting controls on water quality at Loch Leven (Carvalho *et al*, 2012; Dudley *et al*, 2012a; Spears *et al*, 2012). Surrounded by towns, villages, arable and cattle farming and industry, Loch Leven suffered serious degradation primarily due to the effects of nutrient enrichment (May *et al*, 2012). While Loch Leven is a relatively nutrient rich water body, human activities can accelerate the rate at which nutrients enter ecosystems causing the nutrient balance to be disrupted. Detailed water quality monitoring by the Centre for Ecology & Hydrology (CEH) shows that whilst point source discharges were addressed in the late 1990's and levels of pollution have declined over the last five years, diffuse pollution continues to cause problems. This is an important issue because the degradation or loss of any part of an ecosystem can reduce its resilience, i.e. its capacity to tolerate environmental alterations such as climate change (Folke *et al*, 2004). Recent improvements in water quality and ecological health at Loch Leven (Carvalho *et al*, 2012; Dudley *et al*, 2012b) may prove important for the ecosystem's capacity to adapt to future climate change.



Map 1. The distribution of Scotland's NNR's, and the location of Loch Leven NNR in east central Scotland.

Loch Leven has been important to people living around its shores for centuries; using its waters at various times through history for a world famous trout fishery, industry, recreation, and waste disposal. Figure 1 lists key benefits or 'services' Loch Leven provides to people.

Figure 1. A summary of ecosystem services provided by Loch Leven (adapted from May & Spears, 2012).

Loch Leven's well documented history of water quality problems resulting from nutrient enrichment included an increase in the frequency of algal blooms at the site. By the mid-1980s these had become a serious threat to the high conservation, recreational and economic value of the loch. Let us take a look at how this threat came about.

Industrial pressures: meeting the demand and point-source pollution

In the mid-1830s, Loch Leven underwent a range of hydrological modifications to provide a more reliable water supply to downstream industry. These modifications included straightening of the outflow to lower the water level and the installation of sluice gates to control discharge (Munro, 1994). The water depth was reduced by 1.4 m and the surface area by 4.5 km^2.

Changes in the depth and size of Loch Leven affected its ecology. The installation of sluice gates prevented salmon, sea trout and charr from entering via the outflow, and the lowering of the water level adversely affected the habitat and food supply of the fish community. However, the associated 25% increase in flushing rate may have helped reduce the likelihood of algal blooms in later years, when the loch started to become a more nutrient rich system.

The observed degradation in water quality from the 1960s to the 1980s was attributed mostly to increased discharges from waste water treatment works and effluent from industrial sources. By 1985, some 57% of the total phosphorus (TP) input was attributable to these sources (Bailey-Watts & Kirika, 1987).

Land management pressures: diffuse pollution in an agricultural catchment

Around 80% of Loch Leven's catchment is in relatively intensive agricultural use, consisting of predominantly arable ground with cereals, potatoes and other vegetables. Fertiliser-laden runoff from farms, together with soil erosion from fields, adds to the build-up of nutrients in the loch, particularly phosphorus.

Some parts of the catchment have severe soil erosion problems, caused by the topography of the fields and steeply sloping ground above (Figure 2). Much of the erosion occurs during heavy rainfall events, which, anecdotally, have increased in frequency and severity in recent years. Surface run-off originating on the steep slopes of the Lomond, Ochil and Cleish Hills, is channelled across arable fields (Figure 3) causing soil erosion, which eventually makes its way into Loch Leven. Eroding gullies 20-30 cm deep were annually recorded in some arable fields – a classic hotspot feature (Lockett, 2014).

Figure 2. A field prone to soil erosion in the Loch Leven catchment. Note the steeper ground in the background.

Combined, these sources of nutrient enrichment caused algal blooms which reduced the clarity of the water so much that by 1990 plants could only thrive in water less than two metres deep (May & Carvalho, 2010; Dudley *et al*, 2012b). This in turn reduced the diversity and abundance of plants and invertebrates in the loch (Dudley *et al*, 2012b; Gunn *et al*, 2012).

Pressures from a changing climate

It is often assumed that climate change will have negative effects on water quality, especially an increased frequency and severity of algal blooms (Paerl & Huisman, 2008). Research by CEH at Loch Leven demonstrates that climate change cannot be viewed as a single 'pressure'. Some seasonal changes in temperature and rainfall can have positive impacts on water quality whilst other seasonal changes can have negative impacts (Carvalho *et al*, 2012; Defew, 2005 and see Table 1). The net effect of climate change on Loch Leven is complex; to some extent it is dependent on whether seasonal changes in rainfall or temperature are greater).

Projected climate change	Effects on Loch Leven	Effect on water quality?
Hotter, drier summers	*Reduced run-off and associated low loch during a dry summer may increase the concentration and residence times of pollutants.*	–
	Reduced run-off reduces the influx of pollutants from diffuse sources over the summer.	+
	Warmer temperatures result in reduced dissolved oxygen concentration of the loch water. De-oxygenation of the deeper waters can lead to a release of phosphorus and nitrogen from the loch sediments. This increases the internal nutrient load to the loch.	–
	Warmer summer temperatures will, however, also lead to increased denitrification, reducing nitrate concentrations in the loch.	+
	Algal blooms occur naturally at Loch Leven, but during warm, dry and calm weather, they can be more severe, especially when there are too many nutrients in the water.	–
Milder, wetter winters	*Wetter winters will increase erosion and subsequent silt and nutrient-laden run-off to the loch.*	–
	Wetter conditions can also lower the water residence time within lochs and increase flushing, which may reduce the concentration of nutrients within a loch, if the water entering the loch has a lower nutrient load than the loch water.	+
	Early commencement of growth of macrophytes and emergence of zooplankton feeding on algae reduces likelihood of algal blooms.	+
More extreme weather (e.g. high winds, very heavy rain)	*Spells of windy weather cause turbulence in the water column, which mobilises pollutants stored in the loch-floor muds, back into the water column.*	–
	Intense rainfall events can cause severe localised soil erosion problems, increasing the flux of soil and pollutants to the loch.	–

Table 1. A summary of some of the possible effects of climate change on Loch Leven.

Low flushing rates at Loch Leven during summer have led to an accumulation of phosphorus in the silts and muds lying on the bottom of the loch (Spears *et al*, 2012). The combination of warmer, drier summers, wetter winters and more extreme rainfall events projected for the future in this part of Scotland means that preventing soil and nutrients getting into burns (Figure 3), drainage ditches and ultimately into the loch is increasingly important.

Figure 3. Arable field flooded during heavy rain, with tonnes of topsoil washed into watercourse. Image: Brian D'Arcy, 2011.

In future, east-central Scotland is projected to experience hotter, drier summers (Murphy *et al*, 2010). A warming trend here may exacerbate some water quality problems, particularly harmful algal blooms, if the nutrient load is not controlled in the long term (Table 1).

In order to future-proof the loch and the many benefits or 'services' it brings local communities and industries (Figure 1), we have to continue to reduce pollution pressures.

2. The adaptation measures: reducing other pressures

Industrial pressures

Between 1985 and 1995, controls were imposed on industrial discharges (May *et al*, 2012) and local sewage treatment facilities were upgraded, reducing the TP input to the loch by around 60%.

A 53% reduction in diffuse inputs of TP was also recorded between 1985-1995 (Bailey-Watts & Kirika, 1999). By 1995, the external TP load to the loch had fallen to about 8 t y^{-1}, although some of this reduction may have been caused by variation in rainfall rather than changes in catchment management activities.

Land management pressures

Scottish Natural Heritage has funded work to raise awareness of the issue of agricultural diffuse pollution and to help farmers do what they can to reduce the risk of nutrient and soil losses. The latest project involved a series of workshops for land managers and potato contractors as well as one-to-one farm visits. On a practical level this builds on work carried out in the late 1990s, which focused on the creation of buffer strips on either side of water courses to help prevent soil laden run-off from making it into the burns (Figure 4). Erosion prone crops, such as potatoes, can be a particular issue and cultivating fields after harvesting makes a big difference. The project initiated innovative solutions such as silt traps (Figures 5a & 5b); filter fencing (Figure 6) and interceptor drains where erosion problems are locally severe. Buffer strips (Figure 4) continue to play an important role, along with soil testing, steading improvements and the careful use of fertilisers and manures.

Figure 4. A stream and buffer strip near Milnathort in the Loch Leven catchment. Densely vegetated buffer strips trap soil from neighbouring fields, preventing it from entering the watercourses.

Figure 5a. Ditch filled with silt running into silt trap.

Figure 5b. The silt trap full of eroded soils from nearby fields. The pipe under the path is 600mm diameter.

Figure 6. A filter fence in the Loch Leven catchment trapping soil eroded from agricultural land. Filter fencing has to be carefully put in along the contour line or it will just focus the runoff downhill.

Other tactics employed across the Loch Leven catchment include working closely with farmers to:

– encourage strict adherence to farm waste management plans for slurry/manure spreading;
– improve natural infiltration of catchment soils and percolation to groundwater by restoring organic matter levels and avoiding soil compaction by stock or heavy machinery;
– make sure that any crops grown are appropriate to the erosion sensitivity of the land in order to minimise erosion and siltation of water courses;
– encourage farm nutrient budgeting to ensure nutrient (nitrogen and phosphorus) applications to crops are the minimum necessary for healthy growth, based on methods with high uptake efficiencies;
– encourage use of low-nutrient livestock feeds with high efficiencies of nutrient uptake; and
– convert flood prone fields into permanent grassland or woodland management and reduce river bank erosion by planting riparian habitat.

Planning and septic tanks

Perth and Kinross Council Local Plan Policy requires that all new development proposals within the Loch Leven catchment, that are not discharging to mains drainage, must include phosphorus mitigation measures. Applicants must demonstrate that the proposed waste water treatment system will produce no net increase in TP loading associated with their development. This usually results in a higher standard of waste water treatment than would be the norm and can also include upgrades to existing septic tank systems.

3. The result: a more resilient freshwater system?

Loch Leven's recovery has been slow despite the wide-ranging management interventions. Researchers found that, because of the large internal sources of phosphorus that accumulated in the loch floor muds over decades of pollution, it has taken more than 15 years for water quality to respond to the reduced inputs from the catchment.

Evidence from Loch Leven indicates that the abundance of algae in the last six years is now much lower than previous decades (Figure 7).

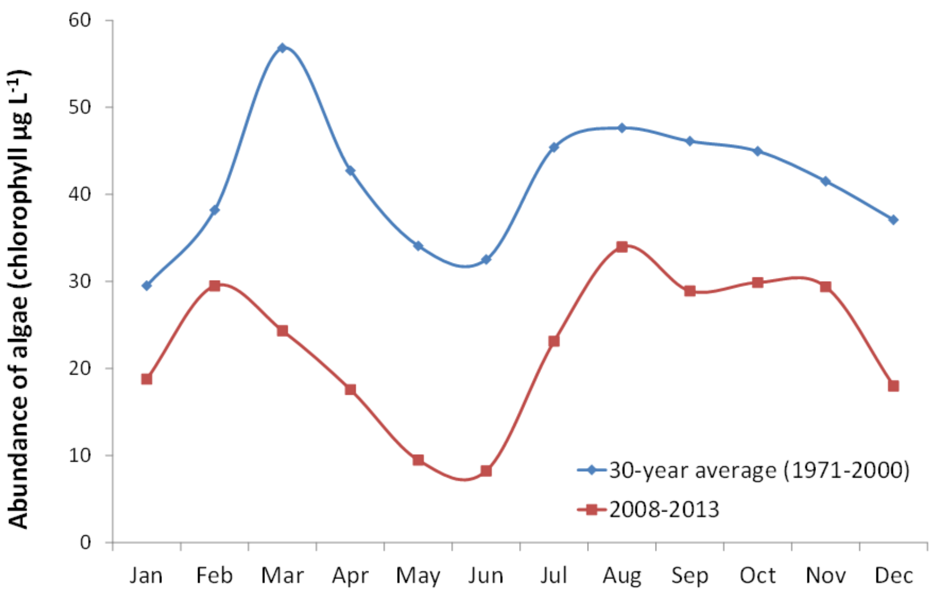


Figure 7. Graph showing the monthly abundance of algae in Loch Leven over the last 30 years, and during the period 2008-2013, reflecting an improving water quality situation.

The great news is that aquatic plants have responded to the reduced nutrient inputs from the catchment, growing once more in deeper water of up to 4 metres depth, and returning to some of the shores from where they had previously disappeared (May & Carvalho, 2010). One species, long-stalked pondweed (*Potamogeton praelongus*), has recently been re-recorded in Loch Leven after an absence of over 100 years (CEH, *pers. comm*).

Encouragingly there are some early signs that Loch Leven is becoming steadily more resilient to the effects of hot, dry summers. The abundance of algae in 2013, a hot dry summer, was relatively low (Figure 8) and potentially harmful cyanobacteria (blue-green algae) were recorded at high levels for shorter periods of the summer than previous decades (CEH, unpublished data – *pers. comm*).

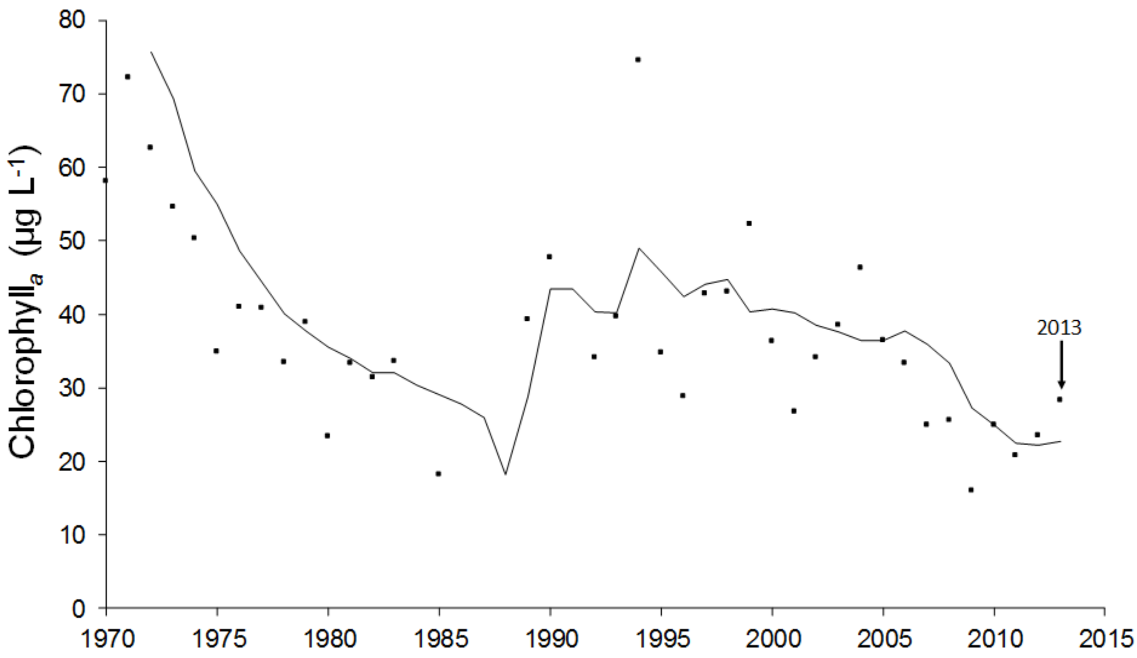


Figure 8. Graph showing annual concentrations of algae in Loch Leven. Note that despite being a hot, dry summer 2013 ranks fairly low.

Extended periods of recovery are common in water bodies like Loch Leven, but with a catchment management plan in place to ensure external pressures are tightly controlled, the loch now stands a better chance of long-term recovery and adaptation to future climatic pressures. Reducing nutrients, especially phosphorus, is important for reducing the severity of harmful algal blooms associated with climate warming (Carvalho *et al*, 2013). With such long lead-in times for some adaptation measures, it is important to start adaptation early.

4. Wider benefits

Reducing pressures on Loch Leven, and the associated improvement in water quality and ecosystem resilience is providing many wider benefits or ‘ecosystem services.’ As outlined in Figure 1, these can be split into four categories. Here we look at some examples.

Supporting services

- bird species that feed in the loch, such as coot, great crested grebe, tufted duck and pochard, have all been increasing since 2000, bucking national trends (Carss et al, 2012).
- holy grass (*Hierochloe odorata*) spread significantly in emergent vegetation around the margins of Loch Leven.
- extent of fringing reed beds – an important home to many species - has increased 3x since the 1970s.

Provisioning services

- fish catches (per hour fishing) in 2013 were also some of the highest recorded in the past 40 years, with the largest brown trout on record caught in 2013.

Cultural services

- the total value of the ecosystem services provided by Loch Leven for angling, bird-watching, recreation and tourism is being examined in current research and is likely to be substantial.
- Loch Leven is now promoted as a destination, and part of the promotion includes its image as a large clear loch with thriving wildlife. In 2012 there were up to 300,000 visitors to the loch.
- to accommodate the increasing visitor numbers, a number of facilities have opened immediately adjacent to the loch, including a circular trail around the loch, which is the longest continuous all-abilities trail in Scotland.

Regulating services

- as well as improving water quality, other initiatives around the margins of the loch include reversion of agricultural land to wetland at RSPB Loch Leven, and wetland restoration of raised bogs and marsh grassland. All of this will serve to attenuate the effects of heavy rainfall and soil run-off.
- reduced water treatment costs required by downstream distilleries and paper mills.

The case of Loch Leven demonstrates that climate change is expected to impact the freshwater ecosystem here through multiple pathways. A pro-active approach tackling management at both the catchment-wide and localised scale is proving an effective adaptation strategy in this setting.
Loch Leven’s improving water quality is not only benefitting wildlife, but is also advantageous to local people, visitors and industry. It is, therefore, important that we are able to manage the system so that a balance of services between catchment and loch is achieved, not one service at the expense of another (May & Spears, 2012). SNH continues to work closely with Kinross Estate Company, RSPB, CEH and others in the Loch Leven catchment to establish management priorities amongst stakeholders, whilst at the same time ensuring that pressures on the ecosystem are reduced. From the latest data (Figure 7 and 8) it seems that Loch Leven’s resilience to the wide-ranging effects of climate change may finally be improving, helping to sustain the services it provides in the long term.

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For more information about long-term lake monitoring carried out by CEH's Freshwater Ecology Group, see www.ceh.ac.uk/our-science/monitoring-site/lake-observatories

For more information on Loch Leven National Nature Reserve and its management, please visit www.nnr-scotland.org.uk/loch-leven/

For more information on how SNH is helping nature adapt to climate change, please contact Christina Wood christina.wood@snh.gov.uk
or visit http://www.snh.gov.uk/climate-change/taking-action/adapting-to-change/helping-nature-adapt/

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