Linlithgow Loch Catchment Management Plan

A plan for the improvement of water quality and biodiversity

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West Lothian Council recognises the very significant contribution that Linlithgow Loch makes to the town in terms of both its landscape setting and environmental quality. Together with the rich history associated with the Palace and The Peel, it attracts a large number of visitors to the town providing a tremendous boost to the local economy. It is disappointing to learn that a wide range of land uses in the catchment are having a negative impact on the loch and that its long-term use for sport and leisure purposes and as a Site of Special Scientific Interest may be under threat. We are committed, therefore, to better understanding the loch's risk of flooding and aim to halt the decline in water quality by working together with a range of other partners and stakeholders to deliver measures that will make a difference. The Linlithgow Loch Catchment Management Plan represents a significant milestone in the process.

Foreword

Councillor Tom Conn (Labour)
Executive Councillor for the Environment
Chair of the Environment Policy Development & Scrutiny Panel & Elected Representative for the Linlithgow Ward on West Lothian Council

Author Contact Details

Dr. Bryan Spears & Bradley Fairclough
NERC Centre for Ecology & Hydrology, Bush Estate, Penicuik, Midlothian, Scotland, UK. EH26 0QB
t] 0131-445-4343, f] 0131-445-3943, e] spear@ceh.ac.uk

Andrew MacAlpine
Forth Area Federation of Anglers – Linlithgow Loch, FAFA Lodge, South Shore, Linlithgow, West Lothian, Scotland, UK.
t| 01506 671 753, e|enquiries@fafa-linlithgowloch.org.uk

Malcolm Fraser
Scottish Natural Heritage, Lothians Area Office, Silvan House, 3rd Floor East, 231 Corstorphine Road, Edinburgh, Scotland, UK. EH12 7AT
t] 0131 316 2647, f] 0131 316 2690, e] Malcolm.Fraser@snh.gov.uk.

Graeme Hedger & Chris Alcorn
West Lothian Council, Operational Services c/o, Guildyhaugh Depot, Bathgate;
& Planning Services c/o County Buildings, High Street, Linlithgow. EH49 7EZ
t] 01506- 776554 & 01506-282428
e] Graeme.hedger@westlothian.gov.uk and chris.alcorn@westlothian.gov.uk

Historic Scotland Rangers Service Historic Scotland, Rangers' Office, Linlithgow Peel, Linlithgow, West Lothian, Scotland, UK. EH49 7AL.
Education Centre, 1 Queen's Drive, Holyrood Park, Edinburgh, EH8 8HG
t] 01506 842065, or 0131 652 8150 f] 0131 6528151 e] hs.rangers@scotland.gsi.gov.uk

Chris McDonald
Chris McDonald, Farm Business Services, SAC Consulting, Bush Estate, Penicuik, Midlothian, Scotland, UK. EH26 0PH
t] 0131 535 3436 f] 0131 535 3431 e] chris.mcdonald@sac.co.uk

Lindsay McFadzean / Harry Millar
River Avon Management Committee / Linlithgow Angling Club

Jill Gillard & Mervyn McGregor
Scottish Environment Protection Agency
Clearwater house, Research Park North, Riccarton, Edinburgh, Scotland, UK. EH14 4AP
t] 0131 449 7296 e] jill.gillard@sepa.org.uk/mervyn.macgregor@SEPA.org.uk

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The Biodiversity and amenity value of Linlithgow Loch has been damaged due to nutrient pollution and invasion by alien aquatic plant species. Additionaly, the loch acts to regulate flood risk to the properties within Linlithgow. This plan was designed to identify the main threats to the loch and to propose priority management measures or additional information required to address them.

Linlithgow Loch

Linlithgow Loch is a shallow freshwater loch, in the central lowlands of Scotland. The loch is moderately sized (40.6 Ha) and shallow, with an average depth of 2.3 m. The loch is home to a number of overwintering waterfowl species which are important both ecologically and as a local feature of interest. The site has been designated as a Site of Special Scientific Interest (SSSI) on account of its native aquatic plant community which is characteristic of a eutrophic (i.e. characterised naturally by high biological diversity and productivity), loch.

Objectives of this Plan

This plan aims to provide a summary of the water quality issues at Linlithgow Loch, identify the main causes of these problems, and to provide advice and appropriate information to improve water quality management into the future.

This information is important to provide:

- effective management advice in accordance with the responsibilities of the key stakeholders of Linlithgow Loch,
- clean and safe water which is necessary to support tourism, recreation, education and local businesses, and,
- high quality freshwater habitat which is required to sustain the loch's protected species and overall biodiversity.

Principles of Loch Management

Effective management of lochs requires continuous monitoring of quality indicators against agreed targets. Management measures should be identified and adequately assessed to ensure that no unintended consequences occur that may negatively impact on other desirable services provided by the loch, including the socio-economic benefits enjoyed by the local community.

Management Goals

The primary management goal for Linlithgow Loch is to reduce nutrient pollution for the benefit of biodiversity and public health. To achieve this, it is essential that sources of nutrients are identified and controlled, which in turn will lead to an improvement in ecological quality. An increase in aquatic plant diversity and an overall increase in biodiversity are common goals of loch restoration projects. However, in Linlithgow Loch, secondary management of alien aquatic plant species and flood risk is also required.

Setting Targets

A list of water quality targets has been agreed for Linlithgow Loch. These targets were set in consultation with a range of stakeholders, all of whom would benefit from the improvements in water quality driven by these targets. All stakeholders require access to the loch be unrestricted and so the reduction of potentially toxic cyanobacterial blooms, which can result in restricted access due to public health risks, is a common goal. The targets are summarised in Table 1 and 2.

Monitoring the Environment

Most commonly, failure of loch management projects is due to a lack of understanding of processes in the catchment and loch that sustain poor water quality. This is often the result of insufficient monitoring of the environment. It is, therefore, essential that a comprehensive and continuous monitoring programme be implemented and maintained. In Linlithgow Loch the following

monitoring activities are currently being conducted.

- monthly surveys of chemical indicators in loch water, and the inflowing Bells' and hatchery Burns are carried out by SEPA,
- *ad hoc* monitoring of combined sewer overflows and surface water outfalls by SEPA and Historic Scotland Rangers' team,
- seasonal ecological surveys and ad-hoc monitoring of cyanobacterial blooms when requested by SEPA,
- winter monthly bird counts of the waterfowl, summer breeding bird surveys, and monthly water clarity assessments (Historic Scotland),
- annual fish stocking review (Forth Area Federation of Anglers)

Recommendations for supplementary monitoring are made throughout the plan.

Assess Current Status against Targets

Quarterly meetings are held by the Linlithgow Loch Catchment Management Group (LLCMG) to review the water quality monitoring data against targets. The stakeholders present an update at each meeting which includes incidences of poor practice in the catchment and specific failures in water quality. The stakeholder group includes:

- Scottish Environment Protection Agency (SEPA),
- Scottish Natural Heritage (SNH),
- West Lothian Council (WLC),
- Historic Scotland (HS),
- River Avon Management Committee,
- Forth Area Federation of Anglers (FAFA),
- Centre for Ecology & Hydrology (CEH)
- Scottish Agricultural College (SAC),
- Scottish Water (SW)
- National Farmers' Union Scotland (NFUS) and
- Transport Scotland

However, The LLCMG has identified that the long-term changes needed for the loch to recover will require significant funding and collaboration across a wider range of stakeholders than is currently included. It is recognised that each

of the organisations represented on the LLCMG would continue to have an important role to play.

The LLCMG is exploring whether the establishment of a charitable Trust or the inclusion of specific objectives into the constitution of an existing or newly-established charitable body in the town might be helpful in terms of providing focus, engaging more effectively with local people, attracting funding and helping to lobby and put in place the practical measures necessary for the loch's recovery.

This plan is designed to highlight the management measures necessary for improving water quality at Linlithgow Loch and to identify additional information required to underpin the design of monitoring and management programmes to continue this long-term work into the future.

The Importance of Linlithgow Loch

Linlithgow Loch provides important services at the local and national level. It is designated a Site of Special Scientific Interest (SSSI) on account of its aquatic plant community; it supports an important community of waterfowl; and it is an important asset for local interest groups and businesses.

Aquatic Plants

The aquatic plant (macrophytes) community is the main qualifying feature for the loch's SSSI status, with the requirements being that six of the listed desirable species must be present.

The native macrophyte taxa recorded in Linlithgow Loch has varied considerably between 1934 and 2007, with only one species being recorded throughout the 1950s indicating very poor habitat conditions. In fact, Linlithgow Loch has consistently failed to achieve favourable status when assessed using common standard monitoring methods outlined by the Joint Nature Conservancy Council in 1977, 2004, and 2007. Five desirable species were recorded in 2007 and 2004 with four being recorded in 1977. However, the characteristic species recorded in 1977 were different from those observed in 2004 and 2007, indicating a variable and changing community capable of recovery.

In recent years, the plant community has also been classified as being of unfavourable status due to the presence of the alien invasive species *Elodea nuttallii* and *Elodea canadensis*.

In 2007, the following characteristic species were recorded:

- *Callitriche hermaphroditica*
- *Chara virgata*
- *Lemna minor*
- *Lemna trisulca*
- *Potamogeton pusillus*

However, it should be noted that sample effort has varied between historical surveys and so, in 2007 for

example, some desirable species may have been missed.

***Management recommendation 1**: One additional desirable aquatic plant species is required for the community to be classified as favourable in line with the loch's SSSI designation. It may, therefore, be beneficial to conduct transplantation trials, where a robust desirable macrophyte species is removed from another loch or grown from seed in the laboratory and planted in Linlithgow Loch. The US Army Core has developed a lake habitat model capable of assessing the likelihood of establishing specific macrophyte species under specific environmental conditions. This modelling approach may be useful in identifying a suitably robust desirable species for introduction to Linlithgow Loch. It should be stressed that the macrophyte community may be restricted due to poor water quality and that this issue may need to be addressed first, before other plant species are able to thrive in the loch.*

Waterfowl

Linlithgow Loch supports a wide range of waterfowl species such as the mute swan and the tufted duck. Of the 38 species recorded at Linlithgow Loch between 1961 and 2009, 29 are listed under the European Birds Directive (Directive 2009/147/EC). The birds help to support education and tourism at the site and perform important ecological functions.

Though the waterfowl at Linlithgow are in abundance they require clean, safe water to maintain their presence at the loch. Many of the species depend on diverse stands of aquatic plants which support the provision of food and nesting habitat. Many of the species are negatively impacted by reductions in aquatic plant cover related to nutrient pollution and algal blooms.

The number of bird species recorded at Linlithgow Loch that are listed under the European Birds Directive increased between 1961 and 2009 (Figure x). A decline of 6 species was observed between 2004 and 2009. This suggests that the diversity of the bird population has generally improved (i.e. increased) between 1961 and 2009. Although it is impossible to forecast bird numbers, given the current lack of understanding of the factors driving bird population numbers at Linlithgow Loch, it is clear that the

recent decreasing trend is a cause for concern.

Although no targets are currently set for the waterfowl population, consistently decreasing trends in mallard, great crested grebe and little grebe were observed between 1995 and 2009. It is expected that the poor water quality at Linlithgow Loch will have contributed to this decline. However external factors may also be driving waterfowl trends, including climate change and increased competition between species for food or space leading to behavioural changes and population fluctuations.

***Management recommendation 2**: The reasons behind the general increase in waterfowl diversity and the decreasing trends in mallard, great crested grebe and little grebe should be identified. A plan should be developed to reverse the decreasing trends described above. These measures will likely be species specific and relate to behaviour, local habitat quality and regional and national scale climate patterns.*

Mammals and amphibians

Otters and mink are present on the River Avon and its tributaries within approximately 1.5 miles of the Loch. There is good anecdotal evidence for occasional visits from both otter and mink to the loch, and also personal observations of water shrews, brown rat, fox, rabbit, grey squirrel, short tailed field vole, common shrew, mole, hedgehog and wood and house mouse.

In addition several species of bats are present within the Peel. Recorded bat species include the Daubenton's bat, Soprano bat, Bandit Pippistrelle bat and the occasional Brown Long Eared bat.

The common toads and smooth newt are also known to inhabit the loch, although the extent of amphibian populations is not well recorded.

***Management recommendation 3**: A full amphibian and mammal survey should be carried out within the catchment to determine the presence of different species and the threats to these species associated with poor water and habitat quality in and around Linlithgow Loch. This*

could be done as an extension of the mammal survey being carried out on the Avon and its tributaries under the auspices of the River Avon Federation in conjunction with Falkirk Environmental Trust.

Fish

Linlithgow Loch is a popular destination for anglers and in 1962, management of the fishing at the loch was taken on by the Forth Area Federation of Anglers (FAFA). Historically, the loch was renowned for its large brown trout, but recently stocking of rainbow trout has taken place.

The performance of the fishery has varied between 2001 and 2010. In particular, the total weight of fish introduced to the loch along with the average weight of individual fish landed has increased from 2001 to 2009 (Figure x). These results highlight a change in the performance of the fishery from relatively more, but smaller, fish being caught in the early 2000s to fewer, but larger, fish being caught up to 2009.

Although the stocking data are specific to rainbow trout, Linlithgow Loch is also home to a range of other fish species including brown trout, blue trout, pike, perch, roach, eels, minnow and sticklebacks.

The behaviour of the fish population may be adversely affected by environmental conditions. Habitat quality targets for dissolved oxygen (lower level target of 3 mg l^{-1}), total suspended sediments (upper level target of 100 mg l^{-1}) and water temperature (upper level target of 23.4^{o}C) have been proposed for Linlithgow Loch by the stakeholder group. All of these targets are maximum or minimum allowable limits and can be considered together to identify high risk events or seasons in terms of fish survival. However, it is recognised that that the effects of algal blooms can also negatively impact on the fish population either directly, through the production of toxic substances, or indirectly by altering oxygen concentrations and water clarity. Finally, access restrictions associated with cyanobacterial blooms clearly have a negative impact on angling at Linlithgow Loch.

***Management recommendation 4**: The increase in fish stocking reported in recent years may have shifted the balance of the food web*

in the loch to favour a higher yield of algae. This has been reported in similar lakes across Europe where abundances of the main algal grazers, zooplankton (e.g. Daphnia sp.), are reduced under high stocking densities of zooplanktivorous fish. An assessment of the zooplankton community composition and biomass in relation to fish stocks and phytoplankton community composition and biomass should be conducted. In addition, a comprehensive surcvey of predator-prey relationships, to include cormorant-trout interactions should be conducted. A management plan should be prepared to review the above and to propose recommendations to achieve a sustainable fishery at Linlithgow Loch.

Economy and Tourism

A number of local businesses or interest groups require good water quality in Linlithgow Loch. These include:

- the Forth Area Federation of Anglers, for recreational fishing,
- Low Port Centre, for water sports, trekking, and educational activities,
- Historic Scotland, for visitors to Linlithgow Palace and its grounds, and educatoinal activities, and,
- formal and informal Walking groups such as Ramblers, Paths to Health, and local residents.

Many other businesses may also be negatively impacted by poor water quality at Linlithgow Loch, especially the negative press attention associtaed with toxic cyanobacterial blooms.

***Management recommendation 5**: It is recommended that a thorough socio-economic assessment be conducted to estimate the value of Linlithgow Loch to the town and the cost of poor water quality on socio-economic capacity. This activity could constitue a Social Return on Investment (SROI) exercise, currently being pioneered by Greenspace Scotland.*

Education

The Peel, or Royal Park, surrounds Linlithgow Palace and provides an attractive setting for what is

arguably the most impressive of Scotland's medieval palaces.

Historic Scotland has received about 58,500 visitors between 2007-2011 to Linlithgow Palace. Of these visitors, about 30% are estimated to be from Scotland, with high visitor numbers also from countries including England, Germany, France, Italy, USA, Spain, Australia and New Zealand.

The Peel today is used extensively by locals and external groups, both formally and informally. Linlithgow Loch plays a significant part in the educational, cultural and amenity value of the historic site.

Historic Scotland Ranger Service at Linlithgow Peel has delivered annually an average of 40 educational visits, 15 events, and 14 other groups (Data 2007-11).

Separately, the Palace also welcomes many hundreds of educational visitors a year, and many visits to the Palace and Ranger Services coincide with school residential visits to the adjacent Low Port Outdoor Education Centre. Many of the educational visits to 'the Low Port' involve water sports or access to the loch shore. As such, the loch's use for education is dependent on the provision of clean water to support a diverse range of organisms. Many of the educational groups are led by the Ranger Service and include bird watching, pond dipping and responsible bird feeding activities. In addition, history lessons draw heavily on the presence of the loch to explain the existence and history of the establishment of Linlithgow and its Palace; how natural resources were used in the past and they are used now; and how man's interaction with the natural world has affected the environment over time.

From the beginning, the Peel formed an integral part of the Royal residence. The siting of significant buildings here for almost a millennium will have been influenced by the topography of a hill almost entirely surrounded by water, a location providing both defence and access to the resources of water and food. Well stocked with swan, ducks, eels and other fish, the loch was an historically important source of food for the Palace. The open space was used in a variety of ways, as gardens and orchards; and for sporting activities such as archery, tennis and jousting.

Now it is used for Historic Scotland events, community events, school sports and a range of other recreational activities. The loch itself presents a significant archaeological resource. The loch appears to contain the remains of two crannogs (man-made islands, formerly linked to the shore) which also feature in the town's coat of arms. In addition to these crannogs, the southerly loch shores have seen extensive use, not just by the Palace but also by the town, through linen works, leatherwork and glue making for which the burgh was known, relying heavily on the loch waters for production.

It is important for this setting to be protected as it is vital to the understanding of the functioning of the Palace as well as being archaeologically sensitive.

***Management recommendation 6**: The public should be encouraged and aided to continue to manage the pressures on Linlithgow Loch. This should be aimed at a variety of audience groups and conducted through continuation of public events, liaisons with local schools and interest groups, and targeted education campaigns (e.g. for septic tank maintenance and the spread of invasive species as well as education on appropriate feeding of wildfowl through grain or seeds rather than bread). Given the local importance of Linlithgow Palace, the continuing work commissioned by Historic Scotland in the Peel should be used to demonstrate the long and rich history of occupation and human use of Linlithgow Loch.*

Threats to Water Quality, Flood Risk & Biodiversity

Nutrient Sources

Linlithgow Loch has suffered from nutrient pollution for many years. The main symptoms of this pollution have included an increased public health risk associated with toxin producing cyanobacteria, a loss of important species, and deterioration of habitat for fish, plants and waterfowl. The invasion of alien aquatic plants may also negatively impact habitat quality and lead to the loss of native plant species. Finally, the loch is known to regulate flooding of the surrounding properties of Linlithgow.

Nutrients (phosphorus and nitrogen) enter Linlithgow Loch from a wide range of sources. In the catchment, nutrient sources include sewage waste from septic tanks and combined sewer overflows, soil *via* erosion, fertiliser application and run-off, and other human activities, both current and historical. These sources have, over time, led to the build up of nutrients in the loch bed sediments which represent an ongoing source of soluble phosphorus to the overlying loch waters, especially during summer months. It is essential that all nutrient sources are identified and controlled if water quality is to be improved at the site.

An increase in the supply of nutrients (phosphorus and nitrogen) to Linlithgow Loch has resulted in:

- An increase in algal blooms,
- fish kills associated with decreased concentrations of dissolved oxygen,
- habitat degradation and loss of native aquatic plant species, and,
- an increased health risk for animals and humans associated with an increase in toxin producing cyanobacterial, associated with algal blooms.

The current status of water quality in Linlithgow Loch was compared to agreed water quality targets (Table 1). In recent years (2005-2010), the loch failed to meet the required targets for:

- total phosphorus (target: 35-50 µg/l),
- chlorophyll *a* (target: 15-20 µg/l),
- cyanobacteria (target: 20,000 cells/ml),
- aquatic plant community composition and cover (targets outlined previously), and,
- water clarity (target: Secchi disk reading of at least 2.4 m).

Nutrient Sources in the Catchment

A risk assessment of potential sources of nutrients in the catchment was recently conducted.

The major land use in the catchment (not including Linlithgow town) was agricultural and high risk issues relating to agricultural practices were identified. High risk non-agricultural rural sources of nutrients included fertiliser applications associated with urban and non-agricultural practices, combined sewer overflows, surface water outfalls, and un-sewered rural properties within the catchment. A septic tank registration scheme has been recently conducted in the catchment to identify related sources.

The sewerage from the town itself is directed to Linlithgow sewage treatment works beyond the west end of the loch and is, therefore, not expected to cause a significant problem when operating correctly. However, incidences of storm overflow should be assessed further.

There are two Scottish Water overflows which can discharge into the loch. These are the Springfield Road Pumping Station Emergency Overflow and the Vennel combined sewer overflow. Scottish Water have recently improved the facilities at the pumping station which now includes an online storage capacity of 63 m^3 and 10 mm screening.

The Venel CSO is located behind the building known as The Vennel. The CSO has recently been refurbished and now includes screening to remove solids.

In both these cases the facilities have been improved to reduce the number of discharges to the loch and the physical condition of the discharge. Both facilities have event recorders to record the frequency and duration of discharge events.

Other potential sources included the local roads and railway lines, unmaintained drainage sediment traps, precipitation, feeding of birds, groundwater inputs, waterfowl guano, and overflows from the Union Canal.

***Management recommendation 7**: It is recommended that a full and quantitative source apportionment survey be conducted in the Linlithgow Loch catchment to identify and prioritise management of main sources. An assessment of nutrient loading from inflowing streams should be conducted over a one year period and catchment surveys should be conducted to assess loads from 'hot spot' sources identified in the recent risk assessment. Specific management measures will be required to address different types of nutrient source. Event data from sewage overflows should be documented and assessed to aid management of these systems and to reduce the impact on the loch.*

Collaboration between Scotland's Rural College (SRUC - formerly Scottish Agricultural College) and the farming community should continue to deliver improvements in high risk agricultural practices in the catchment and measures should be implemented to control or intercept nutrients from these sources where appropriate, and would benefit land management practices.

In-Loch Nutrient Sources

In-loch sources are predominantly derived from the release of legacy phosphorus inputs from bed sediments stores. Nutrients naturally accumulate in bed sediments in shallow lochs and recent pollution in the Linlithgow Loch catchment will have increased the rate of accumulation. This source ensures a steady release of nutrients (mainly phosphorus) into the loch, especially during the warm summer months when nutrient release from sediments coincides with the onset of potentially toxic cyanobacterial blooms.

Over winter, the high water run-off from the catchment ensures a high

input of nutrients into the loch, replenishing the store of nutrients in the sediment. When the precipitation is lower during the summer months, the loch exhibits a high internal release of phosphorus from its sediment, during a period when flushing of loch water, and therefore removal of phosphorus from the loch, is characteristically low. It was estimated that the overall amount of phosphorus, within the upper 2 cm of bed sediments alone, was 4.3 tonnes in 2010. This store of phosphorus is significantly higher than the peak mass of phosphorus recorded in the water column (i.e. 0.47 tonnes in summer 1996), especially when one considers the depth of sediment in the loch is likely to be in excess of 1 m deep.

The in-loch phosphorus load has been the dominant source of phosphorus during summer months in recent years. However, management of internal loading can be expensive and should not be attempted without also considering significant reduction of catchment derived phosphorus and nitrogen sources.

***Management recommendation 8**: It is recommended that a comprehensive survey of bed sediments be conducted and that the Centre for Ecology & Hydrology continue to investigate management options through laboratory and in-loch trials. These management measures may include treatment of bed sediments with materials known to adsorb phosphorus, regulation of flushing rate, or removal of nutrient rich sediments. It is stressed that control of internal loading should be considered only in combination with the control of nutrient sources in the catchment.*

Threats Posed by Cyanobacterial blooms

Linlithgow Loch has a history of cyanobacterial blooms that represent a significant public health risk (i.e. in excess of 100,000 cells ml^{-1}). These algal blooms commonly result in negative press coverage for the loch, for example in June 1994 and August 2001.

Cyanobacteria can produce potentially toxic secondary metabolites known as cyanotoxins. These can have harmful effects on the local wildlife and people who come into contact with the bloom.

Cyanobacterial blooms can have negative economic effects. Public access for charged activities on the loch may be restricted. With respect to the local community, cyanobacterial blooms also impact negatively on the amenity value of the site. Negative press attention may result in a drop in visitor numbers to the area. Fish kills have been reported in Linlithgow Loch, although no direct link has been made between toxin concentrations and fish mortality. The last significant fish kill occurred in 1948 when the loch lost most, if not all, of its fish. Finally, the cost of managing the problem can be significant.

Cyanobacteria are present across the world and are commonly found in terrestrial and aquatic habitats. The dominant cyanobacteria in Linlithgow Loch are from the genus *Anabeana*, *Microcystis Aphanizomenon, and Gomphosphearia,* all of which produce specific toxins.

Under high nutrient conditions, cyanobacteria can dominate the algal community in lakes forming dense surface water blooms. Bloom formation is driven also by weather conditions and the shape and size of the loch.

Cyanotoxins are among the most potent naturally occurring toxins. They are categorised by their effect on the human body and include:

- neurotoxins, which affect the nervous system,
- hepatoxins, which affect the liver, and,
- toxic alkaloids, which cause gastrointestinal problems or even kidney disease.

Exposure to cyanotoxins can involve drinking contaminated water or contact with the skin.

Symptoms following contact with the skin include:

- allergic reactions
- skin irritation
- rashes
- blisters around the mouth and nose, and,
- irritation of the eye.

If the toxins are ingested, symptoms can include:

- stomach cramps,
- vomiting and/or diarrhoea,
- nausea and/or headaches,
- fever,
- sore throat,

- joint and muscle pain,
- blisters around and inside the mouth,
- skin irritation,
- liver damage.

The toxins are also harmful to animals, birds and fish. Fish kills are common during algal blooms and care should be taken when walking dogs beside contaminated water as they are also prone to similar symptoms.

***Management recommendation 9**: It is recommended that the current monitoring programme be developed to include comprehensive monitoring of cyanobacterial bloom occurrence to safeguard public health. This should be coupled with the completion of a rapid response public communication initiative, which is already under development. Nutrient reductions should be prioritised to reduce the likelihood of cyanobacterial blooms. It is also important to define the difference between a perceived problem of cloudy water/excessive weed growth and an actual cyanobacterial bloom.*

Threats Posed By Alien Invasive Plants

There are two alien species of aquatic plant which threaten to out-compete the protected native species. These alien species are Nutall's pondweed (*Elodea nuttallii*) and the Canadian pondweed (*Elodea canadensis*), both of which are very common in UK waters. In the late 1970's, native pondweeds began to decrease in Linlithgow Loch and the first alien species of pondweed (Canadian pondweed) took hold in 1980, with Nutall's pondweed being recorded for the first time in 2004. Canadian pondweed was not recorded in the loch in 2007, leaving Nutall's pondweed as the main alien threat.

In addition there are several small patches of Japanese Knotweed (*Fallopia japonica*) within the area of the Peel and on the burns that flow into the Loch. Specifically these are at St Michaels RC Church and on the Lochmill Burn, both sites being recently (summer 2011) surveyed during the INNS plant survey of the River Avon catchment carried out in conjunction with the River Forth Fisheries Trust. These stands can easily spread to the loch shores via

the burns. Japanese Knotweed has been associated with structural damage to footpaths and, buildings and roads. Himalayan Balsam (*Impatiens glandulifera*) is present along the Edinburgh Road and on the Bells' Burn providing a route for seed to enter the loch.

***Management recommendation 10**: A survey of aquatic plants should be conducted annually to map the extent and spread (i.e. spatial maps) of desirable and non-native invasive species in the loch. These maps will provide the baseline data with which the efficacy of aquatic plant community control techniques may be assessed. For example, the use of jute netting has recently been demonstrated in water bodies to effectively reduce non-native species cover whilst acting to support the emergence of native (charophyte and angiosperm) species. Similar surveys should be conducted for terrestrial non-native invasive species including Japanese Knotweed and Himalayan Balsam. A non-native species management plan should be considered to manage all current and potential invasions.*

Increased Flood Risk

The Flood Risk Management (Scotland) Act places a duty on local authorities to exercise their powers with a view to reducing overall flood risk.

A number of discreet areas of Linlithgow are vulnerable to flooding from surface water. There is also a history of flood events associated with tributaries of the loch. The loch itself has a history of 'overtopping' in the Town Bay area. Anecdotal information suggested that flows from the loch were heavily controlled by the level of the culvert which conveys the Mill Burn, draining the loch, beneath St. Ninians's Road.

In order to determine the extent of any risk associated with the loch, specialist consultants were commissioned by West Lothian Council in 2010/2011 to determine the risk of flooding to land and property located around the loch in the event that prolonged and heavy rainfall should affect the catchment.

It was concluded that the loch provides a significant attenuating effect within the catchment which

operates over a modest range and is subject to the form and hydraulic behaviour of the structural controls at the outfall. In the absence of flow and level data there is significant room for error and the study does suggest a potentially significant risk of flooding to land and property surrounding the loch under certain circumstances.

Robust and locally-derived meteorological data is available for the loch catchment. Whilst there is a staff gauge at the outfall, there is no system for recording water levels and, thus, the relative responses to rainfall within the catchment are currently not monitored.

***Management recommendation 11**: It is recommended that a further study be conducted to install level sensors on the tributaries of the loch and on the Mill Burn which drains the loch. This comprehensive monitoring system will provide more high frequency flow data with which flood risk can be more accurately assessed. This study is required to underpin the assessment of measures required to reduce any flood risk associated with the loch for inclusion in the Local Flood Risk Management Plan for wider West Lothian due for publication by West Lothian Council in 2015. Finally, a rapid response procedure should be considered further with respect to communicating and responding to flood risk in 'real-time'.*

Table 1. Summary of Environmental Quality Standards (EQS) relevant to Linlithgow Loch and recent trends in relation to these targets.

				3 year trend relative (%) *cf*. 2001-2009 mean values[4]				
Determinand	Freshwater EQS	Type of standard[1]	Incidence of failure in raw data[3]	Annual	Spring	Summer	Autumn	Winter
Ammonia		NTS		-95	-26	-133	-71	-70
Chloride	250 mg/l	AA- Non. Stat.	O	-1	+9	0	-12	-2
Chlorine	2 µg/l	AA- WFD	O					
Copper dissolved	28 µg/l	AA- WFD	O					
Iron dissolved[1]	1 mg/l	AA- WFD	O					
pH		NTS		+1	-1	-3	+7	+1
Sodium		NTS						
Zinc	75 µg/l	AA- WFD	O					
Total phosphorus	35-50 µg/l	AA- Site Specific Target	X	+5	+82	-36	+37	-42
Chlorophyll a	15-20 µg/l	AA- Site Specific Target	X	+31	+63	-18	+37	+23
Cyanobacteria	20,000 cells/ml	MAL[5]	X					
Macrophyte community	Various[2]	JNCC (2004)[6]	X					
Macrophyte colonisation depth	3 m	Lake specific target						
Secchi depth	2.4 m	AA- Site specific target	X					
BOD		NTS		+25	+79	-4	-2	+14
DO	3 mg/l	Lethal limit for fish	O	+4	-5	-10	+22	+13
SiO_2		NTS		+41	+122	+80	-15	+45
TON		NTS		-89	-148	-128	-49	-67
DIN		NTS		-91	-144	-145	-66	-68
PO_4-P		NTS		+6	-38	-20	+57	-116
TSS	100 mg/l	MAL- Site specific target	---	+62	+81	-83	+145	+19
Conductivity		NTS		+3	+10	+4	-11	+10
Alkalinity		NTS		+11	+21	+9	-4	+17
Temperature	23.4 ^{o}C	Lethal limit for fish	---	-4	+19	+4	-27	-15

[1] All WFD and non-statutory EQS outlined in SEPA (2010), including site specific targets for TP, chlorophyll *a* and Secchi depth as agreed by LLCMG and standards for TSS and DO proposed in this study (Section 3.2.2); AA = annual average; MAL = maximum allowable level; NTS = no target set. [2] EQS for macrophytes discussed in detail in Section 3.3.1. [3] X = failure in 2005-2010; --- = failure 1980-2005; O = no failure during 1980-2010. [4] Short term cumulative increase or decrease expressed as percentage relative to 2001 - 2009 average value; blanks indicate insufficient data. [5] SEHD (2003). [6]Joint Nature Conservation Committee (2004).

Table 2 Condition monitoring assessments of site attributes from surveys conducted in 2004 (SNH, 2005) and 2007 (SEPA, 2007) in accordance with common standard monitoring methods outlined by JNCC (2004 and 2007). NS = not surveyed.

Attribute	Target	SNH Survey 15/09/2004	SEPA survey 23-25/7/07
Extent	No loss of extent of standing water	Favourable	NS
Macrophyte community composition	Presence of at least 6 characteristic species (see Box 4, Appendix) and one broadleafed *Potamogeton* species.	Unfavourable	Unfavourable
	No loss of characteristic species recorded from the site (see Box 4, Appendix)	Unfavourable	Unfavourable
	Presence of characteristic species in at least 6 out of 10 sampling locations	Unfavourable	Favourable
Negative macrophyte indicator species	Invasive, non-native species *Crassula helmsii*, *Hydrocotyle ranunculoides*, *Myriophyllum aquaticum* and *Azolla filiculoides* absent	Favourable	Favourable
	Relative frequency of occurrence of less invasive, non-native species, e.g. *Elodea nuttallii*, *Elodea canadensis* , < 25%.	Unfavourable	Favourable
	Non-*Chara* algal dominance: less than 20 % of sample points to have cover values of 3 for filamentous algae. (This threshold is under review, but the limit is unlikely to increase.)	Unfavourable	Unfavourable
Macrophyte community structure	Characteristic zones of vegetation should be present.	Favourable	Favourable
	Maximum depth distribution of macrophyte colonisation should be maintained.	NS	NS
Water quality	Stable nutrient levels appropriate for the lake type. The type-specific management limit for total phosphorus (TP) in naturally eutrophic standing water features is between 35 and 50 μg P l^{-1}. Setting of site-specific targets is recommended.	Unfavourable	NS
	No excessive growth of cyanobacteria or green algae.	Unfavourable	Favourable
Hydrology	There should be a natural hydrological regime; where hydrological regime has been altered before designation and the alterations do not constitute a risk to a feature, a standing water may be judged by SNH to be in favourable condition.	Favourable	NS
Lake substrate character	Maintain the natural shoreline of the lake; where the shoreline has been altered before designation and the alterations do not constitute a risk to a feature, a standing water may be judged by SNH to be in favourable condition.	Favourable	NS
	Maintain natural and characteristic substrate for lake type.	Favourable	NS
Sediment load	Maintain natural sediment load.	Favourable	NS
Indicators of local distinctiveness	Maintain distinctive elements (e.g. rare plant or invertebrate species, habitat features) at current extent/levels and/or in current locations.	Unfavourable	Unfavourable