UK Technical Advisory Group

on the Water Framework Directive

UPDATED RECOMMENDATIONS ON PHOSPHORUS STANDARDS FOR RIVERS

River Basin Management (2015-2021)

Final Report

August 2013

Water Framework Directive UK TAG

Executive Summary

This paper sets out the UK Technical Advisory Group on the Water Framework Directive's (UKTAG) recommendations on revised phosphorus standards for rivers. UKTAG is a working group of experts drawn from environment agencies and conservation agencies[1.] It also includes representatives from the Republic of Ireland.

The recommendations are intended help with the development of second river basin management plans, due to be published in 2015. A draft of the recommendations was subject to public consultation between December 2012 and February 2013. Ministers will now decide whether to instruct the UK environment agencies accordingly on their use.

The revised standards benefit from improvements in understanding of the relationship between phosphorus concentrations and the response of river plant communities. They have been derived using a new approach to setting phosphorus standards that produces site-specific estimates of natural phosphorus concentrations, taking account of a site's alkalinity and altitude.

The new standards have the effect of reducing the mismatch between classifications based on biology and phosphorus. However, the relationship is not perfect. There is still a large amount of unexplained error in the model. This means that there remains a substantial chance of misclassifying sites. Because of the uncertainty, UKTAG continues to recommend that expensive action to reduce phosphorus concentrations at a site should be considered only where there is supporting evidence of adverse biological impacts.

The uncertainty in the standards is thought to be as a result of other environmental factors such as sunlight and nitrogen, which have not yet been possible to account for in modeling the relationship between biology and phosphorus. UKTAG is continuing work aimed at accounting for such factors.

[1] Natural Resources Wales, Natural England (NE), Environment Agency, Northern Ireland Environment Agency (NIEA), Joint Nature Conservation Committee (JNCC), Scottish Environment Protection Agency (SEPA), Scottish Natural Heritage (SNH), Republic of Ireland's Department of Environment, Community and Local Government (DECLG).

CONTENTS

1. Introduction

1.1 This paper recommends new phosphorus standards for rivers for consideration by the UK government administrations.

1.2 Phosphorus is a plant nutrient and elevated concentrations in rivers can lead to accelerated growth of algae and other plants. The impact on the composition and abundance of plant species can have adverse implications for other aspects of water quality, such as oxygen levels, and for the characteristics of river habitats. These various changes can cause undesirable disturbances to populations of water animals, such as invertebrates and fish.

1.3 Phosphorus standards are used in managing the risk of these adverse ecological impacts. Where rivers are already adversely affected, phosphorus standards can indicate the likely degree to which phosphorus concentrations would need to be reduced (e.g. by reducing concentrations in discharges) to improve ecological quality. Where a new discharge is proposed, phosphorus standards can indicate whether or not the river is likely to be able to accommodate the additional inputs without significant risk of adverse ecological effects. The relevant standards for nutrients must also be met for a river to be classed as being at good or high ecological status.

1.4 UKTAG first made recommendations on phosphorus standards for rivers in 2006 [1]. UKTAG has undertaken a review of these earlier recommendations because:

(a) the existing standards for algae and other plants that the phosphorus standards aimed to protect are changing[2]; and
(b) the existing phosphorus standards were producing a high number of mismatches between phosphorus and biology classifications.

2. Recommended standards

2.1 The recommended standard for a site is calculated using the following equation:

$$Standard = 10^{\wedge}((1.0497 \times \log_{10}(EQR)+1.066) \times (\log_{10}(\text{reference condition RP}) - \log_{10}(3{,}500)) + \log_{10}(3{,}500))$$

2.2 The equation produces standards in the form of annual mean concentrations of reactive phosphorus in µg/l estimated for the lower class boundary of high, good, moderate and poor ecological status, depending on the value of "EQR" used.

2.3 “Reactive phosphorus" means the concentration of phosphorus as determined using the phosphomolybdenum blue colorimetric method. Where necessary to ensure the accuracy of the method, samples are recommended to be filtered using a filter not smaller than 0.45 µm pore

[2] The biological standards are changing as a result of the Europe-wide intercalibration exercise aimed at ensuring good status standards are comparable. Information on UKTAG’s recommendations on new biology standards is available on UKTAG’s website. The biological standards defined for high and good have been checked for comparability with the corresponding standards established by other Member States.

size to remove gross particulate matter[3].

2.4 "EQR" means the ecological quality ratio of the combined diatom and macrophyte assessment methods where the range of modelled phosphorus of adjacent classes (i.e. between high & good, good & moderate, moderate & poor, poor & bad) overlap. The values for EQR in the standard equation are: High, 0.702; good, 0.532; moderate, 0.356; poor, 0.166 (the crosses in Figure 1, for details see Appendix 1 in [4])

2.5 "Reference condition RP" means the reactive phosphorus concentration at near natural conditions as estimated using the equation below.

Reference condition RP = 10^(0.454 (log_{10}alk) – 0.0018 (altitude) + 0.476)

2.6 If the predicted value of reference condition RP predicted is < 7 µg/l, reference condition RP is set to 7 µg/l.

2.7 "Log10alk" means log10(alkalinity), where alkalinity is the concentration of $CaCO_3$ in mg/l. For sites with an alkalinity greater than 250, alkalinity is set to 250. For sites with an alkalinity less than 2, it is set to 2.

2.8 "Altitude" means the site's altitude above mean sea level in metres. For sites with an altitude greater than 355 metres, altitude is set to 355 metres.

3. Method used to derive new standards

3.1 The standards for phosphorus recommended by UKTAG for the first river basin management plans [1] were derived by assembling a set of sites whose ecology was measured as being at good status. The approach looked at the values for the annual mean reactive phosphorus concentration across all the sites of the same river type. The types were defined by particular ranges of altitudes and alkalinities. For example, the lowland, high alkalinity river type included all rivers with altitudes of no more than 80 metres above sea level and with alkalinities of 50 mg/l or more of calcium carbonate.

3.2 UKTAG's review [4] involved a thorough mathematical analysis of a large set of biological and chemical data. It also involved a review of the scientific literature on eutrophication in rivers and collation of the sparse information available on the standards used in other EU countries. The review led to the development of a revised approach to identifying phosphorus standards.

3.3 The revised approach first predicted the concentration of phosphorus expected if a site were at what are called "reference conditions" – an estimate of the natural condition of the site. The prediction used values of alkalinity and altitude to represent key geological and geographic factors that determine a site's natural phosphorus concentrations.

3.4 The approach calculated the ratio between the estimated "natural" phosphorus concentration and the concentration actually measured at the site. It then developed a regression equation

[3] Previous UKTAG standards were referred to as soluble reactive phosphorus (SRP). Most analyses by UK agencies are of molybdate reactive phosphorus in unfiltered samples from which large particles have been allowed to settle and referred to here as "reactive phosphorus" (RP). In practice, the difference between RP and SRP is usually minor.

representing the link between the biological data (the worst classed of macrophytes and diatoms) and these phosphorus ratios. Provided a site's alkalinity and altitude are known, the equation can be used to estimate the likely ranges of phosphorus concentrations at the site associated with each biological status class.

3.5 The regression equation was re-arranged and used to calculate the most likely phosphorus concentration at the midpoint[4] of each biological class. As an example the most likely concentrations for the midpoints of the five biological classes for a particular pair of values of alkalinity and altitude are shown in Figure 1 as small shapes at the centre of coloured horizontal lines. The lines represent ranges in the estimates of the phosphorus concentrations predicted by the regression model at the mid-point of the biological class. The "EQR" values on the Y axis represent the degree of disturbance to the biology compared with near undisturbed conditions. The results are for a lowland, high alkalinity river.

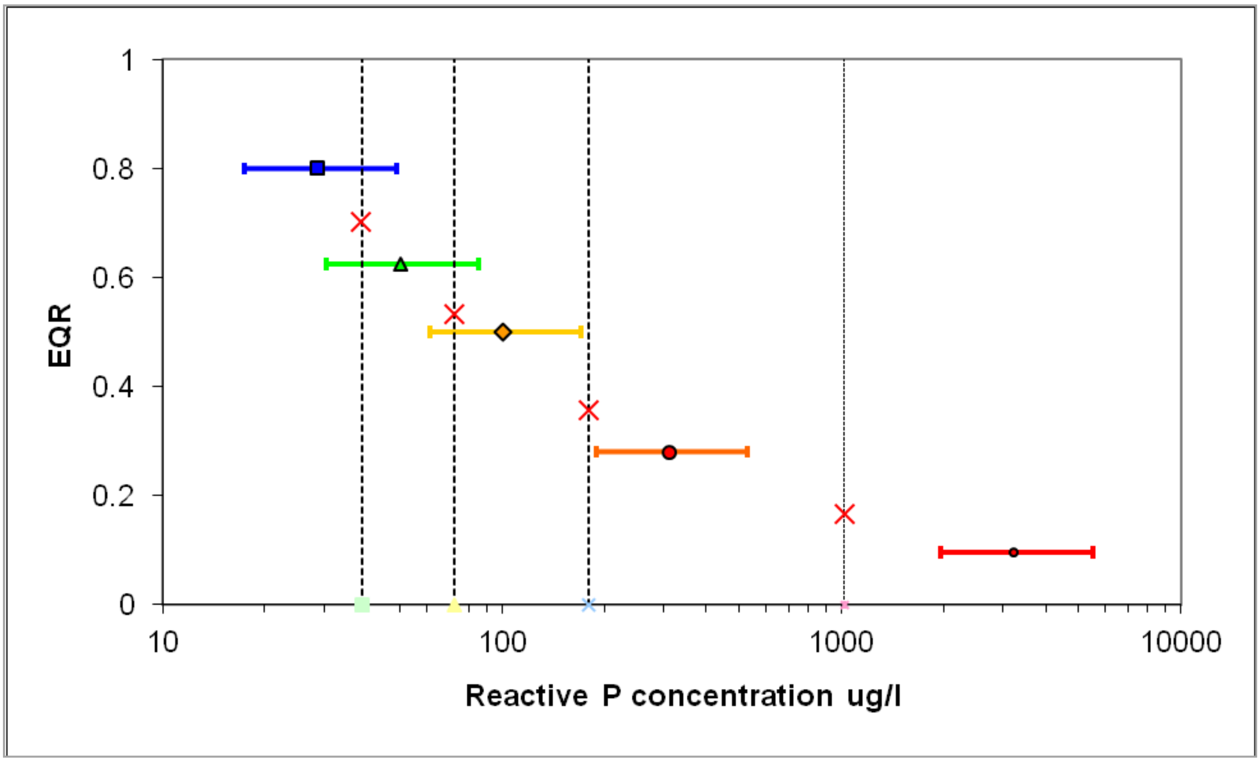

Figure 1: Links between phosphorus and biological quality

3.6 Like all environmental standards, phosphorus standards are intended to help in managing environmental risks. They are designed to describe the likely tolerance limits to phosphorus of each biological status class. Identifying the recommended standards involved seeking a best match with the boundaries of the parallel biological status classes.

3.7 The recommended phosphorus standards are set at a position midway between the estimated mid-point phosphorus concentrations. The midway position represents a concentration at which there is equal statistical confidence of the biology being in adjacent classes. The class boundaries are the vertical dotted lines in the example illustrated in Figure 1 with the

[5] The value for the biological data is put into in the equation and the resulting concentration of phosphorus is expressed as a single value with a range associated with the mathematical "goodness of fit" for the regression equation.

corresponding EQR values marked as a cross. For any site, the phosphorus concentrations at these boundaries are calculated using the equation in paragraph 2.1 above. The resulting standards are more likely on average, than the existing standards, to classify phosphorus in the same status class as the biology.

3.8 A benefit of the approach is that it does not rely on dividing rivers up into types. By using the alkalinity and altitude of the site concerned, the method identifies phosphorus standards that are, in principle, specific to each point in a river. In contrast, the existing method specifies a single standard applicable to the continuum of waters within a type.

4. Peer review

4.1 The proposed method for deriving the standards has been reviewed by four independent experts. Two are river ecologists (Steve Ormerod and David Harper); one is a general expert in nutrient flux (Louise Heathwaite), and one an expert on statistical approaches (Steve Juggins). Given the available data and the need to revise the current standards for phosphorus, Harper and Ormerod supported the work and said that the resulting standards were better than the current standards.

4.2 All agreed that with current knowledge, the link between phosphorus and biology will come through as a fuzzy equation. Harper concluded that with this starting point, the analysis behind the proposed standards was sound. Ormerod and Juggins suggested further work to increase precision. This will not produce different standards, but could trim the uncertainty about them, and so justify decisions on actions that would otherwise be borderline.

4.3 Heathwaite thought that the approach was pragmatic given the available data and the assumptions made about key explanatory variables. She also thought the statistical approaches were appropriate. Heathwaite and Ormerod suggested that the literature review was limited. Nevertheless, Heathwaite considered that the knowledge used was adequate. She also suggested that alternative analyses such as fuzzy-rules based approaches may allow further insight given the nature of the available data and its uncertainties.

5. Comparison of the revised standards with existing standards

5.1 Comparing the revised standards with the existing phosphorus standards is not straightforward because the revised standards are site-specific standards rather than type-specific. In principle, there are as many new standards as there are unique combinations of altitude and alkalinity.

5.2 Table 1 shows the median of the revised phosphorus standards for a set of 819 sites with relevant chemistry monitoring data. The theoretical ranges of standards across all rivers are also shown. In the great majority of cases, the revised standards are lower concentrations of phosphorus than the existing standards.

Table 1: Comparison of existing and revised standards for phosphorus								
Type (for existing standards)	Annual mean of reactive phosphorus (µg per litre)							
	High		Good		Moderate		Poor	
	Existing	New	Existing	New	Existing	New	Existing	New
Lowland, low alkalinity	30	19 (13-26)	50	40 (28-52)	150	114 (87-140)	500	842 (752-918)
Upland, low alkalinity	20	13 (13-20)	40	28 (28-41)	150	87 (87-117)	500	752 (752-851)
Lowland, high alkalinity	50	36 (27-50)	120	69 (52-91)	250	173 (141-215)	1000	1003 (921-1098)
Upland, high alkalinity	50	24 (18-37)	120	48 (28-70)	250	132 (109-177)	1000	898 (829-1012)

Notes:

The revised standards illustrated are the medians from, respectively, 456 lowland, high alkalinity sites; 129 upland high alkalinity sites; 137, lowland, low alkalinity sites; and 97 upland, low alkalinity sites.
The numbers in parentheses are the upper and lower 5th and 95th percentiles of the standards for the sites in each type.
"Lowland" means less than or equal to 80 metres above mean sea level.
"Upland" means more than 80 metres above mean sea level.
"Low alkalinity" with a concentration $CaCO_3$ of less than 50 mg per litre.
"High alkalinity" with a concentration $CaCO_3$ of greater than or equal to 50 mg per litre.

5.3 In general, the revised standards produce narrower class widths than the existing standards. This is illustrated in Table 2. The median class widths at high status under the revised standards are typically around half to a quarter of those under the existing standards. The median widths at good status in high alkalinity rivers are around half to one third those under the existing standards. For low alkalinity rivers, the effect at good status is a quarter narrower class widths for upland sites. For lowland sites, the median width under the revised standards is slightly greater than under the existing standards.

Table 2: Comparison of the class widths of the existing and revised standards for phosphorus						
Type (for existing standards)	Annual mean of reactive phosphorus (µg per litre)					
	High		Good		Moderate	
	Existing	New	Existing	New	Existing	New
Lowland, low alkalinity	21 (13-29)	9 (6-26)	20	21 (15-27)	100	74 (59-91)
Upland, low alkalinity	14 (8-19)	8 (6-20)	20	15 (15-22)	100	59 (59-77)
Lowland, high alkalinity	28 (14-49)	15 (9-54)	20	32 (23-44)	100	105 (81-131)
Upland, high alkalinity	37 (25-49)	10 (6-34)	20	24 (15-35)	100	84 (59-111)

Notes:

The class widths illustrated are the medians from, respectively, 456 lowland, high alkalinity sites; 129 upland high alkalinity sites; 137, lowland, low alkalinity sites; and 97 upland, low alkalinity sites. The figures in parentheses are the minimum and maximum class widths for these sites.
"Lowland" means less than or equal to 80 metres above mean sea level.
"Upland" means more than 80 metres above mean sea level.
"Low alkalinity" with a concentration $CaCO_3$ of less than 50 mg per litre.

"High alkalinity" with a concentration $CaCO_3$ of greater than or equal to 50 mg per litre.

5.4 Comparison with standards set by other countries is also complicated because of the wide variety of river types; different approaches to setting standards; and the use of different of phosphorus and summary statistics. According to a recent review by one of the European Working Groups on the implementation of the Water Framework Directive[5], there is a large range in the values of the standards established by different countries. The report suggests that standards for good for annual mean total phosphorus concentration may range from less than 10 µg per litre to up to around 1,000 µg per litre. However, no general conclusions could be reached about the reasons for the apparent differences. The lowest concentration standards for good being proposed by UKTAG are higher than the standards for some countries but of a similar magnitude to those in countries such as The Netherlands, allowing for the differences in the determinand and in the summary statistics used to define the standards.

6. Implications of the proposed standards

6.1 The revised standards were identified using a larger dataset than was available when the existing standards were developed and a new methodology. These developments have improved scientific understanding and enabled UKTAG to identify revised standards that are matched to the average biological response to phosphorus. This contrasts with the existing phosphorus standards, which the review found are on average overly lax. The existing standards have a strong tendency to place phosphorus in a better class than biology and this bias remains when the new standards for algae and other plants are taken into account.

6.2 The proposed new standards would decrease the proportion of sites with a phosphorus class of good or high from around 80% to 65% (see Table 3).

Table 3: Phosphorus classifications under the existing and recommended new phosphorus standards

Phosphorus class	Proportion of sites (%)									
	England (221 sites)		Wales (62 sites)		Northern Ireland (300 sites)		Scotland (221 sites)		All UK (804 sites)	
	E	N	E	N	E	N	E	N	E	N
High	43	32	79	66	51	33	61	43	54	38
Good	19	21	13	19	33	32	28	27	26	27
Moderate	15	18	8	11	14	28	10	26	13	23
Poor or bad	23	29	0	3	2	7	1	4	7	11

Note
"E" means existing phosphorus standards
"N" means new phosphorus standards

6.3 However, classifications combining the new standards for algae and other river plants and the recommended new phosphorus standards would increase the proportion of sites classed as high or good status for both biology and phosphorus from 34% to 47%. Around 14% fewer

[5] WFD CIS ECOSTAT WG A Report (2012); Comparison of Environmental Quality Objectives, Threshold Values or Water Quality Targets Set for the Demands of the European Water Framework Directive. 29 February 2012.

waters would be classed as worse than good status (see Table 4).

Table 4: Combined status class of phosphorus and biology (diatoms & macrophytes) as proportion of sites (%)

Combined Class	Proportion of sites (%)														
	England (221 sites)			Wales (62 sites)			Northern Ireland (300 sites)			Scotland (221 sites)			All UK (804 sites)		
	B	E	N	B	E	N	B	E	N	B	E	N	B	E	N
High	12	7	10	16	8	15	9	9	8	32	19	21	17	11	12
Good	28	17	23	48	21	44	51	24	40	50	27	40	44	23	35
Moderate	46	30	33	35	37	39	35	53	40	18	52	35	33	45	37
Poor	14	39	30	0	32	3	6	15	13	0	1	4	6	19	14
Bad	0	6	5	0	2	0	0	0	0	0	0	0	0	2	1

Note
"B" means the biology class based on the proposed new macrophyte and diatom standards
"E" means combined class based on the existing phosphorus & the existing biology standards
"N" means combined class based on the proposed new phosphorus & the new biology standards.

6.4 The application of the new biological standards for diatoms and macrophytes leads to an appreciable reduction in classification mismatches, from 75% of sites to 67% of sites. Application of the new phosphorus standards results in a further reduction of about 5%. However, mismatched classifications still dominate over aligned classifications with 62% of the assessed sites still having mismatched classifications (see Table 5).

Table 5: Implications of the recommended new phosphorus standards for classification mismatches

	Proportion of classification mismatches (%)					
Standards	Existing & existing biology		Existing & new biology		New & new biology	
Bias: biology cf RP class	Biology better	Biology worse	Biology better	Biology worse	Biology better	Biology worse
England (221 sites)	77		67		68	
	22	55	20	48	29	39
Wales (62 sites)	84		79		73	
	6	77	5	74	8	65
Northern Ireland (300 sites)	79		69		60	
	6	73	8	62	18	42
Scotland (221 sites)	66		60		56	
	7	58	14	46	28	28
UK – combined (804 sites)	75		67		62	
	11	65	13	54	23	39

Notes:
"Existing" means the existing phosphorus standards, as previously recommended by UKTAG
"New" means the proposed new phosphorus standards.
"Existing biology" means the existing biology standards for macrophytes and diatoms, as previously recommended by UKTAG.
"New biology" means the proposed new biology standards for macrophytes and diatoms.

6.5 Under the existing standards, the bias in classification mismatches is high, with biology being in a worse class than phosphorus in 65% of sites compared with 11% where biology is in a better class. The recommended new phosphorus standards would significantly reduce but not eliminate this bias. The number of overly stringent and overly lax cases would be more balanced than under the existing standards.

6.6 Because of the uncertainty in the relationship between phosphorus and biological response, UKTAG continues to recommend that expensive action to reduce phosphorus concentrations at a site should be considered only where there is supporting evidence of adverse biological impacts. A significant advantage of the recommended new standards is that the risk of error is understood and quantified. This allows scope for it to be factored into decision-making. For example, when planning improvements at an individual site, the potential for error could be mitigated at least in part by planning improvements as a series of iteratively evaluated steps, depending on the biological effect achieved. The regression model provides a means of defining sensible steps.

6.7 In general, the revised standards represent lower concentrations of phosphorus than the corresponding existing standards. Because the revised standards are site-specific, the degree to which they are more stringent than the existing, type-specific standards varies considerably from site-to-site. At some sites, there is little or no difference between the revised standards and the existing standards. At others, the difference is large.

6.8 The general increased stringency of the revised standards means that the phosphorus concentrations needed for good ecological status (the Directive's default restoration target) would typically be lower than under the existing standards. An important context for this is that, for a significant proportion of sites, the existing standards do not provide any indication of the likely reduction in phosphorus concentrations needed to restore good ecological quality. Of the sites assessed by UKTAG, about 44% are classed as worse than good status under the combination of the existing phosphorus standards and the new biology standards. For 54% of these (24% of all the sites), phosphorus is classed as good or high. For around 10% (5% of all sites), biology is classed as good or better.

6.9 The increased stringency also means generally narrower class widths (see Table 2). The narrower the class width, the smaller the change in concentration (e.g. as a result of a new inputs) that would result in a breach of a standard. However, narrower class widths do not mean that all sites would have less capacity than they do under the existing standards to accommodate new inputs of phosphorus before a standard is breached. This is because another effect of more stringent standards is to place a significant proportion of sites in a lower phosphorus class than their class under the existing phosphorus standards. For example, for the sites assessed by UKTAG, the proportion at high status for phosphorus would decrease by 16%. Because phosphorus class widths increase from high to poor, a site previously in high and re-classified as good or moderate may be in a wider class than it is under the existing standards.

6.10 Of the sites assessed by UKTAG, the proportion very close (within 1 µg/l) to a class boundary (i.e. a phosphorus standard) under the revised standards is expected to remain at around 2%. The proportion within 1 to 5 µg/l would increase from 5% under the existing standards to 14% and the proportion more than10 µg/l from a class boundary would decrease from 82% to 67%.

7. Dealing with uncertainty in the regression model and further work

7.1 The relationship between phosphorus and biological quality in the data used to develop the regression model is highly variable - there is a lot of scatter in the data. As a result, a regression model cannot produce standards that perfectly correspond to every site's biological status class boundaries. The biology at a significant proportion of sites will be more affected by phosphorus than indicated by the standards. At others, it will be significantly less affected.

7.2 Part of the reason for this is the inevitable statistical errors in the summary statistics of phosphorus and biology used in setting up the regression equation used to derive the standards. However, UKTAG considers the major reason to be that biological response to phosphorus is affected by other factors as well as those represented by a site's alkalinity and altitude. For example, shade, river flow, river bed composition, grazing and the effects of other plant nutrients, such as nitrates, or the presence of other pressures could all influence the biological response to phosphorus.

7.3 In the longer term, it may be possible to produce better models of the relationship between phosphorus concentrations and accelerated plant growth by incorporating information about such additional factors. UKTAG will ensure that support for the development of such models is part of its on-going work programme.

References

GENERAL

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