UK Technical Advisory Group

Proposed Biological and Environmental Standards for River Basin Planning

Annexes

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Water Framework Directive UK TAG

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Annex A – River Flow

Background

1.1 River flow standards were recommended in the first report from the United Kingdom Technical Advisory Group (UKTAG) on environmental standards and conditions (2008)[1], with subsequent review and revisions in 2009 and 2013. The environmental standards for river flows were developed from work undertaken by SNIFFER project WFD48. The environmental standards were developed in order to assess the risk to ecological status posed by alterations in flows across the flow regime.

1.2 Environmental standards for flows have been defined for all five ecological status classes although, under the Water Framework Directive (European Commission 2000), hydrology is stipulated as a determinant of ecological status only at High status. For other status classes, hydrology can be used as supporting element.

1.3 The current flow standards are in the form of a series of limits of allowable reduction from natural flows (essentially abstraction limits) at a range of flow conditions (flow percentiles, as defined by a flow duration curve). The limits vary according to river type, and the standards for Good status also vary by season. These standards apply on an instantaneous basis i.e. any breach constitutes a failure.

The basis for reviewing the hydrology river flow standards

1.4 Ahead of the third cycle of river basin plans there now exists an opportunity to review the flow standards. It is recognised that revisions to the flow standards may be put forward where improved understanding of the relationship between flow alteration and ecology response (through research and monitoring, or the benefit of experience in their practical application), can identify specific recommendations.

1.5 The following standards review criteria have been used to determine if there is case to revise aspects of the flow standards:

- A technical problem has been identified with the derivation of the standard;
- A step change in the science that underpins standard derivation has been identified;
- Where there is a gap in standards coverage, sufficient evidence is amassed to address this.

1.6 The UKTAG Water Resources Task Team (WRTT) reviewed the evidence base to determine if this supported a case to revise using the above criteria. These findings were put to an expert workshop [1].

1.7 As will be shown in the sections below the evidence supports the case for revision of some aspects of the environmental standards for river flow.

[1] The Environment Agency uses the Environmental Flow Indicator, derived from the flow standards.

A1. Artificially increased flows

Standards review criterion	Met?
A technical problem has been identified with the derivation of the standard	✗
A step change in the science that underpins standard derivation has been identified	✓
Where there is a gap in standards coverage, sufficient evidence is amassed to address this	✓

1.8 Some waters have flows that are significantly increased over the natural position due to the transfers of water into the catchment. This happens if drinking water originating from abstractions in one catchment is discharged as treated effluent from a sewage treatment works in a different catchment. Less common is the case where there is a pumped transfer of raw water between catchments, for the purposes of distributing water resources.

1.9 It has been known for some time that, conceptually at least, artificially increased flows could impact ecological health e.g. Richter et al. 1996 [2] and SNIFFER 2012 [3]. In the period since the existing flow standards were developed, there has been growing evidence from the UK to support the theory that augmented flows (arising from additional flow from discharges (from reservoirs or treated effluent) or water transfers) have a detrimental impact on riverine ecology.

Summary of evidence

1.10 Large datasets are now available which match historical macroinvertebrate monitoring data to the degree of flow alteration from natural, alongside levels of other pressures such as physical modification. An Environment Agency commissioned report [4] used statistical modelling (generalised additive mixed effects models) to analyse macroinvertebrate data, linked to flow alteration data (described as deviation of recent actual flow from natural) from over 3,500 monitoring sites across England, Wales and Scotland. This dataset covered depleted, natural and flows artificially increased due to catchment transfers or reservoir releases.

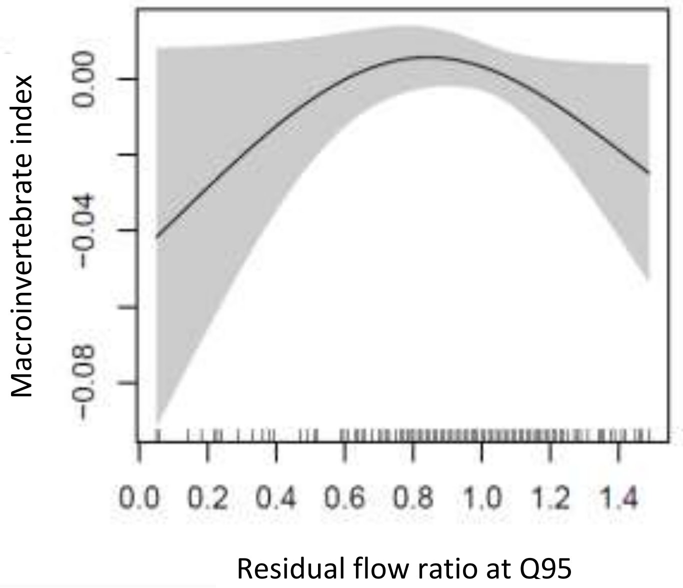
1.11 Sites with poor water quality which might override the relationship between the macroinvertebrate community and flow alteration were excluded.

1.12 Results showed a clear negative impact of elevated flows on macroinvertebrate scores. The elevated flows in the dataset were those where augmentation occurs for the majority of time, thereby eradicating low flow variability. The study did not present evidence indicating that short-term flow elevations such as freshet releases or scour valve operations had a detrimental impact on downstream ecology.

1.13 The impact of elevated flows upon macroinvertebrates is evident in the relationship between macroinvertebrate score and flow deviation at Q95, shown in Figure A1.1. Here, the x axis shows the proportion of natural flow remaining at Q95 (a low flow), with values less than 1 representing reduced flows (abstraction) and those greater than 1 representing artificially increased flows.

1.14 Within the above mentioned Environment Agency report, a similar relationship is shown for flow deviations at higher flows (Q30).

Figure A1.1
The relationship between the residual flow ratio at Q95 (x axis) and macroinvertebrate index (y axis). Note: data used in this graph are from the CAMS dataset for non-headwater rivers.



1.15 Unpublished work by the Environment Agency using the DRIED-UP 2 dataset has indicated that macroinvertebrate LIFE scores in upland catchments respond not only to variation in low flows, but also natural inter-annual variation in high flow variability.

1.16 Natural England's review of the evidence base [5] similarly concluded that artificially increased flows and water levels have ecological impacts, such as the loss of fauna associated with exposed riverine sediments and flora and fauna associated with ephemeral streams (such as winterbournes) and seasonally inundated margins.

Recommendations for the revision of environmental standards

1.17 Evidence has been presented here which suggests that artificially increased flows have a negative impact on river biota. Under WFD, high ecological status is defined as near naturalness associated with no or very low human pressure. Consequently the evidence provided supports a change for high hydrological status to take account of persistent, artificially elevated flows in addition to the current limits on flow from abstraction pressures. It may be appropriate to extend this approach for standards for less than high status in the future but further evidence will be required to support derivation of thresholds.

1.18 It is recommended that the existing flow standards for high hydrological status are amended to include an upper threshold of 5% deviation above natural at flow less than or equal to Qn95, and 10% deviation above natural where flows are greater than Qn95. This mirrors the thresholds for flow reduction for high status.

1.19 This proposal brings greater alignment with the WFD normative definition for high ecological status, for which the quantity and dynamics of flow should reflect totally, or nearly totally, undisturbed conditions. It also brings greater alignment with the Common Standards Monitoring Guidance (CSMG), used for condition assessment of river sites with conservation designations. This specifies flow targets in the form of percent deviations from natural flow, which includes artificial increases.

1.20 Whilst artificially increased flows would not be part of the standards for less than high, we recommend that the impact of these flows should be considered when confirming good status or determining what action is required to address water bodies at less than good status.

1.21 The above recommendations do not apply to Heavily Modified Water Bodies (HMWBs). Separate guidance is provided on river flows for HMWBs [6]. We recommend that this guidance is reviewed to ensure it takes account of the evidence provided that artificially elevated flows have an adverse impact on river ecology whilst ensuring that measures associated with flow augmentation for conservation purposes are not compromised.

The impact of the proposed changes on water body classification

1.22 The scale of impact on agency and water resource operator's business will be informed by how many water bodies will change status from high to less than high as a result of this amendment. In addition, each region may have different types of water resource use leading to flow augmentation. Some consideration of how these are regulated is required.

1.23 In the second river basin planning cycle hydrology class is generally in a "one-out-all-out" test across all quality elements to determine overall high status. Where all other quality elements are high, hydrology class may downgrade overall status to no less than good.

1.24 The flow standards are implemented differently across the UK Administrations, and therefore information on implementation of the proposed revisions to the standards, and the business implications, are considered separately on a country basis in the following sections:

1.25 **England:** There are a maximum of five water bodies which could be affected (from 5442 reportable surface water bodies in England), since they have an objective of high ecological status and are all meeting that objective.

1.26 **Northern Ireland:** NI used flow augmentation in the second river basin planning cycle to classify river water bodies for all hydrological classes (High to Bad). Therefore as this is already applied in NI, it would have no implications for WFD classification, objective setting or regulatory licencing. There are no river water bodies in NI that currently have managed elevated flows for protection of habitats. The river water bodies impacted by flow augmentation in NI are due to large UWWT discharges at low flow where public drinking water supply is from a different catchment (transfer). Application of flow augmentation test had no impact on overall status.

1.27 **Scotland:** There are approximately 2000 non-HMWB river water bodies in Scotland. Of these, there are 84 which meet the current high hydrology environmental standard but would breach the revised standard. However, of these, only 2 would drop in overall ecological status from high to good with the other 82 already being at less than high status due to other parameters. The 2 water bodies which would be downgraded are those with elevated flows due to catchment transfers as part of large storage hydropower schemes. As a consequence, it is felt that the regulatory impact of this revision on non-HMWBs would be small.

1.28 **Wales:** Wales has 4 water bodies at high morphological status and no water bodies at overall high status, therefore amendment to guidance should have limited impact.

A2. Short-term abstraction

Standards review criterion	Met?
A technical problem has been identified with the derivation of the standard	✗
A step change in the science that underpins standard derivation has been identified	✗
Where there is a gap in standards coverage, sufficient evidence is amassed to address this	✓

1.29 The current flow standards are in the form of a series of limits of allowable reduction from natural flows (essentially abstraction limits) at a range of flow conditions (flow percentiles, as defined by a flow duration curve). However, this takes no account of the duration of an abstraction, nor how frequently it occurs. This means that an abstraction that breaches a standard for a few days once a year is treated the same as one causing a continuous breach; the same limits apply to both. In terms of ecological impact, the two are likely to be very different, and for temporary, occasional abstractions the current flow standards may be over-precautionary.

Summary of evidence

1.30 River animals and plants have evolved in an environment of variability, for example in the flow regime. This includes short-term periods of naturally low flow, to which animals and plants are well adapted.

1.31 The WRTT commissioned a review of evidence of the impacts of short-term flow reductions on river ecology [7], particularly those caused by abstraction and with a focus on the interacting effects of the magnitude and duration of low flow events. Evidence for the interacting effects of frequency, timing/ sequencing and rate of change were also considered. The review output includes an accompanying decision framework [8]. A summary of the findings of this review is presented here. For further detail, and for references to relevant publications, see the full report.

1.32 The direct influence of flow on ecology is primarily a result of its defining of physical habitat, in particular hydraulic elements (depth, velocity, wetted width). Organisms respond to hydrological changes via these hydraulic conditions which define the river habitat.

1.33 During low flow events there will be a reduction in habitat availability, as depth, velocity and wetted width reduce. Several phases of habitat change can be identified as flow progressively reduces, including:

- Loss of connectivity to the riparian zone
- Shrinkage of habitat
- Dewatering of riffles, leading to loss of connectivity and isolated pools
- Complete loss of surface water (dewatering)

1.34 For flow reductions lasting less than one month, impacts on aquatic organisms were found to be low, provided some flowing water remains in the channel. Fish and invertebrates will move from areas where habitat is lost, or becomes unfavourable, to more favourable areas, such as deeper pools, or into river bed gravels. Several studies found that reductions in habitat size (but with connectivity retained) due to extreme low flow events lasting up to a month in the summer almost universally resulted in increases in macroinvertebrate density, but had no effect on taxonomic composition.

1.35 High intensity abstraction for longer periods (more than three months) can cause impacts on macroinvertebrate community composition. However, the evidence suggests that recovery can occur as long as there is more than one month between abstraction events.

1.36 There are fewer studies on fish, but these indicate rapid movement in response to reduced flows, and a rapid ability to recolonise habitats made unsuitable by lack of flow. There may be some increased mortality due to greater vulnerability to predation.

1.37 There is a lack of information on the effects of short-term low flow events on aquatic plants. One study showed diatoms (phytobenthos) to be unaffected by extreme low flow events of less than a month duration. There is no information for higher plants (macrophytes), but it is expected that those in areas left exposed would survive for short periods but not survive prolonged desiccation.

1.38 In contrast to the general resilience of aquatic organisms to reduced habitat quantity and quality resulting from low flows, macroinvertebrates and fish are not resistant to the impacts of isolation of habitats. This is particularly the case for loss of longitudinal connectivity and formation of isolated pools. The duration over which such events can be survived is variable and may be short. Increased water temperature and reduced dissolved oxygen can be critical factors influencing this duration. Loss of connectivity, with longitudinal isolation of habitats (isolated pools), is a critical threshold where extreme low-flow events can cause significant ecological impacts.

1.39 The findings of the review for low flow events above and below the key threshold of maintaining habitat connectivity, as outlined above, are summarised in Table A2.1.

Table A2.1
Review of low flow events

Event characteristics	Element	Risk of impact	Certainty* (no. studies)
Reduced habitat but connectivity maintained, event duration <1 month and >1 month between events	Macroinvertebrates	Low	High (9)
	Fish	Low	Low (7)
	Phytobenthos	Low	Low (1)
	Macrophytes	Unknown	(0)
Loss of connectivity – formation of isolated pools, isolated event, >1 week duration	Macroinvertebrates	High	Moderate (6)
	Fish	Medium	Low (4)
	Phytobenthos	Unknown	(0)
	Macrophytes	Unknown	(0)

*certainty based on number of non-conflicting peer-reviewed studies and conceptual understanding.

Recommendations for flow standards for short-term abstraction

1.40 The UKTAG recommends that a temporal element is applied to the flow standards, such that, depending upon frequency and duration, short-term exceedances of the flow standard threshold might not result in a deterioration in class. The magnitude of allowable exceedance would depend on both its duration and the typical interval between exceedances. This accounts for the resilience of aquatic ecology to short low flow events but also the need for a recovery period.

1.41 The proposed allowable exceedances would apply across all flows, provided that longitudinal connectivity of the water environment in the river channel is maintained. To ensure this condition, it is proposed that the exceedances only apply to flow deviations that meet the poor standard or above and where natural flows exceed Qn98[2]. Deviations greater than the poor standard can potentially cause significant ecological impacts after even a short duration, especially where habitat fragmentation or dewatering occurs. Similarly, daily mean flows less than a Qn98 are, by definition, exceptionally low and the risk of a disruption in the longitudinal wetted channel connectivity is high.

1.42 Table A2.2 shows a matrix of allowable flow standard exceedances for short-term flow reductions. An allowable exceedance means a higher class may be assigned. Exceedances are not permitted, i.e. current standards continue to apply, where:

- The standard for poor is exceeded, or
- An exceedance lasts more than twenty days, or
- Exceedances typically occur more frequently than once every two months.
- The natural daily mean flow is below Qn98

[2] A flow of Qn98 is one which is equalled or exceeded for 98 percent of the time.

Table A2.2
Revised classification accounting for short-term flow deviations

Median interval between abstraction events - select as appropriate	>3 years					≤3 years to >1 year					≤1 year to >2 months				
Abstraction event reducing flow to H/G/M/P/B - select as appropriate	H	G	M	P	B	H	G	M	P	B	H	G	M	P	B
Abstraction Event Duration (days):	Revised class														
>10 to ≤20	H	G	G	M	B	H	G	M	P	B	H	G	M	P	B
>5 to ≤10	H	G	G	M	B	H	G	G	M	B	H	G	M	P	B
≤5	H	H	G	G	B	H	G	G	M	B	H	G	G	M	B

Note: look up event interval, magnitude (class) and duration to find revised class

1.43 The revision allows an increasing degree of exceedance of the current standards as flow reduction events become shorter and less frequent. For example, an event of a magnitude that exceeds the existing moderate standard (i.e. poor class) which occurs typically between one and six times per year (interval 2 months to ≤1 year) and lasts up to five days would still meet the moderate short-term standard. However a similar abstraction regime but with event durations longer than five days would not and the result would be a class of poor.

1.44 The allowable exceedances would mean that, where the frequencies and durations of abstraction events are small, a higher class than permitted by the current standards may be assigned. This would apply to the water body (not an individual abstraction) and would need to take account of any cumulative effects from multiple abstractions, as well as effects on flow on any downstream water bodies. Normal classification spatial rules would apply.

1.45 Some examples of how the short-term standards would apply are given in Annex A4.

The impact of the proposed changes on water body classification

1.46 **England, Northern Ireland, and Wales:** This change does not apply as England, Northern Ireland and Wales do not use flow as a defining element to classify good ecological status but uses flow as a supporting element only. There would therefore be no changes in status of any river water bodies. This information would be useful however in interpreting ecological evidence.

1.47 **Scotland:** In the absence of ecological classification metrics sufficiently sensitive to water resource pressures the environmental flow standards have been used in Scotland as an element to indicate ecological status' of moderate, good and high. Currently, a hydrology class of poor (or bad) is only assigned where evidence from ecological indicators confirms ecological impact equivalent to poor (or bad) status. The impact on the proposed change will be on water bodies currently assigned a class of moderate or good for hydrology due to the impact of intermittent abstractions, typically for irrigation. Calculation of a revised classification is not possible at this time, but it is estimated that up to 20 water bodies could change class from moderate to good status.

A3. Examples of applying the short-term abstraction revision

Case 1

35% of the natural low flow (Qn95) of a river water body is abstracted for irrigation on two separate occasions in a year, each lasting for 3 days. The river is type B2 and the environmental standard indicating moderate is greater than 20% to 45% of flow at Qn95.

Current standards: The magnitude of flow reduction **breaches the good environmental standard**, so is at moderate.

Revised standards: The interval between events is 6 months and the magnitude of flow alteration is consistent with the existing moderate environmental standard. The abstraction has a duration of less than 5 days so the breach of the good standard is allowed; it remains consistent with **meeting the good environmental standard**, so changes to good.

Case 2

35% of the natural low flow (Qn95) of a river water body is abstracted for irrigation on two separate occasions in a year, one lasting for 11 days the other for 14 days. The river is type B2 and the environmental standard indicating moderate is greater than 20% to 45% of flow at Qn95. This is the same as for Case 1 except that the events have longer durations.

Current standards: The magnitude of flow reduction **breaches the good environmental standard**, so is at moderate.

Revised standards: The interval between events is 6 months and the magnitude of flow alteration is consistent with the existing moderate environmental standard. The abstraction has a duration of more than 10 days so the breach of the good standard is not allowed; it continues to **breach the good environmental standard**, so stays at moderate.

Case 3
50% of the natural low flow (Qn95) of a river water body is abstracted for irrigation for 4 days in dry years only (less than once every 3 years). The river is type B2 and the environmental standard indicating poor is greater than 45 to 70% of flow at Qn95.

> **Current standards:** The magnitude of flow reduction **breaches the moderate environmental standard**, so is at poor.
>
> **Revised standards:** The interval between events is >3 years and the magnitude of flow alteration is consistent with the existing poor environmental standard. The abstraction has a duration of less than 5 days and in this case the result would be that it **meets the good environmental standard.**

Case 4
75% of the natural low flow (Qn95) of a river water body is abstracted for irrigation for 5 days in dry years only (once every 3 years on average). The river is type B2 and the environmental standard indicating poor is greater than 45% to 70% of flow at Qn95.

> **Current standards:** The water body **breaches poor environmental standard,** so is at bad.
>
> **Revised standards:** In this case, breach of the poor status environmental standard gives a risk to the continuity of the river, its lateral connectivity and provision of sufficient depths and velocities for fish. As such, breaches are not permissible, so the abstraction still **breaches the poor environmental standard and it remains at bad.**

References

[1] APEM (2018) Workshop to Consider New Evidence to Inform UKTAG Environmental Flow Standards: 9th January 2018. Report to the Environment Agency. Final Report, 85pp

[2] Richter B.D., Baumgartner J.V., Powell, J. & Braun, D.P. (1996). A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10:1163-1174.

[3] SNIFFER Project WFD21D (2012). Ecological indicators of the effects of abstraction and flow regulation; and optimisation of flow releases from water storage reservoirs: https://www.wfduk.org/resources%20/ecological-indicators-effects-abstraction-and-flow-regulation-and-optimisation-flow

[4] WRc (2018): Macroinvertebrate response to flow alteration: does it vary by river type?

[5] MAINSTONE, C.P. (2010): An evidence base for setting flow targets to protect river habitat. Natural England Research Reports, Number 035. Natural England, Sheffield.

[6] UKTAG (2013): River Flows for Good Ecological Potential

[7] APEM (2017): Literature review of short-term flow reduction ecological impacts and recovery. Report to SEPA. https://www.sepa.org.uk/media/336665/sepa-literature-review-of-short-term-flow-reduction-ecological-impacts-and-recovery.pdf

[8] SEPA: https://www.sepa.org.uk/about-us/how-we-work/our-research/tools-techniques-and-technologies/

ANNEX B – Invasive Species

B1. Classification of aquatic alien species according to their level of impact

Species on the high impact list are used within WFD Classification process. This version contains the species to be used in classification during river basin planning cycle 3. The changes made to Table B1.1 are set in context in the UKTAG paper entitled *Aquatic alien species and the WFD: proposed amendments to the impact classification in the UKTAG alien species guidance* which documents the principles to be adopted by agencies responsible for implementing the Water Framework Directive (WFD) in the UK.

Table B1.1
Classification of aquatic alien species found in the UK in terms of their impact on native habitats and biota.

	Common name	Species	Plant/ Animal/Fish	Habitat	GB Risk Assessments
HIGH IMPACT	Freshwater mollusc - Asiatic clam	*Corbicula fluminea*	Animal	Freshwater	Yes
	Freshwater amphipod	*Dikerogammarus haemobaphes*	Animal	Freshwater	Yes
	Freshwater amphipod	*Dikerogammarus villosus*	Animal	Freshwater	Yes
	Zebra mussel	*Dreissena polymorpha*	Animal	Freshwater	Yes
	Quagga mussel	*Dreissena rostriformis bugensis*	Animal	Freshwater	Yes
	Mysid crustacean	*Hemimysis anomala*	Animal	Freshwater	No
	Virile crayfish	*Orconectes virilis*	Animal	Freshwater	Yes
	North American signal crayfish	*Pacifastacus leniusculus*	Animal	Freshwater	Yes
	Red swamp crayfish	*Procambarus clarkii*	Animal	Freshwater	Yes
	Goldfish	*Carassius auratus*	Fish	Freshwater	No
	Common Carp	*Cyprinus carpio*	Fish	Freshwater	Pending
	Topmouth gudgeon	*Pseudorasbora parva*	Fish	Freshwater	Yes
	Water Fern	*Azolla caroliniana*	Plant	Freshwater	Yes
	Water fern	*Azolla filiculoides*	Plant	Freshwater	Yes
	Australian swamp stonecrop	*Crassula helmsii*	Plant	Freshwater	Yes
	Nuttall's pondweed	*Elodea nuttallii*	Plant	Freshwater	Yes
	Floating pennywort	*Hydrocotyle ranunculoides*	Plant	Freshwater	Yes
	Curly water-thyme	*Lagarosiphon major*	Plant	Freshwater	Yes
	Water primrose	*Ludwigia grandiflora*	Plant	Freshwater	Yes

HIGH IMPACT	Floating primrose willow	*Ludwigia peploides*	Plant	Freshwater	Yes
	American skunk-cabbage	*Lysichiton americanus*	Plant	Freshwater	Yes
	Parrot's feather	*Myriophyllum aquaticum*	Plant	Freshwater	Yes
	Two-leaf water-milfoil	*Myriophyllum heterophyllum*	Plant	Freshwater	Pending
	Japanese knotweed	*Fallopia japonica*	Plant	Riparian	Yes
	Giant knotweed	*Fallopia sachalinensis*	Plant	Riparian	Yes
	Japanese knotweed/ Giant knotweed hybrid	*Fallopia* x *bohemica*	Plant	Riparian	No
	Gunnera manicata & tinctoria	*Gunnera* spp.	Plant	Riparian	Yes
	Giant hogweed	*Heracleum mantegazzianum*	Plant	Riparian	Pending
	Himalayan balsam	*Impatiens glandulifera*	Plant	Riparian	Pending
	Himalayan knotweed	*Persicaria wallichii*	Plant	Riparian	Yes
	Rhododendron	*Rhododendron ponticum* (+ hybrids)	Plant	Riparian	Yes
	Chinese mitten crab	*Eriocheir sinensis*	Animal	Freshwater/ Brackish	Yes
	Gulf wedge clam	*Rangia cuneata*	Animal	Freshwater/ Brackish	Yes
	Marine tubeworm	*Ficopomatus enigmaticus*	Animal	Brackish	No
	Slipper limpet	*Crepidula fornicata*	Animal	Marine	Yes
	Colonial tunicate	*Didemnum* spp. (Non-native)	Animal	Marine	Yes
	Asian shore crab	*Hemigrapsus sanguineus*	Animal	Marine	Yes
	Asian shore crab	*Hemigrapsus takanoi*	Animal	Marine	Yes
	American lobster	*Homarus americanus*	Animal	Marine	Yes
	Leathery sea squirt	*Styela clava*	Animal	Marine	No

	Common name	Species	Plant/ Animal/Fish	Habitat	GB Risk Assessments
MODERATE IMPACT	Spiny cheeked crayfish	*Orconectes limosus*	Animal	Freshwater	Yes
	Jenkins' spire shell	*Potamopyrgus antipodarum*	Animal	Freshwater	Yes
	White river crayfish	*Procambarus acutus*	Animal	Freshwater	Yes
	Marbled crayfish	*Procambarus spp.*	Animal	Freshwater	Yes
	Pumpkinseed	*Lepomis gibbosus*	Animal	Freshwater	Yes
	Pikeperch (zander)	*Sander lucioperca*	Fish	Freshwater	Pending
	Carolina water-shield	*Cabomba caroliniana*	Plant	Freshwater	Yes
	Large-flowered water-thyme	*Egeria densa*	Plant	Freshwater	Yes
	Canadian pondweed	*Elodea canadensis*	Plant	Freshwater	Yes
	Least duckweed	*Lemna minuta (minuscula)*	Plant	Freshwater	Pending
	Monkey-flower	*Mimulus cupreus, M. guttatus* and hybrids	Plant	Riparian	Yes
	Japanese skeleton shrimp	*Caprella mutica*	Animal	Marine	Yes
	Pacific oyster	*Crassostrea gigas*	Animal	Marine	Yes
	Red seaweeds	*Bonnemaisonia hamifera*	Plant	Marine	Pending
	Marine alga	*Gracilaria vermiculophylla*	Plant	Marine	Yes

	Common name	Species	Plant/ Animal/Fish	Habitat	GB Risk Assessments
LOW IMPACT	Noble crayfish	*Astacus astacus*	Animal	Freshwater	Yes
	Narrow-clawed (Turkish) crayfish	*Astacus leptodactylus*	Animal	Freshwater	Yes
	Freshwater amphipod	*Crangonyx pseudogracilis*	Animal	Freshwater	Yes
	Grass carp	*Ctenopharyngodon idella*	Fish	Freshwater	No
	Orfe	*Leuciscus idus*	Fish	Freshwater	No
	Rainbow trout	*Oncorhynchus mykiss*	Fish	Freshwater	No
	European (wels) catfish	*Silurus glanis*	Fish	Freshwater	Pending
	Sweetflag	*Acorus calamus*	Plant	Freshwater	No
	Cape pondweed	*Aponogeton distachyos*	Plant	Freshwater	Pending
	Water hyacinth	*Eichhornia crassipes*	Plant	Freshwater	Yes
	South American waterweed	*Elodea callitrichoides/Hydrocharis callitrichoides*	Plant	Freshwater	Pending

LOW IMPACT	Montbretia	*Crocosmia x crocosmiiflora*	Plant	Riparian	Pending
	Orange balsam	*Impatiens capensis*	Plant	Riparian	No
	Lupin	*Lupinus nootkatensis*	Plant	Riparian	No
	Pink purslane	*Montia sibirica*	Plant	Riparian	No
	Giant butterbur	*Petasites japonicus*	Plant	Riparian	Pending
	Marine copepod	*Acartia tonsa*	Animal	Marine	Pending
	Magellan mussel	*Aulacomya ater*	Animal	Marine	No
	Bamboo worm	*Clymenella torquata*	Animal	Marine	No
	Marine amphipod	*Corophium sextonae*	Animal	Marine	No
	Barnacle species	*Elminius modestus*	Animal	Marine	No
	Marine polychaete	*Goniadella gracilis*	Animal	Marine	Pending
	Marine hydrozoan	*Gonionemus vertens*	Animal	Marine	Pending
	Marine polychaete	*Marenzellaria viridis*	Animal	Marine	No
	American hard-shell clam	*Mercenaria mercenaria*	Animal	Marine	No
	American piddock	*Petricola pholadiformis*	Animal	Marine	Pending
	Zuiderzee or dwarf crab	*Rhithropanopeus harrisii*	Animal	Marine	Pending
	Manilla Clam	*Ruditapes philippinarum*	Animal	Marine	Yes
	New Zealand flat oyster	*Tiostrea lutaria*	Animal	Marine	No
	Red seaweeds	*Agardhiella subulata*	Plant	Marine	Pending
	Captain pike's weed	*Pikea californica*	Plant	Marine	No
	Japanese weed	*Sargassum muticum*	Plant	Marine	Yes
	Tapegrass	*Vallisneria spiralis*	Plant	Marine	No

	Common name	**Species**	**Plant/ Animal**	**Habitat**	**GB Risk Assessments**
UNKNOWN IMPACT	Freshwater copepods	*Achtheres percarum*	Animal	Freshwater	No
	Other freshwater malacostracans	*Asellus communis*	Animal	Freshwater	No
	Freshwater oligochaetes	*Branchiura sowerbyi*	Animal	Freshwater	No
	Freshwater cnidarian	*Cordylophora caspia*	Animal	Freshwater	No
	Freshwater coelenterate	*Craspedacusta sowerbyi*	Animal	Freshwater	No
	Freshwater triclads	*Dugesia tigrina*	Animal	Freshwater	No

UNKNOWN IMPACT	Freshwater amphipod	*Echinogammarus ischnus*	Animal	Freshwater	No
	Freshwater amphipod	*Echinogammarus trichiatus*	Animal	Freshwater	No
	Freshwater copepods	*Ergasilus briani*	Animal	Freshwater	No
	Freshwater copepods	*Ergasilus sieboldi*	Animal	Freshwater	No
	Freshwater molluscs	*Ferissia wautieri*	Animal	Freshwater	No
	Freshwater oligochaetes	*Limnodrilus cervix*	Animal	Freshwater	No
	Freshwater molluscs	*Marstoniopsis scholtzi*	Animal	Freshwater	No
	Freshwater molluscs	*Menetus dilatatus*	Animal	Freshwater	No
	Freshwater molluscs	*Musculium transversum*	Animal	Freshwater	No
	Freshwater copepods	*Neoergasilus japonicus*	Animal	Freshwater	No
	Freshwater triclads	*Phagocata woodworthi*	Animal	Freshwater	No
	Freshwater molluscs	*Physa acuta*	Animal	Freshwater	No
	Freshwater molluscs	*Physa gyrina*	Animal	Freshwater	No
	Freshwater molluscs	*Physa heterostropha*	Animal	Freshwater	No
	Freshwater triclads	*Planaria torva*	Animal	Freshwater	No
	Freshwater copepods	*Tracheliastes polycolpus*	Animal	Freshwater	No
	Sunbleak	*Leucaspius delineatus*	Fish	Freshwater	Pending
	Bitterling	*Rhodeus amarus*	Fish	Freshwater	No
	Brook charr	*Salvelinus fontinalis*	Fish	Freshwater	No
	Other non-native Myriophyllum species	*Myriophyllum spp.*	Plant	Freshwater	Pending
	Swordleaf rush	*Juncus ensifolius*	Plant	Riparian	No
	Other freshwater malacostracans	*Corophium curvispinum*	Animal	Freshwater/ Brackish	No
	Polychaete	*Hypania invalida*	Animal	Freshwater/ Brackish	No
	Sterlet/Sturgeons	*Acipenser spp. (not A. sturio, which is protected on Schedule 5 of the Wildlife & Countryside Act)*	Animal	Freshwater/ Marine	Pending
	Sea spider	*Ammothea hilgendorfi*	Animal	Marine	No
	Barnacle	*Balanus amphitrite*	Animal	Marine	No
	Marine hydroid	*Clavopsella navis*	Animal	Marine	No
	Oyster thief	*Colpomenia peregrina*	Animal	Marine	No
	American jack knife clam	*Ensis americanus*	Animal	Marine	No
	Marine copepod	*Eusarsiella zostericola*	Animal	Marine	No
	Orange-striped sea anemone	*Haliplanella lineata*	Animal	Marine	No
	Marine tubeworms	*Hydroides dianthus*	Animal	Marine	No

UNKNOWN IMPACT	Marine tubeworms	*Hydroides ezoensis*	Animal	Marine	No
	Marine tubeworms	*Janua brasiliensis*	Animal	Marine	No
	Kuruma prawn	*Marsupenaeus japonicus*	Animal	Marine	No
	Soft-shelled clam	*Mya arenaria*	Animal	Marine	No
	Dark false mussel	*Mytilopsis leucophaeata*	Animal	Marine	No
	Marine tubeworms	*Pileolaria berkeleyana*	Animal	Marine	No
	Marine mollusc	*Pinctada imbricata radiata*	Animal	Marine	No
	Red seaweeds	*Antithamnionella spirographidis*	Plant	Marine	No
	Red seaweeds	*Antithamnionella ternifolia*	Plant	Marine	No
	Red seaweeds	*Asparagopsis armata*	Plant	Marine	No
	Wright's Golden Membrane Weed	*Chrysymenia wrightii*	Plant	Marine	No
	Green seaweeds	*Codium fragile subspp. atlanticum* and *tomentosoides*	Plant	Marine	No
	Diatoms	*Coscinodiscus wailesii*	Plant	Marine	No
	Red seaweeds	*Grateloupia doryphora*	Plant	Marine	No
	Red seaweeds	*Grateloupia filicina* var. *luxurians*	Plant	Marine	No
	Diatoms	*Odontella sinensis*	Plant	Marine	No
	Diatoms	*Pleurosigma simonsensii*	Plant	Marine	No
	Red seaweeds	*Polysiphonia harveyi*	Plant	Marine	No
	Red seaweeds	*Solieria chordalis*	Plant	Marine	No
	Diatoms	*Thalassiosira punctigera*	Plant	Marine	No
	Diatoms	*Thalassiosira tealata*	Plant	Marine	No

Ecoregion 17 High Impact list

	Common Name	Species	Plant/ Animal	Habitat	Updated ER17 Risk Assessments
Ecoregion 17 HIGH IMPACT	Water Fern	*Azol la filiculoides*	Plant	Freshwater	Yes + Expert Judgment
	Asian clam	*Corbicula fluminea*	Animal	Freshwater/ Brackish	Yes
	Pacific Oyster	*Crassostrea gigas*	Animal	Marine	Yes
	Australian Swamp Stonecrop	*Crassula helmsii*	Plant	Freshwater	Yes
	Slipper Limpet	*Crepidula fornicata*	Animal	Marine	Yes
	Common Carp	*Cyprinus carpio*	Fish	Freshwater	Yes
	Ascidian species	*Didemnum vexillum*	Animal	Marine	Yes
	Zebra Mussel	*Dreissena polymorpha*	Animal	Freshwater	Yes
	Brazilian waterweed	*Egeria densa*	Plant	Freshwater	Yes
	Nuttall's Pondweed	*Elodea nuttallii*	Plant	Freshwater	Yes
	Japanese Knotweed,	*Fallopia japonica and hybrids*	Plant	Riparian	Yes
	Giant Knotweed	*Fallopia sachalinensis and hybrids*	Plant	Riparian	Yes
	Giant Rhubarbs/ Gunnera	*Gunnera spp. (G. manicata and G. tinctoria)*	Plant		
	Bloody red shrimp	*Hemimysis anomala*	Animal	Freshwater	Yes
	Giant Hogweed	*Heracleum mantegazzianum*	Plant	Riparian	Yes
	Floating Pennywort	*Hydrocotyle ranunculoides*	Plant	Freshwater	Yes
	Himalayan balsam	*Impatiens glandulifera*	Plant	Riparian	Yes
	Curly Waterweed	*Lagarosiphon major*	Plant	Freshwater	Yes
	Dace	*Leuciscus leuciscus*	Fish	Freshwater	Yes + Expert Judgement
	Parrot Feather	*Myriophyllum aquaticum*	Plant	Freshwater	Yes
	Fringed Water-Lily	*Nymphoides peltata*	Plant	Freshwater	Yes
	Himalayan knotweed	*Persicaria wallichii*	Plant	Riparian	Yes + Expert Judgement
	Roach	*Rutilus rutilus*	Fish	Freshwater	Yes + Expert Judgement
	Wire Weed	*Sargassum muticum*	Plant	Marine	Yes
	Common Cord-Grass	*Spartina anglica*	Plant	Marine	Yes
	Leathery Sea-squirt	*Styela clava*	Animal	Marine	Yes

Note: Yes + Expert Judgment = Risk assessment produced a score less than the 18 used to define High Impact Alien Species, and expert judgment was used to determine placement on the ER17 High Impact Alien Species List

ANNEX C – LAKES - Nitrogen

C1. Development of total nitrogen standards for lakes

Methods

3.1 Datasets of phytoplankton and macrophyte ecological quality ratios (EQRs) and corresponding arithmetic mean total phosphorus (TP) and total nitrogen (TN) concentrations for lakes in England, Wales and Scotland were collated from information provided by all UK agencies. The data covered a period of three or four years for phytoplankton, six years for macrophytes, and three to six years for nutrients, depending on which quality element was being considered (Table C1.1).

3.2 Data for lakes in Northern Ireland were not included in the development datasets because no TN data were available. Heavily modified water bodies where expert judgement indicated that water level fluctuations influenced macrophyte status were excluded from the macrophyte dataset. Only water bodies for which all three phytoplankton metrics (Phytoplankton Trophic Index, cyanobacteria and chlorophyll) were available were included in the phytoplankton dataset.

3.3 Prior to calculating mean TP and TN values the nutrient data were checked for outliers by inspection of box plots. Values below the limit of detection ("less thans") were halved. Lake typology categories (depth type, humic type and alkalinity type) were taken from Version 3 of the UK Lakes database (data now available on the UK Lakes Portal).

Table C1.1
Survey periods used in analysis.

	England	Wales	Scotland
Phytoplankton	2013-2015	2012-2014	2013-2016
Macrophytes	2010-2015	2009-2014	2011-2016

3.4 Analysis was undertaken in R [1] using the statistical 'tool kit' of scripts produced in support of the best practice guidance on establishing nutrient concentrations to support good ecological status [2]. The scripts are described in detail in the Appendix to the best practice guide and are only considered briefly here.

3.5 Box plots were used to compare the range of TN concentrations within each WFD biological class and to check for outlier values (*Script 01_TKit_check_data*). Scatter plots were used to visualise the relationships between biological EQRs and TN concentration and to identify additional obvious outliers. The shape of the relationship was determined by fitting generalised additive models (GAMs), and linear ranges of the data were identified with segmented linear regression (*Script 03b_TKit_N_check_linearity*).

3.6 Linear regression over the linear range of the data was used to estimate TN concentrations at the Good/Moderate and High/Good boundaries (*Script 04b_TKit_N_fit_lin_mod1*). Three different linear regression methods were used. These were (i) an ordinary least squares (OLS) model of EQR on log TN, (ii) an OLS model of log TN on EQR and (iii) ranged major axis (RMA) regression. Linear regression models that included alkalinity type, humic type or depth type (and combinations thereof) as a categorical variable were also fitted to the data (*Script 05b_TKit_N_fit_lin_mod2*). In these models the linear regression line for each lake type had the same slope and only differed in intercept. Again, three different linear regression methods were used. These were (i) an OLS model of EQR on log TN, (ii) an OLS model of log TN on EQR and (iii) a geometric mean regression (SMA) where the slope was derived from the geometric mean of the slopes from the two OLS models (RMA regression is not appropriate when a categorical variable is included in the regression model). The best models were selected using Akaike's Information Criterion (AIC), a measure of goodness of fit.

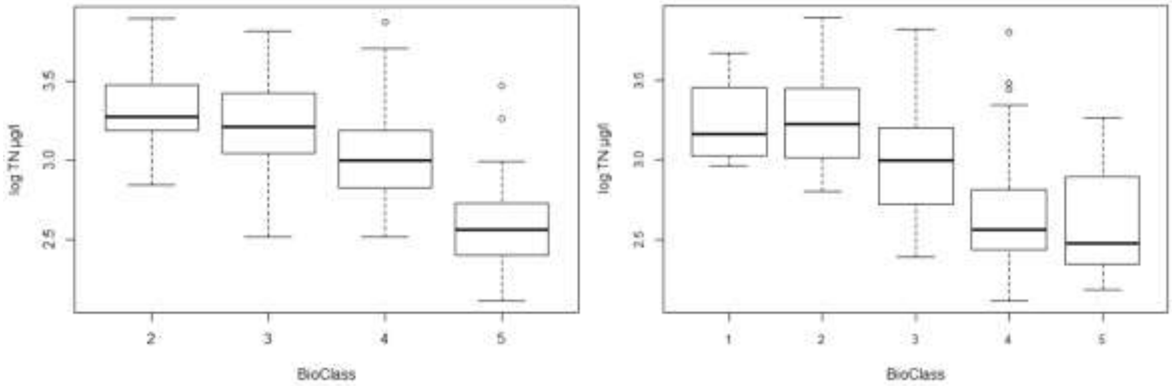
3.7 TN (and TP) concentrations at the High/Good and Good/Moderate boundaries were also estimated by fitting multivariate models that included both TN and TP as predictor variables (*Script 07_Tkit_NP_model*). Because it was difficult to determine the linear range for the multivariate models the full dataset was used for both the phytoplankton models and macrophyte models.

Results

3.8 Box plots of TN concentration categorised by biological class are shown in Figure C1. The data spanned four biological classes (Poor to High) for phytoplankton and five (Bad to High) for macrophytes. There was relatively little overlap in TN concentrations between classes for phytoplankton. This was not the case for macrophytes where there was a high degree of overlap between TN concentrations in the high and good classes. This suggests that the macrophyte dataset would not suitable for delineating the High/Good TN boundary (for all lake types). Several (high) outliers were identified in the box plots although these were not excluded at this stage (Figure C1.1).

Figure C1.1

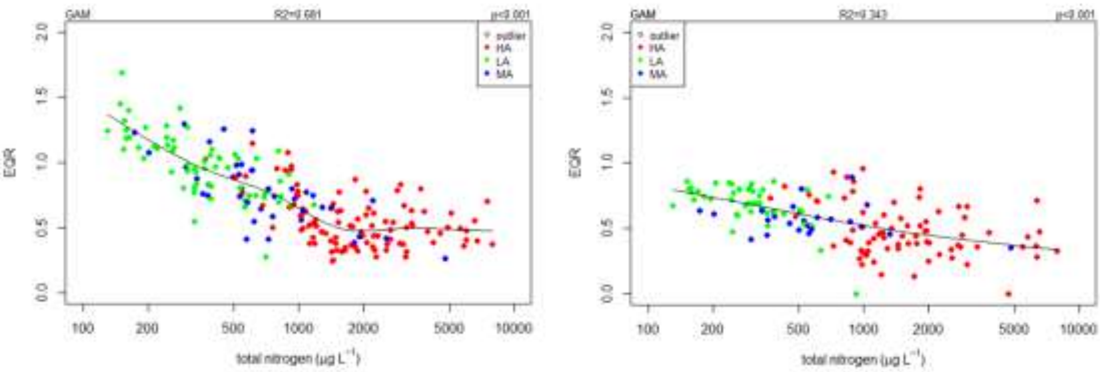
Box plots of TN concentration categorised by biological class for phytoplankton (left) and macrophytes (right). WFD biological classes range from 1 (Bad) to 5 (High). Note overlap between good and high classes for macrophytes. Outliers are identified by circles. Note log scale for TN.



3.9 Scatter plots showing the relationship between TN concentration and biological EQR for phytoplankton and macrophytes with fitted general linear models (GAMS) are shown in Figure C1.2. The GAM clearly indicates that the relationship between TN and EQR is nonlinear for phytoplankton over the range of TN concentrations represented in the dataset. There is more scatter in the relationship between TN and biological EQR for macrophytes and the GAM provides little evidence that the relationship is nonlinear. The water bodies in the scatter plots are colour coded by alkalinity type. High and low alkalinity water bodies form distinct groups on the plots indicating that high alkalinity water bodies tend to have the higher TN concentrations and lower biological EQRs.

Figure C1.2

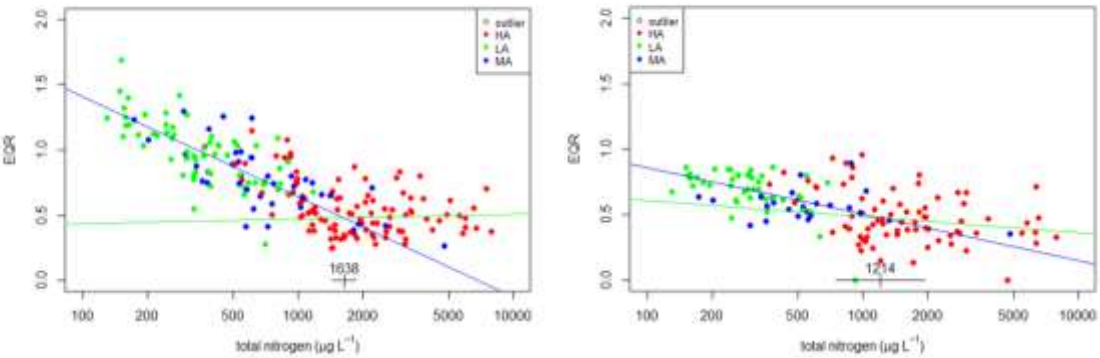
Relationships between TN and phytoplankton EQR (left) and TN and macrophyte EQR (right) with fitted general additive models (GAM). Water bodies are colour coded by alkalinity type (low, moderate, high).



3.10 Scatter plots showing the relationship between TN concentration and biological EQR for phytoplankton and macrophytes with fitted segmented linear regression models are shown in Figure C1.3. This identified breakpoints in the TN vs EQR relationship at 1638 µg/l for phytoplankton and 1214 µg/l for macrophytes. These values indicate the upper limit of the range over which linear regression is appropriate. However, although an upper limit of 1638 µg/l was used to fit linear regression models to the phytoplankton dataset, no upper limit was used to fit linear regression models to the macrophyte dataset. This was because given the high degree of scatter in the macrophyte EQR vs TN relationship, neither the GAM nor the segmented regression models provided convincing evidence of a nonlinear response over the entire TN range.

Figure C1.3

Relationships between TN and phytoplankton EQR (left) and TN and macrophyte EQR (right) with fitted segmented linear regression models. Water bodies are colour coded by alkalinity type (low, moderate, high). The crosses indicate the breakpoints in the segmented linear regression models.



3.11 Scatter plots showing the relationships between TN concentration and biological EQR for all lake types combined with fitted linear models are shown in Figures C1.4 and C1.5. Good/Moderate and High/Good boundary TN concentrations derived from the RMA regression (the preferred intermediate approach) of TN vs phytoplankton EQR were 1048 µg/l and 618 µg/l respectively. The boundary TN concentrations derived from the RMA regression of TN vs macrophyte EQR were markedly lower (645 µg/l and 216 µg/l respectively).

Figure C1.4
Relationship between TN and phytoplankton EQR with fitted linear models. Vertical solid lines indicate Good/Moderate boundary with dashed lines indicating % confidence limits. Open circles indicate water bodies that were not included in the models (TN concentration >1638 µg/l).

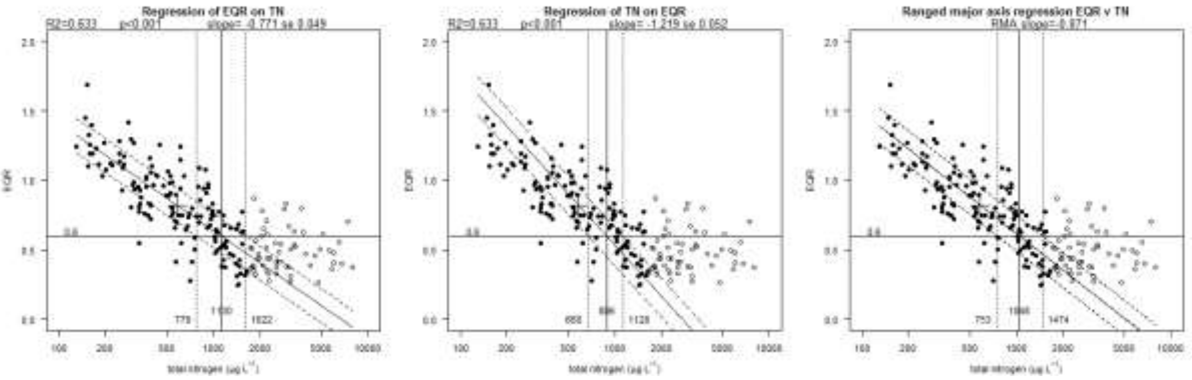
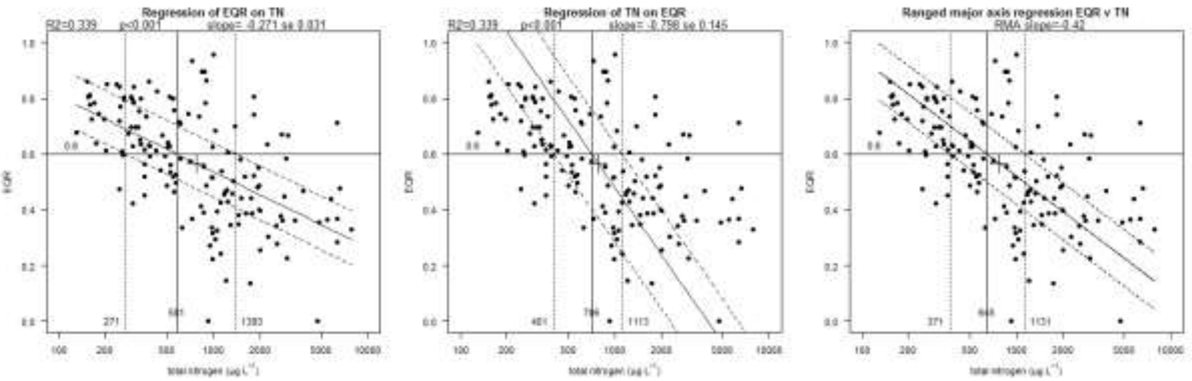


Figure C1.5
Relationship between TN and macrophyte EQR with fitted linear models. Vertical solid lines indicate Good/Moderate boundary with dashed lines indicating % confidence limits.



3.12 Inclusion of depth type and humic type (but not alkalinity type) as a categorical variable in the linear regression models resulted in an improvement of model fit (Table C1.2). The 'best' model for phytoplankton (as determined by AIC) included both depth type and humic type. The 'best' model for macrophytes included depth type only (AIC indicated that a fixed slope model that included both depth type and humic type as categorical variables in the regression was inappropriate). Scatter plots showing the relationship between TN concentration and biological EQR with fitted linear models that included depth type or humic type as a categorical variable are shown in Figures C1.6 to C1.9 (the models including alkalinity type and combinations of depth type and humic type have been omitted for clarity). For a given TN concentration, biological EQRs tended to be higher in humic lakes than in clear lakes, and in shallow lakes than in deep lakes. This was true for both phytoplankton and macrophytes.

Table C1.2

Goodness of fit data for linear models relating TN to biological EQR. In each case model ‘a’ has a fixed slope and model ‘b’ has a variable slope. The “best” model (lowest AIC) for each biological element is underlined.

Model	**df**	**Phytoplankton**		**Macrophytes**	
		AIC	**r^2**	**AIC**	**r^2**
Base model	3	-95.01	0.6300	-116.76	0.3348
Humic type model a	4	-144.00	0.7366	-126.93	0.3834
Humic type model b	5	-143.39	0.7373	-124.96	0.3792
Depth type model a	5	-97.27	0.6405	<u>-129.61</u>	<u>0.3985</u>
Depth type model b	7	-95.79	0.6415	-128.65	0.4025
Alkalinity type model a	5	-91.01	0.6248	-113.93	0.3308
Alkalinity type model b	7	-91.78	0.6316	-114.47	0.3420
Humic & Depth type model a	8	<u>-146.04</u>	<u>0.7470</u>	-141.28	0.4552
Humic & Depth type model b	13	-138.43	0.7418	-142.20	0.4755

3.13 Good/Moderate and High/Good boundary TN concentrations derived from the geometric mean (SMA) regression model for phytoplankton that included both depth and humic type as categorical variables are presented in Table C1.3. Given the much higher scatter in the linear regression models, equivalent boundary concentrations derived from the relationship between TN concentration and macrophytes have not been presented.

Figure C1.6

Linear regression models of TN vs phytoplankton EQR that include humic type as a categorical variable. Plots show Good/Moderate boundaries (top) and High/Good boundaries (bottom).

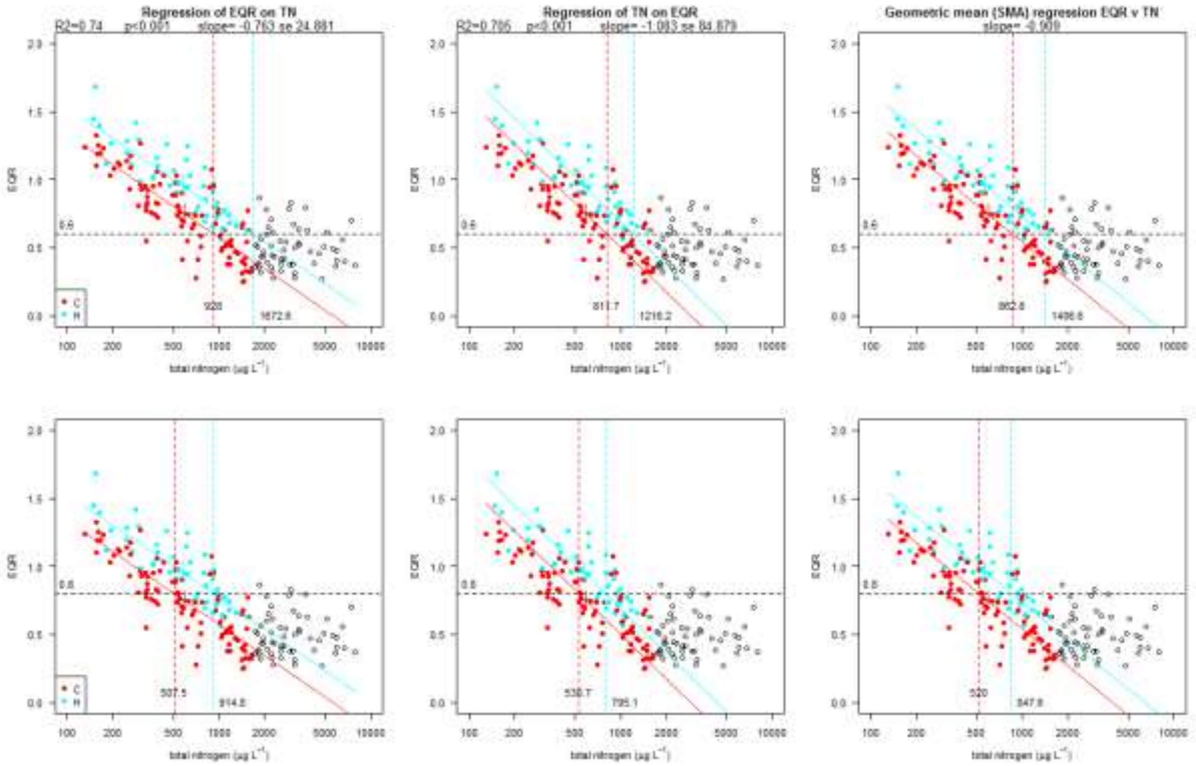


Figure C1.7
Linear regression models of TN vs phytoplankton EQR that include depth type as a categorical variable. Plots show Good/Moderate boundaries (top) and High/Good boundaries (bottom).

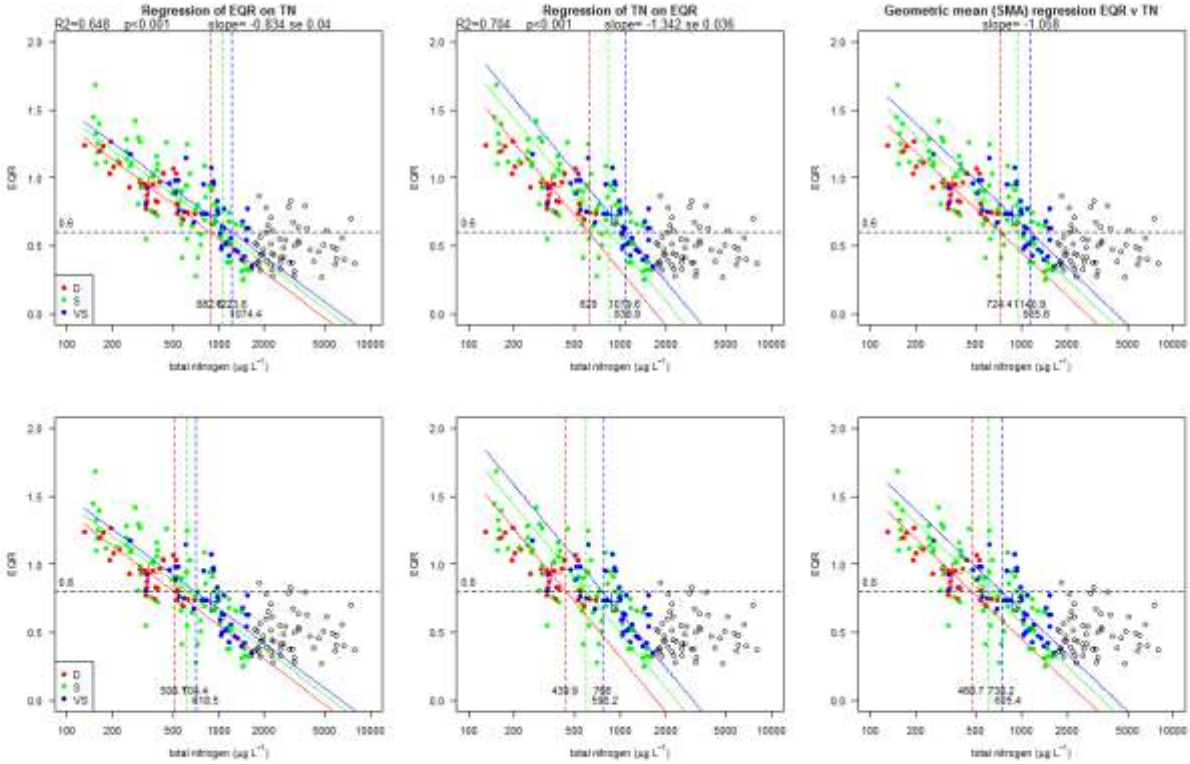


Figure C1.8
Linear regression models of TN vs macrophyte EQR that include humic type as a categorical variable. Plots show Good/Moderate boundaries (top) and High/Good boundaries (bottom).

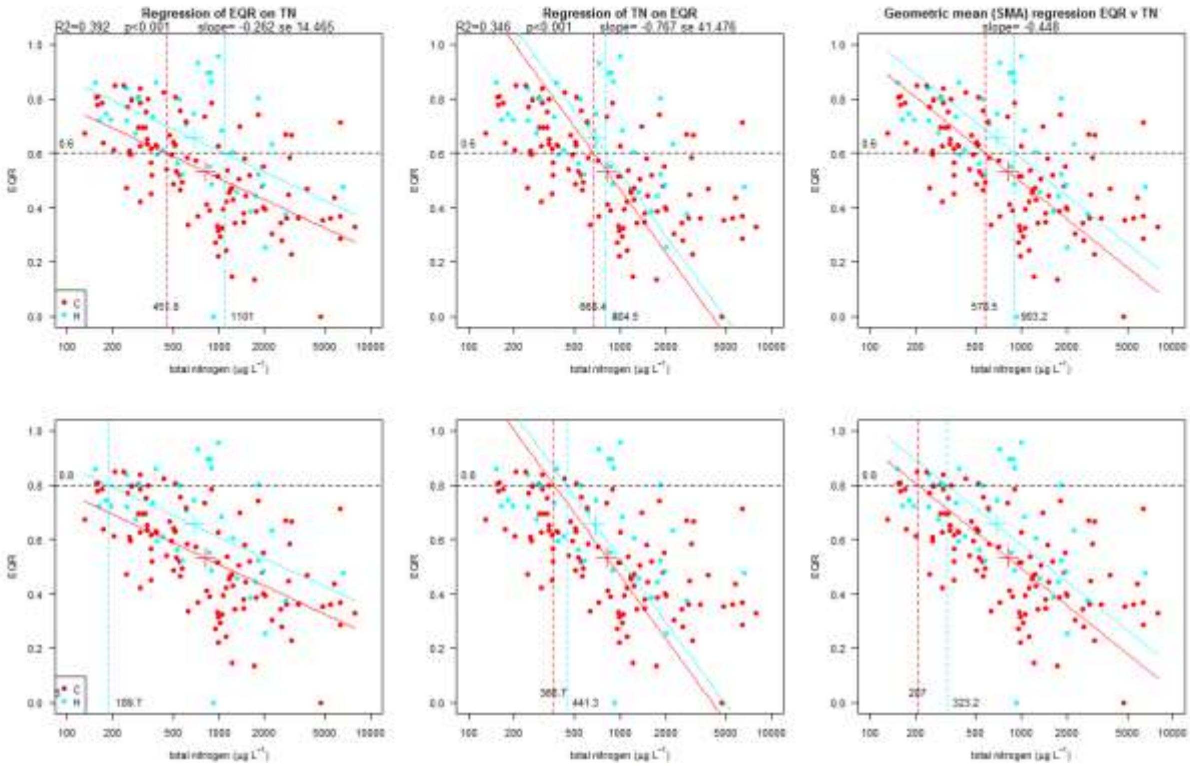


Figure C1.9
Linear regression models of TN vs macrophyte EQR that include depth type as a categorical variable. Plots show Good/Moderate boundaries (top) and High/Good boundaries (bottom).

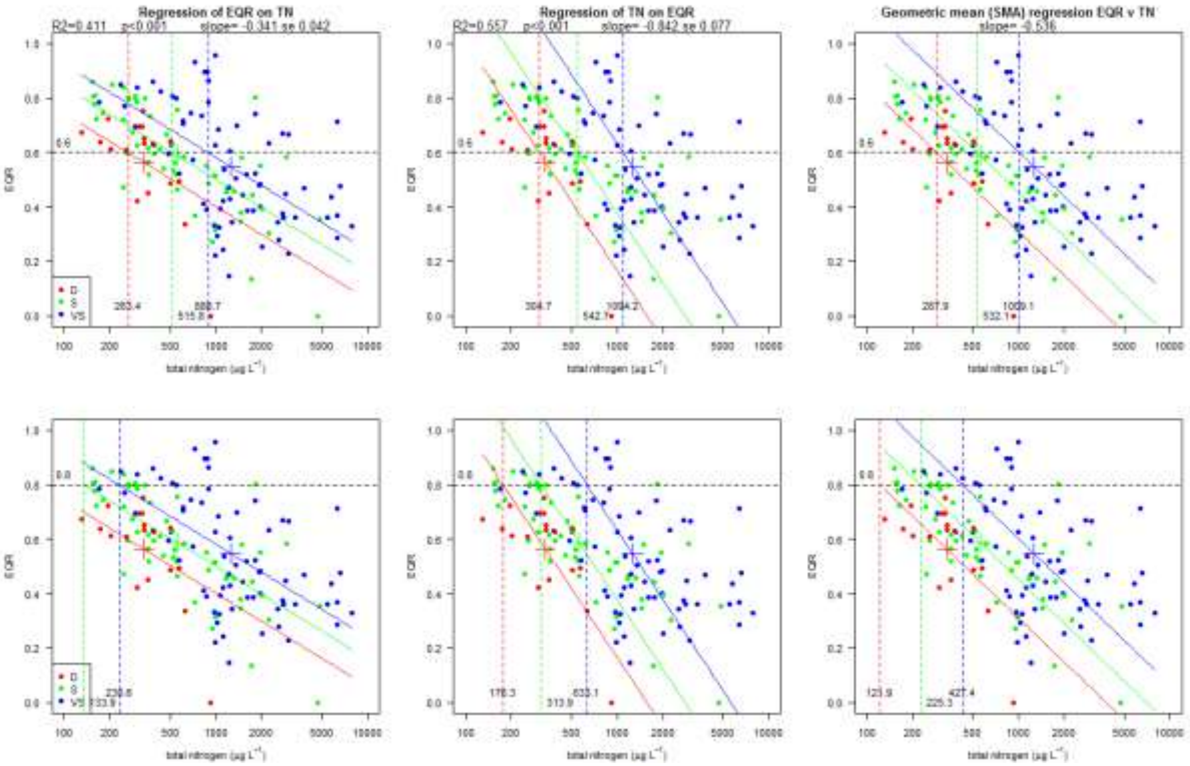


Table C1.3
Good/Moderate and High/Good boundary TN concentrations derived from the best geometric mean (SMA) regression model for TN vs phytoplankton EQR. The model included both depth type and humic type as categorical variables.

Humic type	Depth type	Good/Moderate (µg/l)	High/Good (µg/l)
Clear	Very shallow	1067	664
	Shallow	769	478
	Deep	736	458
Humic	Very shallow	1463	911
	Shallow	1301	809
	Deep	1162	723

3.14 The relationships between TN and TP concentrations for all water bodies included in the phytoplankton and macrophyte datasets are shown in Figures C1.10 and C1.11. The majority of water bodies had N:P ratios of more than 15:1 suggesting that N limitation was unlikely. However, over the entire TP and TN range, TN concentration was a better predictor of biological EQR than TP concentration for both phytoplankton and macrophytes (Table C1.4). The best models included both TN and TP as predictor variables. Good/Moderate and High/Good boundary TN and TP concentrations derived from these models are included in the plots in Figures C1.10 and C1.11.

Table C1.4
Goodness of fit data for linear regression models relating biological EQR to TP and TN concentrations. These models used the entire range of the TN and TP data, not just the linear portion.

Model	df	Phytoplankton		Macrophytes	
		AIC	r^2	AIC	r^2
TN model	3	-105.44	0.6036	-116.76	0.3348
TP model	3	-73.43	0.5366	-113.33	0.3191
TN and TP model	4	-125.43	0.6422	-120.88	0.3574

Figure C1.10
Relationship between TN and TP for phytoplankton dataset (all lake types). Points coloured by WFD class, dotted line marks the mean N:P ratio, broken orange line ratio of 15:1. Green and blue lines mark contours of the good/moderate and high/good boundaries predicted from multivariate model.

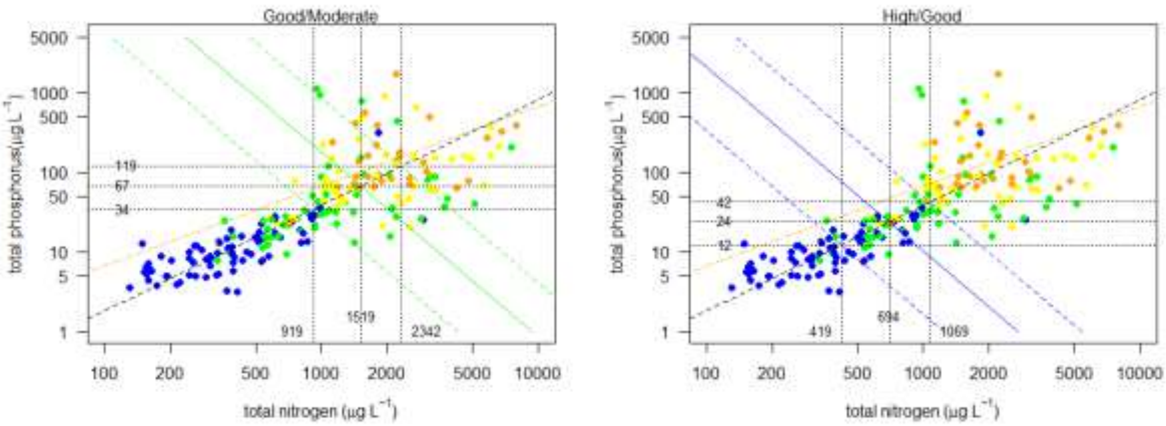
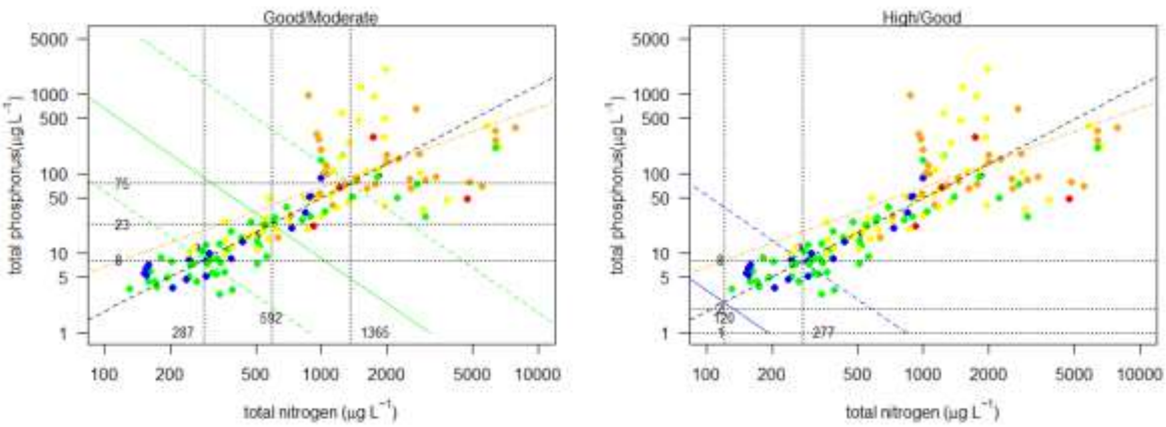


Figure C1.11
Relationship between TN and TP for macrophyte dataset (all lake types). Points coloured by WFD class, dotted line marks the mean N:P ratio, broken orange line ratio of 15:1. Green and blue lines mark contours of the good/moderate and high/good boundaries predicted from multivariate model.



References

[1] R Core Team (2014). R: A Language for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, http://www.R-project.org.

[2] WFD CIS (2018) Best practice for establishing nutrient concentrations to support good ecological status. https://circabc.europa.eu/sd/a/5aa80709-9ce8-411d-94e8-f0577f3632fa/CIS_Guidance_for_Ecostat_Oct18.pdf

C2 Review of scientific evidence for nutrient nitrogen thresholds relevant to UK standing waters

3.15 The role of nitrogen in eutrophication of standing waters has been less widely investigated than that of phosphorus, but there is an increasing body of scientific evidence indicating that both nutrients should be considered. A key finding of the European Nitrogen Assessment's consideration of nitrogen processes in aquatic ecosystems [1] was that in eutrophicated standing freshwaters control of both nitrogen and phosphorus loading is often needed if ecological quality is to be restored.

3.16 Studies in the UK [2], [3], The Netherlands [4] and Denmark [5], [6] have stressed the importance of nitrogen in controlling eutrophication in lakes, particularly shallow lakes. Shallow lakes (<3m), in their macrophyte-dominated state are structurally more complex than deep lakes, so need to be considered separately. Van der Molen et al. [4] found that a summer mean TN <1.35 mg/l would be required to reduce phytoplankton sufficiently to allow light to the sediments and therefore recolonisation by the submerged macrophytes (based on a data set of 682 lake-years for lakes in The Netherlands). They proposed a combined lake-specific approach of nitrogen and phosphorus emission reduction to combat eutrophication, due to atmospheric nitrogen fixation by blue-green algae in lakes with a growth limiting nitrogen concentration.

3.17 Correlations among macrophyte species richness, phytoplankton and periphyton standing stock with N and P concentrations in 42 small (<75 ha), shallow, macrophyte dominated lakes within the UK also suggest that some lakes are N–limited [2]. For these lakes it was found that winter nitrate was the most significant variable in explaining a reduction in macrophyte species richness, while no significant relationship between an increase in phosphorus concentration and reduced macrophyte species richness was found. Winter concentrations effectively give a measure of the amounts available in spring for plant growth; uptake and denitrification complicate the relationship if summer concentrations are used. Reasonably diverse plant communities were found only at winter nitrate below 1-2 mg NO_3-N/l.

3.18 Søndergaard et al. [5] used chemical and biological data from 709 Danish lakes to investigate whether and how different lake types respond to eutrophication. Ecological classification into high, good, moderate, bad and poor ecological quality was based on TP values; within each TP category, median values for 22 other biological and environmental indicators were determined, including TN. A mean depth of 3m was used to separate shallow (S) and deep (D) lakes. TN values ranged from <1.0 mg TN/l for high and good status lakes to >2.0 mg TN/l for bad status (Table C2.1). TN responded markedly to changes in TP, suggesting TN is a potential indicator for the classification of lakes relative to eutrophication. However, strong correlation was found between TP, TN, total alkalinity and pH, emphasising the problem of correlation between indicators for defining ecological classes.

Table C2.1
Concentrations of total phosphorus (TP) and total nitrogen (TN) associated with a classification 709 deep (D) and shallow (S) lakes by ecological quality (High-Low). From Søndergaard et al. [5]

Concentrations of total phosphorus (TP) and total nitrogen (TN) associated with a classification 709 deep (D) and shallow (S) lakes by ecological quality (High-Low)										
	High		Good		Moderate		Poor		Bad	
	D	S	D	S	D	S	D	S	D	S
TP (µg P/l)	<12.5	<25	<25	<50	<50	<100	<100	<200	>100	>200
TN (mg N/l)	-	<1.0	<1.0	<1.0	<1.0	<1.4	<1.4	<2.0	<2.2	<2.9

3.19 González Sagriario et al. [6] undertook a 3-month (summer) mesocosm experiment on a shallow Danish lake to investigate the effect of TN and TP loading on trophic structure and water clarity (natural lake concentrations of 0.1 mg P/l, 2 mg N/l). Minor or no effects on the biomass of macrophytes and phytoplankton were observed in treatments with single nutrient addition; in contrast, a strong effect was observed with high P addition (0.2 mg P/l) when accompanied by N addition (4 or 10 mg N/l). The shift to a turbid phytoplankton dominated state with low plant coverage occurred at an overall mean TN between 1.2 and 2 mg N/l and TP>0.13-0.2 mg P/l, suggesting high nitrogen loading may be important in the loss of submerged macrophytes in shallow lakes. Using empirical relationships between summer mean lake N concentrations, discharge-weighted inlet concentrations and an annual mean lake retention time of 3 months, a lake N concentration of 1.2 mg N/l corresponds to an inlet concentration of 2.5 mg N/l (similarly, 2 mg N/l corresponds to 5.7 mg N/l); inlet concentrations of 2.5-5.7 mg N/l are well below the 11.3 mg N/l drinking water limit. The authors note that as the data stems from a cold northern temperate region, the results should not be transferred directly to other regions; N thresholds may be higher due to high plant growth efficacy in warmer climates.

3.20 Increased nitrogen loading may lead to changes in productivity or biodiversity in freshwater systems. Field surveys have shown reduced species richness of submerged and floating-leaved plant communities in shallow lakes as winter nitrate concentrations, a surrogate for nitrate loading, have risen above 1-2 mg NO_3-N/l.

3.21 Barker et al [7] reported the use of experimental tank mesocosms, containing about 3 m^3 of water and sediment from Hickling Broad, Norfolk, UK that were initially planted with eleven submerged plant species from the lake and its connected waterway. Constant phosphorus loadings (designed to give added concentrations of 50 µg P/l) were provided to all tanks. Four nitrate loadings were given in a randomised block design with twelve-fold replication. Loadings were designed to increase the concentration in the water by 1, 2, 5 and 10 mg NO_3-N/l (treatments identified as N1, N2, N5 and N10, respectively). Nitrate loading increased phytoplankton and periphyton chlorophyll a in the N2, N5 and N10 treatments compared with N1. In contrast, total plant volume decreased and treatments had varied effects on different species, with most species indifferent, a few (mostly charophytes) declining above the N1 treatment, and one (*Elodea canadensis*) performing best in N2 and N5 compared with N1 and N10. Species richness of submerged macrophytes declined with time in all treatments and with increasing nitrogen load in the first year. In the second year, species richness did not further decline in the N1 treatment but declined at increasing rates with increasing nitrogen load in others. The rate of decline in the second year, plotted against nitrate load, fitted an exponential relationship, allowing calculation in inflow water, or of an empirically determined equivalent TN concentration in the lake water of about 1.50 mg N/l. This value broadly corresponds with estimates from field data for concentrations associated with declining species richness and is much lower than values currently often found in lowland agricultural areas in Europe.

3.22 A study commissioned by Natural England [8] tried to understand the lack of response of macrophyte species richness to variation water chemistry in certain SSSI designated meres. Macrophyte species were converted to trophic ranking scores using the systems of Palmer et al. [9] and Willby (pers comm.). The two TRS systems were strongly correlated and had a slope of 1.0 but the Palmer et al. system produced scores that were greater than the Willby system by 1.5. Relationships between the two Trophic Ranking Scores, based on the average for all the species present at a site, and winter concentrations of NO_x-N or total phosphorus were not significant (Fig. 6.4 in [8]). The data suggest, however, that above winter concentrations of about 0.5 mg NO_x-N/l and about 0.08 mg TP/l, there was not a major increase in Trophic Ranking Score. This may possibly explain the lack of response in the meres: most of the meres had concentrations of nitrogen and phosphorus that were characteristic of eutrophic water bodies. This lack of sites at lower nutrient concentrations truncates the macrophyte response to the higher, more insensitive end of the nutrient gradient. This result suggests that macrophyte species-richness in the meres cannot be used as a response to set nutrient targets, although the values obtained from the combined study of UK and Polish lakes [2],[7] could still be applicable, suggesting targets of around 1.5 mg/l NO_3-N.

3.23 The presence of nitrogen limitation or co-limitation in the meres means that nitrogen targets are also appropriate at some of the sites. Total nitrogen targets were derived from European datasets relating concentrations of chlorophyll a to total nitrogen for different types of lakes. In turn, the chlorophyll a target was derived from Water Framework Directive standards for different lake types. The Good/ Moderate total nitrogen target varied between 0.4 - 1.4 mg/l.

3.24 Lambert & Davy [10] investigated the relationship between aquatic vegetation and water quality at the principal sites for charophyte biodiversity in the UK. They used hierarchical partitioning to discriminate independent effects of pollutants on their occurrence. A laboratory experiment examined the growth responses of a representative species (*Chara globularis*) to nitrate. Nitrate-N exerted the greatest detrimental effect on charophyte occurrence in the field. Furthermore, growth of *C. globularis* in the laboratory was inhibited above very low concentrations. Smaller independent effects of certain trace metals and phosphate-P on charophyte occurrence were discriminated. The study demonstrated that it is possible to separate the deleterious effects of phosphorus and nitrogen on aquatic plant species in the field. Nitrate is a critical factor. The upper limit for charophyte persistence was shown to be c. 2.5 mg/l nitrate-N. An *in vitro* experiment showed that a concentration of 1-2 mg/l NO_3-N might be necessary to protect charophytes and their services within wetland ecosystems.

3.25 Schindler et al. [11] reported the results of experimental nutrient enrichment (nitrogen and phosphorus) of a single, small Canadian lake. The study concluded that controlling N alone may have limited benefits in controlling eutrophication and, under conditions of P enrichment, N limitation may provide N-fixing cyanobacteria with a competitive advantage.

3.26 The experimental nutrient enrichment of the lake was undertaken for approximately 20 years and peak total nitrogen concentrations of c. 1.2 mg-N/l were recorded towards the end of this time. The highest peak concentrations of total inorganic nitrogen (nitrate plus nitrite plus ammonium) were observed to be 0.128 mg/l. These peak concentrations are considerably lower than the threshold of 1-2 mg.N/l used to help identify and screen lakes with elevated nutrient N as part of this review. Indeed, 75%ile TON concentrations in the vast majority of candidate lakes considered as part of this review are x10-x80 higher than the maximum TIN concentrations reported in the Schindler et al. study.

3.27 Whilst the need to focus on phosphorus is accepted as important in tackling freshwater eutrophication it should be noted that the Schindler *et al.* study [11] relates primarily to a single Canadian lake and the conclusions may not be directly relevant to nutrient enriched lakes in England and Wales. It also focussed on the effects of nutrient enrichment on the phytoplankton without considering the effects, indicated in other recent studies on higher plant (macrophyte) communities (e.g. James *et al.*, [2]). Jeppesen *et al.* [12] concluded that control of both N and P may be necessary to improve the ecological status of shallow lakes.

3.28 A more recent review of the nutrient standards adopted by EU Member States for the Water Framework Directive [13] is in close agreement with the range of values suggested by the scientific literature. The range of Good/Moderate boundary values adopted by member states for all lake types was 0.8 – 2.0 mg/l for total nitrogen, and 0.5 – 1.2 mg/l for nitrate nitrogen.

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Annex D - River fish FCS2 (Scotland)

D1. Water body detail

Table D1.1

Showing where fish class would drop with the new method. Cases where the overall water body status would change are highlighted in yellow.

Water body ID	Water body name	Fish class change	Current overall class
4500	River Devon (Gairney Burn confluence to Estuary)	High - Good	Mod EP
5309	Manor Water	High - Good	Good
6520	Shochie Burn (Source to Ordie Burn Confluence)	High - Good	Good
6638	Camserney Burn	High - Good	Moderate
6701	River Farg	High - Good	Mod EP
6811	Turret Burn (Turret Loch to River Earn confluence)	High - Good	Bad EP
6818	Ruchill Water	High - Good	Good
10132	Allander Water	High - Good	Mod EP
10153	Endrick Water (u/s Blane Water)	High - Good	Good
10160	Luss Water	High - Good	Moderate
10300	River Nant (d/s Loch Nant)	High - Good	Good EP
10536	Moneypool Burn	High - Good	Good
10681	Ewes Water	High - Good	Good
10747	Black Cart Water	High - Good	Good EP
10920	Brock Burn (A726 road bridge to Levern Water)	High - Good	Mod EP
20079	River Evelix	High - Good	Good
20134	Black Water	High - Good	Good
20146	River Skitheach	High - Good	Moderate
20297	Allt na Cailliche	High - Good	Good
20305	River Nairn - Moray Firth to River Farnack confluence	High - Good	Moderate
20329	River Nevis	High - Good	Good EP
20407	River Ailort	High - Good	Good
20414	River Polloch	High - Good	Good
20430	River Shiel	High - Good	Good
20549	Abhainn Cuileig	High - Good	Moderate
20566	River Laxford - Abhainn an Loin	High - Good	Good
20633	Forss Water - Allt Forsiescye to sea	High - Good	Good
20777	Abhainn Mhiabhaig	High - Good	Good
20783	Abhainn Caslabhat	High - Good	Good
23075	Dullan Water	High - Good	Good
23103	Allt Choire Odhair	High - Good	High
23104	Glenbeg Burn	High - Good	Good
23130	River Feshie - Allt Ruadh	High - Good	Good
23231	River Ythan - Methlick to Ellon	High - Good	Moderate
23382	River Moriston - Dundreggan Dam to Bun Loyne	High - Good	Good EP
5266	Leader Water/Kelphope Burn (Cleekhimin Burn confluence to River Tweed)	Good- Mod	Moderate
5805	Noran Water	Good- Mod	Moderate
6000	Dighty Water (lower)	Good- Mod	Moderate

6593	Kinnaird Burn	Good- Mod	Moderate
6651	Acharn Burn	Good- Mod	Good
6652	Allt a Chilleine	Good- Mod	Moderate
10062	North Calder Water (d/s Hillend Reservoir to Shotts Burn)	Good- Mod	Poor
10095	Parkhall Burn	Good- Mod	Good
10162	Inveruglas Water	Good- Mod	Bad EP
10218	River Fyne	Good- Mod	Good EP
10597	Glen Burn (Sheep Burn)	Good- Mod	Moderate
10611	River Nith (Sanquhar - New Cumnock)	Good- Mod	Poor
10647	Corrie Water	Good- Mod	Poor
10675	White Esk (u/s Rae Burn)	Good- Mod	Moderate
10684	Wauchope/Logan Water	Good- Mod	Good
20053	Berriedale Water	Good- Mod	Good
20054	Langwell Water	Good- Mod	Good
20115	Abhainn Gleann na Muic	Good- Mod	Good
20307	Auldearn Burn	Good- Mod	Moderate
20413	River Finnan	Good- Mod	Moderate
20415	River Hurich	Good- Mod	Good
23034	Linkwood Burn	Good- Mod	Bad