About Drought
Maximising the impact of UK research on drought & water scarcity

Photo: Karl McCarthy

Lakes and reservoirs

Report Card 2020

This publication covers the effects of drought and water scarcity on lakes and reservoirs: the ecosystem response, impact scenarios and possible mitigation actions.
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It is one of a series of report cards summarising current and future aspects of water scarcity in the UK's main ecosystems.

Prepared by: Anne Jo Dobel[1], Linda May[1], Iain Gunn[1], Bryan Spears[1] & François Edwards[2].
[1]UKCEH Edinburgh
[2]UKCEH Wallingford

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Natural Environment Research Council

Drought in UK lakes and reservoirs

Droughts and water scarcity are projected to become more extreme and prolonged in the UK with an increase in demand for water (e.g. agriculture, industry and potable water), as the population grows, and because of the impact of climate change (Committee on Climate Change, 2017).

Humans contribute to the impacts of water scarcity by damming and draining lakes, and by abstracting water from reservoirs. Human society derives key goods and services from lakes and reservoirs, which could be threatened by water scarcity, thereby, affecting both regional and national economies.

Droughts and water scarcity vary in duration, frequency, intensity and spatial extent. Some droughts are regional, others national; they can occur in winter or summer; they can be short-lived or span multiple years; they can be manifested as reduced water levels or the complete drying up of lakes and reservoirs; each drought event is unique and, therefore, its impacts are context specific.

It is important to distinguish between droughts in freshwater systems under both natural and altered conditions. Humans affect droughts and their impacts by abstracting water, adding nutrients to water, changing the climate and modifying waterbodies. Under natural conditions, droughts are part of the continuously varying hydrological conditions in lakes, as are floods. Droughts can lead to the death of organisms, disconnection, shrinkage of habitat, etc. but this can be natural. Under unnatural conditions, the impacts of droughts can become more severe, i.e. increased frequency and intensity, or exacerbating other stressors on fresh waters. Here, we describe the potential impacts of severe droughts on UK lakes and reservoirs. In the case of reservoirs, it should be noted that they are generally operated to allow for certain draw-downs and releases to minimise drought impacts, wherever possible, on downstream receiving watercourses.

During a drought, the turbidity, water quality and water temperature of lakes and reservoirs are affected by lower rainfall and by a reduced rate of flushing from the hydrological network. This has a direct impact on human and livestock health, and on wildlife, but also drives up the cost of maintaining fisheries and water treatment. The consequences of increasing turbidity and water temperatures, and degraded water quality, will be greater in shallow lakes, where the faster evaporation of remaining water and the degradation of vital shoreline habitats will occur. However, if a lake is mainly groundwater-fed this might not be the case; as each drought event is unique so is each habitat, which makes the impacts of a drought site-specific.

There are many things that we can do to reduce the impacts of drought in lakes and reservoirs and help build resilience, including better adaptive mitigation, catchment management and water resource planning, as well as more efficient water use.

Drought is a natural phenomenon. Water scarcity is human-related, because we need the right amount of water of the right quality at the right time and in the right place.


Photo: Howden Reservoir, 2018. © K. Muchan

Severity, impact & recovery from drought

This table shows the severity of damage to lakes and reservoirs during droughts, and illustrates at which stage different impacts can be expected. Freshwater systems can recover quickly from some types of drought, to the point that one cannot tell there was any impact. Typically, the response period to a drought can be considered under natural conditions as: short = during the drought; medium = immediately after the drought; long = cycles of drought and wet periods. In this table we highlight likely long-term and notable impacts, especially where they are linked to other stressors or long-term processes. Although the impacts of drought on systems altered by man are complex, we attempt to outline the likely future impact scenarios in the tables that follow.

	Severity of damage to lake ecosystem		
Likelihood*	Mild	Moderate	Severe
Low			Rapid change in lake morphology, ecological state and biodiversity
Medium		Serious disruption to fish spawning and migrations	Eutrophication problems are exacerbated and localised fish kills occur due to deoxygenation
High	Temporary changes to biota and ecological state	Ecosystem structure and function gradually change over time due to cumulative effect of more frequent small droughts	Gradual change in lake morphology, ecological state and biodiversity

* Likelihood is a coarse indicator of a drought instigating damage to a system. It is a combination of the change in duration, timing and volume of the events, and their frequency. Each drought has unique characteristics leading to site-specific responses. As an example, the summer of 2018 water scarcity / drought event created conditions of moderate and severe impacts, and the chances of similar droughts occurring again is classified as 'medium'.

Eutrophication is the over-supply of nutrients causing excessive growth of nuisance algae and aquatic plants

Stages of drought

At drought onset, water levels decrease as inflow is reduced (Left: Derwent Reservoir 2018); the marginal zones are exposed leaving aquatic plants and sediments to dehydrate (Centre: Howden Reservoir, 2018); and evaporation and concentration of remaining water increases the risk of eutrophication (Right: Derwent Reservoir, 2018).

Reduced inflow and decline in water levels
Loss of shoreline habitat

Further decrease in water levels
Exposure of sediment and plants

Photos: Copyright K. Muchan

Loss of depth-specific habitat
Increased evaporation and concentration of remaining water

Habitats affected by drought

1. Loss of shoreline habitat leaving fish fry and invertebrates vulnerable. 2. Aquatic plants and filamentous algae are exposed, and will dry out; mats of aquatic plants can provide refugia for fish and invertebrates during short droughts. 3. Sediments dry out leaving non-motile invertebrates exposed. 4. Evaporation and concentration of the remaining water results in a rise in nutrients and increases the risk of eutrophication and harmful algal blooms.

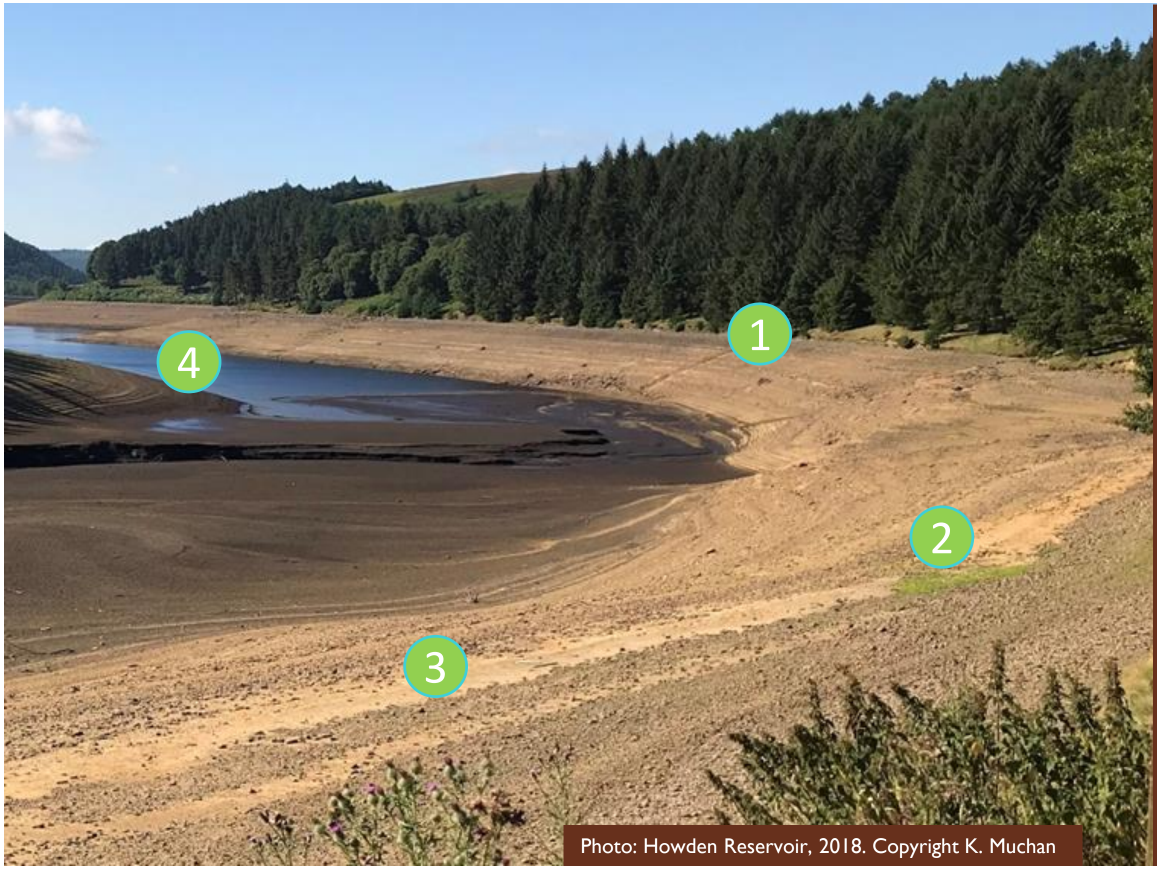

Photo: Howden Reservoir, 2018. Copyright K. Muchan

Zones

1) Shoreline habitat
2) Aquatic plants
3) Sediment
4) Remaining water

Mitigating Actions – Physical 1

Physical effects of drought & mitigating actions

Effects	Response	Impact Scenarios	Mitigation
The physical responses of lakes and reservoirs to droughts are generated, mainly, by lower levels of rainfall and higher air temperatures. Reduced rainfall results in less runoff from the catchment, which, in turn, depresses the hydrological flushing rate of the waterbody (Bailey-Watts et al., 1990). Higher air temperatures are usually associated with lower levels of humidity; together, these lead to increased evaporation rates over the surface of the waterbody.	Lower water levels and increased dryness in shallow and shoreline areas. Stagnant water due to decrease in flushing.	Permanent change in water levels. In reservoirs, impacts may be more severe due to higher abstraction to meet increasing demand for water under drought conditions and due to growing population.	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M2** Adaptive mitigation to river connectivity to avoid disconnection and allow flushing, as well as regeneration of marginal habitat (Everard, 2015).
With decreasing amounts of water entering lakes and reservoirs, flushing rates will be reduced. This increases their sensitivity to other pressures such as acidification, abstraction, eutrophication and invasive species (Whitehead et al., 2009). Shallow lakes are particularly susceptible to changes in residence times (George et al., 2007). During severe droughts, lakes and reservoirs may become disconnected from surrounding waterbodies.	Temporary loss of connectivity, and decrease in water quality and amenity value.	Permanent change in connectivity, and general degradation of water quality and amenity value.	
In shallow waterbodies, reduced water levels can promote wind-induced sediment disturbance leading to increased turbidity in the water column (Mosley et al., 2012).	Higher risk of decreased water clarity leading to lower habitat and recreational value.	Permanent change in habitat and recreational value, due to increased risk of upwelling.	

Mitigating Actions – Physical 2

Physical effects of drought & mitigating actions

Effects	Response	Impact Scenarios	Mitigation
As water levels and volumes in the waterbody decrease, most of the impact is around the perimeter, making shoreline areas exposed and desiccated. This changes the shoreline habitat for biota and may result in an increase in greenhouse gas emissions, because emissions of carbon dioxide and methane from exposed sediments increase during drying and re-wetting (Kosten et al., 2018).	Decreased water levels may lead to changes in shoreline habitat and could result in an increase in greenhouse gas emissions.	Fundamental changes in lake and reservoir morphology, habitat diversity and levels of greenhouse gas emissions.	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M2** Adaptive mitigation to river connectivity to avoid disconnection and allow flushing, as well as regeneration of marginal habitat (Everard, 2015).
Droughts are often coupled with increasing air temperature, leading to higher water temperatures and intensified associated stratification in lakes and reservoirs (Baldwin, 2008; Flanagan et al., 2009). Shallow lakes, and lakes with shallow thermoclines*, are the most susceptible to this warming process (George et al., 2007), while in deeper waterbodies the higher water temperatures tend to lengthen the period of thermal stratification and deepen the thermocline (Hassan et al., 1998). However, where droughts are not associated with increases in air temperature, lakes and reservoirs remain unchanged, even if their water levels fall (Olds et al., 2011; Mosley et al., 2012). * Thermocline is term used for an abrupt temperature gradient in lakes, marked by a layer above and below, in which the water is at different temperatures	Increasing water temperature and stratification can lead to heat stress on biota and low oxygen conditions in deeper water due to increased respiration.	General degradation of the ecological status and changes in the biological community.	**M2** Adaptive mitigation to river connectivity to avoid disconnection and allow flushing, as well as regeneration of marginal habitat (Everard, 2015). **M3** Planting riparian vegetation along the shoreline to reduce water temperature increases.

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Mitigating Actions – Chemical 1

Chemical effects of drought & mitigating actions

Effects	Response	Impact Scenarios	Mitigation
General chemical responses from lakes and reservoirs, mainly situated in North America and Europe, indicate a suite of likely water quality responses including, increases in dissolved organic carbon, inorganic nutrients, pH, salinity, turbidity and redox sensitive metals, and decreases in dissolved oxygen concentrations (Mosley, 2015).	Decreased water quality due to an increase in the evaporation of remaining water.	General decrease in water quality leading to degradation of habitat and recreational value.	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M2** Adaptive mitigation to river connectivity to avoid disconnection and allow flushing, as well as regeneration of marginal habitat (Everard, 2015).
Water level decline and the elevated evaporation and concentration of remaining water are expected to be universal driving processes, however, water chemistry responses can be site-specific (Webster et al., 1996). Groundwater-fed lakes will probably experience a greater impact on their water chemistry from the catchment geology (Webster et al., 2000). In stratifying, deeper waterbodies, water chemistry responses can be more prominent than in shallow waters, where it is only manifested during post-drought re-filling (Baldwin et al., 2008). The effects of post-drought re-filling are greatly determined by the land-use and geology of the catchment, including reconnection with polluting point sources. In lakes predominantly served by surface water, hydrological disconnection during droughts can result in increased evaporation of the remaining water, elevating both nutrient and salinity concentrations. Nutrient responses may also vary with the relative loading from the catchment. The potential for a reduced catchment influence may result in a decline in nutrient loading due to hydraulic disconnection, especially in shallow lakes and surface waters of stratifying lakes (Barros et al., 1995).	Site-specific characteristics make the responses variable across sites on local, regional and national scales, making standardised management and mitigation difficult.	The heterogeneity of responses across sites, even within the same catchment, makes standardised management and mitigation methods ineffective. Increased financial costs for implementing site-specific mitigation and management.	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M2** Adaptive mitigation to river connectivity to avoid disconnection and allow flushing, as well as regeneration of marginal habitat (Everard, 2015). **M4** Site-specific mitigation, using means to increase flushing, reconstructing connectivity etc.

Mitigating Actions – Chemical 2

Chemical effects of drought & mitigating actions

Effects	Response	Impact Scenarios	Mitigation
Elevated water temperatures related to drought, increase the risk of low oxygen conditions due to decreased solubility and increased biological demand. In deeper waterbodies, increasing temperature could strengthen stratification leading to more intense anoxia in bottom waters (Baldwin et al., 2008). Under these conditions, the biogeochemical processes in bed sediments can regulate water chemistry resulting in elevated concentrations of dissolved iron, manganese, ammonium, and phosphate, and reduced concentrations of nitrate. Similarly, an increase in other redox-sensitive metals and metalloids are likely, including arsenic and molybdenum (Jirsa et al., 2013). These chemical effects may, at least temporarily, be extended to surface water following post-drought re-filling.	Increase in redox-sensitive soluble metals and elevated risk of pollution from heavy metals may lead to a degradation of water quality and recreational value of waterbody.	Permanent degradation of water quality and amenity value of waterbody.	**M2** Adaptive mitigation to river connectivity to avoid disconnection and allow flushing, as well as regeneration of marginal habitat (Everard, 2015). **M3** Planting riparian vegetation along the shoreline to decrease water temperature increases.
The production of methane and nitrous dioxide greenhouse gases may also be elevated under reducing bed sediment conditions (Tranvik et al., 2009).	Temporary increase in greenhouse gas emissions.	Increase in greenhouse gas emissions with recurrent drought events.	
In shallow waterbodies, reduced water levels can promote wind-induced sediment disturbance leading to increased turbidity and elevated nutrient concentrations in the water column (Mosley et al., 2012).	Nutrient increases leading to eutrophication of waterbody.	Decreasing water quality and amenity value of waterbody.	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M2** Adaptive mitigation to river connectivity to avoid disconnection and allow flushing, as well as regeneration of marginal habitat (Everard, 2015).

Biological effects of drought & mitigating actions

Effects	**Response**	**Impact Scenarios**	**Mitigation**
Eutrophication: Lower flushing rates (i.e. increased retention times) tend to reduce the resilience of lakes and reservoirs to eutrophication (Dillon & Rigler, 1974; Vollenweider, 1975; Vollenweider & Kerekes, 1982). The increased risk of algal blooms, due to the concentration and retainment of nutrients, and the decreased flushing of the system, favours slower growing species such as blue-greens (cyanobacteria) (Carvalho et al., 2011; Elliott, 2010; Reynolds, 2006; Reynolds & Lund, 1988). Indirect impacts of lower flushing rates (e.g. changes in nutrient availability and the temperature regime) can also affect algal species composition and succession (Bailey-Watts et al., 1990; Carvalho et al., 2011; Elliott, 2010; Jones et al., 2011; Reynolds et al., 2012). Increases in blue-green algal populations, resulting from reduced flushing rates, may be less significant if growth is limited by other factors, such as light and nutrient availability (Elliott, 2012).	Increase in eutrophication and decrease in amenity value of waterbodies. Blue-green algal blooms also result in increased risk to public health (Cox et al., 2018; Facciponte et al., 2018).	Intensified degradation of water quality and risk to public health.	**M2** Adaptive mitigation to river connectivity to avoid disconnection and allow flushing as well as regeneration of marginal habitat (Everard, 2015). **M5** Mitigation measures to decrease nutrient availability in catchment and waterbodies.
Aquatic plants: Even small reductions in water level in shallow lakes may cause large changes in aquatic plant species composition. Some aquatic plants have evolved coping strategies to survive in shoreline habitats where changes in water level occur naturally (e.g. shoreweed, *Littorella uniflora*). Motile species can avoid potential desiccation while some amphibious species have developed tolerances. Reduced water levels in the spring may encourage the growth of submerged plants in shallow systems (Coops et al., 2003). However, excessive or prolonged drawdown in lakes and reservoirs and/or altered timings of low water levels can cause significant losses of aquatic plant species and associated plant biomass, as their physiological limits are exceeded (Hellsten & Dudley, 2006; Zohary & Ostrovsky, 2011). In such extreme conditions, some naturally occurring species may be lost, making lakes vulnerable to colonisation by more invasive generalist species; these may out-compete the remaining native species resulting in an overall loss of biodiversity.	Decrease in aquatic plant biomass and species composition through desiccation. Selection for adapted or amphibious species.	Decline in biodiversity and risk of invasive species out-competing native species.	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M2** Adaptive mitigation to river connectivity to avoid disconnection and allow flushing, as well as regeneration of marginal habitat (Everard, 2015). **M6** Maintaining or creating habitat heterogeneity will ensure resilience of biota. **M7** Adaptive mitigation to create habitat refugia.

Mitigating Actions – Biological 2

Biological effects of drought & mitigating actions

Effects	Response	Impact Scenarios	Mitigation
Invertebrates: In shoreline habitats, where natural changes in water level occur, some invertebrate species will be able to cope with variable water levels while more motile species will use avoidance strategies. The likely associated loss of aquatic plants may also reduce the habitat available to invertebrates, thereby, causing significant reductions in biodiversity within the shoreline community (e.g. Aroviita & Heiki, 2008; Baumgartner et al., 2008; White et al., 2008). Drought impacts may also include a shift in primary production from aquatic plants to planktonic algae, resulting in changes in habitat and food availability that are likely to affect the abundance and species composition of the invertebrate community (e.g. Gunn et al., 2012). Under extreme drought conditions some species may be lost, providing opportunities for more invasive, generalist species to become established and proliferate (Zohary & Ostrovsky, 2011).	Reduction in invertebrate biomass and temporary change in species composition.	Permanent shift to dominance by invasive and generalist species.	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M2** Adaptive mitigation to river connectivity to avoid disconnection and allow flushing, as well as regeneration of marginal habitat (Everard, 2015). **M6** Maintaining or creating habitat heterogeneity will ensure resilience of biota. **M7** Adaptive mitigation to create habitat refugia.
Fish: Although fish are usually widely distributed within lakes and reservoirs, drought inflicted changes in water levels may affect individuals that forage or find physical refuge from predation in littoral areas. This applies especially to younger individuals (Winfield, 2004). Many fish are relatively long-lived so, unless there are major fish kills, the impacts of droughts may not necessarily affect population levels immediately. However, re-occurring droughts could cause a significant decline in fish populations. Lower water levels during the spawning season could adversely affect the reproductive success of most fish species, since spawning occurs in the shoreline zone on suitable aquatic plants or bottom substrates (e.g. Winfield et al., 2004). Lower water levels outside of the spawning season can also affect the suitability of the littoral zone for many fish species by reducing food availability (e.g. Winfield et al.,1998). Extreme lowering of water levels may reduce the volume of the hypolimnion*. This will affect fish requiring relatively low water temperatures and could lead to fish kills. Some of the UK's rarest fish are likely to be most affected (Maitland & Lyle, 1992; Jones et al., 2008). * hypolimnion is the dense, bottom layer of water, below a thermocline, in a thermally-stratified lake.	Fish deaths due to anoxic conditions and loss of spawning habitats over time. Decrease in recreational value of waterbody (particularly for anglers).	With drought being a recurring and increasing issue with climate change, there is a potential for significant decline in fish populations, causing a permanent loss of biodiversity and a reduction in both recreational value and ecosystem function. The lake response model PROTECH has been used to predict the impacts of climate change on the UK's rarest freshwater fish species, the vendace (*Coregonus albula*) (Elliott & Bell, 2011).	

Mitigating Actions – Biological 3

Biological effects of drought & mitigating actions

Effects	**Response**	**Impact Scenarios**	**Mitigation**
Aquatic birds: Aquatic birds use lakes or reservoirs to feed on aquatic plants, invertebrates or fish, so drought impacts that depress these potential food sources may also have knock-on effects on the bird populations. Birds that only forage to limited depths (e.g. dabbling ducks and swans) would be the most affected by these changes. Diving ducks (e.g. tufted duck), which feed at greater depths, would be less affected. Aquatic birds may also be susceptible to losing access to breeding and nursery areas, even if water level changes are relatively small.	Impact in aquatic bird populations through decrease in food availability and suitable or accessible habitat. Decrease of recreational value (e.g. biodiversity, bird watching and wildlife).	Decline in suitable aquatic bird habitat leading to a reduction in bird populations.	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M2** Adaptive mitigation to river connectivity to avoid disconnection and allow flushing as well as regeneration of marginal habitat (Everard, 2015). **M6** Maintaining or creating habitat heterogeneity will ensure resilience of biota. **M7** Adaptive mitigation to create habitat refugia.
Ecosystem function: Lake or reservoir biota have evolved life cycles that accommodate natural water level fluctuations. Under drought conditions, extreme or unusually timed fluctuations in water levels are likely to affect the biota, impairing ecosystem functioning. Changes in flushing rate affect temperature regimes and nutrient availability, which may affect, in turn, the species composition and abundance of primary producers (algae and aquatic plants) and the biota that depend on them for food and shelter (e.g. Bailey-Watts et al., 1990; Reynolds et al., 2012). Loss of aquatic plants can also reduce structural diversity, leading to less habitat for invertebrates and fish. It may cause a regime shift in lake/reservoir functioning, from plant-dominated to algal-dominated. The loss of aquatic plants could also result in significant losses amongst the shoreline invertebrate community (e.g. Aroviita & Heiki, 2008; Baumgartner et al., 2008; White et al., 2008), affecting species that depend on this food supply (e.g. aquatic birds and fish). Under extreme drought conditions, naturally occurring species may be lost, making the ecosystem unstable and vulnerable to colonisation by invasive species with a consequent loss of ecosystem functions. Changes in lake/reservoir depth may affect sensitive fish species (e.g. corgegonids, salmon and trout) and highly specialised aquatic birds (e.g. divers), because of its role in habitat partitioning (e.g. Ferguson & Mason, 1981). This can be a particular threat when combined with nutrient enrichment and deep-water deoxygenation.	General degradation of waterbody: Temporary change in trophic state. Decrease in water quality and recreational use. Decrease of biodiversity and ecosystem function.	Fundamental or permanent degradation of waterbody: Shift in trophic state (to eu- or hyper-eutrophic.) Decrease in water quality and recreational use. Loss of biodiversity and ecosystem function. Especially in reservoirs, decreasing water quality will have a severe impact on public water supplies.	

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