

UKTAG River Assessment Method Macrophytes and Phytobenthos

Macrophytes (River LEAFPACS2)

by

**Water Framework Directive – United Kingdom Technical Advisory Group
(WFD-UKTAG)**



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(WFD-UKTAG)**
c/o SEPA
Strathallan House
Castle Business Park
Stirling
FK9 4TZ
Scotland
www.wfduk.org

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It is also the responsibility of the user if seeking to practise the method outlined here, to gain appropriate permissions for access to water courses and their biological sampling.

UKTAG Guide to Macrophytes in Rivers

River LEAFPACS2

1 Introduction

This classification method enables the assessment of macrophytes in rivers according to the requirements of the Water Framework Directive (WFD). Macrophytes are larger plants of fresh water which are easily seen with the naked eye, including all vascular plants, bryophytes, stoneworts (Characeae) and macro-algal growths. River LEAFPACS2 uses a species nutrient index together with measures of diversity and abundance. This method replaces the classification tool River LEAFPACS used in the first river basin planning cycle in the UK.

River LEAFPACS2 has been developed from the same underlying principles used for River LEAFPACS (Willby *et al*, 2012), but has been improved as a result of analysis of new data and participation in the EU intercalibration process. During the intercalibration exercise, several small revisions were made to the existing method in terms of the metrics included and the weight assigned to them in deriving the overall ecological quality ratio (EQR) for a site:

- (a) The River Macrophyte Hydraulic Index (RMHI), which is based on substrate, depth and stream energy, was dropped from the suite of metrics used. This improved the relationship with diatom classifications by focusing the macrophyte method on eutrophication impacts.
- (b) The weight given to two measures of diversity (NTAXA and NFG) that consider the number of scoring aquatic plant species and functional groups, respectively, was reduced, making them less sensitive to survey effort, and the criteria under which these metrics will contribute to the final EQR was adjusted.

Following these revisions, the method was intercalibrated successfully.

Macrophytes form one part of the WFD biological quality element “macrophytes and phytobenthos” according to the normative definitions in the WFD, Annex V. For reporting purposes, outputs from River LEAFPACS2 will be combined with those from the phytobenthos classification tool DARLEQ2 (available on the UKTAG website) if both are available, with the final class of the combined element being the worst of either of the sub-elements.

1.1 Metrics

The method assesses the condition of the quality element by combining information on the four metrics listed below. The metrics are calculated using information on macrophyte species and groups of such species derived from field survey data. The results for each metric are then used to produce an EQR for the combined metrics. The output of the combined metrics is referred to as River LEAFPACS2.

- **River macrophyte nutrient index (RMNI)** – derived from the RMNI scores of the taxa recorded in the field survey. Taxon scores were derived for the earlier version of LEAFPACS as described in Willby *et al* (2012), and remain unchanged in this version.

- **Number of macrophyte taxa (NTAXA)** - a diversity metric, the number of scoring taxa recorded in the field survey, in this case only taxa which are considered truly aquatic, i.e. hydrophytes* are included
- **Number of functional groups (NFG)** – a diversity metric, individual taxa which are truly aquatic (i.e. hydrophytes) are allocated to 24 “functional groups”**,
- **Cover of green filamentous algae (ALG)** – this is the percentage cover of green filamentous algae over the whole of the surveyed section of river.

EQRs are derived for each of the metrics, based on observed data and predicted reference values. The values are then normalised so they fit the same scale, and finally combined by a set of rules described below to provide an overall EQR representing an ecological status class as defined by the WFD (High, Good, Moderate, Poor or Bad).

*“Hydrophyte” is a plant with exclusively or predominantly submerged or floating leaved foliage under normal flow conditions.

**“Functional group” is a group of organisms which exploit a resource in a similar way.

1.2 Environmental pressures to which the method is sensitive

The method has been designed to reflect the impact on the quality element of nutrient enrichment. It may also be sensitive to some other anthropogenic pressures, including alterations to river flows and modifications to morphological conditions which may act alone or in combination to affect the macrophyte community.

1.3 Geographic application

This assessment method is appropriate for all rivers in the UK and which are assessed in accordance with the Water Framework Directive. It may be less applicable in heavily modified water bodies, and should not be used to assess canals, marsh ditch systems or strongly seasonal watercourses.

1.4 Intercalibration

This is a process whereby all European Member States are required to compare WFD class boundary values for each biological quality element, to ensure similar levels are set across all countries. The process involved some adjustments of class boundary values for many of the classification tools in use, and this process has influenced some of the calculations used in the LEAFPACS method. Once a classification method has been intercalibrated, the method must be adhered to by Member States for the purposes of WFD assessment and reporting.

Intercalibration focused on the EQRs which define the class boundaries between High and Good, or Good and Moderate status (the H/G and G/M class boundaries respectively). For this reason the method tends to refer to class *boundary* values rather than EQRs which define a particular class.

2 Data collection

2.1 River macrophyte survey

The survey method used should conform to CEN 14184 : 2003 Water quality – Guidance standard for the surveying of aquatic macrophytes in running waters.

In order to obtain the data with which to calculate the observed values for each of the parameters, 100 metre stretches of the river should normally be sampled between 1st June and 30th September. Sampling should not be undertaken during or immediately after periods of high flow. Where cold weather or spring floods may have delayed the growth of macrophyte taxa, sampling should commence after 30th June.

Location of the survey stretches should be selected to be representative of the water body as a whole. The number of 100m stretches required to adequately characterise a water body will vary depending on the water body size (length) and heterogeneity of habitat. Previous work to assess variability in river macrophytes (Willby *et al* 2012) indicated that in most water bodies three 100m stretches would be adequate to produce a classification with 95% confidence, and in some very small or very uniform water bodies it may be possible to reduce this number.

Surveying should establish the presence, and percentage of the river channel (up to the height of bank that would typically be submerged for >50% of the year) covered by, any of the macrophyte taxa listed in Appendix A (Table 1). Where it is not possible to identify a macrophyte present in the river to species level, it should be recorded under its genus or other aggregate taxon level if such is listed in Table 1. If there is no genus/aggregate taxon level indicated it is assumed the taxon will be identified to species in all cases.

Each taxon present in the river and listed in Table 1 should be assigned the appropriate taxon cover value in Table 2, according to a visual estimate of its percentage cover in the river channel.

2.2 Other data requirements

Information in addition to the field survey data is required to enable the LEAFACS classification to be applied. These data and measurements enable the prediction of reference conditions, which are needed to calculate the EQRs. These data are referred to as *predictor variables*.

Alkalinity

The mean measured alkalinity (as mg/l CaCO₃) from at least 12, and preferably more samples should be used. Samples should be taken at evenly spaced intervals over a whole year or years. Alkalinity should be determined for a location representative of the water body, as close as possible to the location of the macrophyte surveys. Care should be taken in selecting sampling locations to avoid the influence of discharges, e.g. from sewage treatment works, which can affect the baseline alkalinity of the river.

Altitude of source

Altitude of highest point, in metres above mean sea level, of the furthest upstream point of any tributary of the river shown on a 1:50,000 scale map

Distance from source

The distance, in kilometres, from the upstream end of the sampled stretch of river to the source (located as for altitude of source), measured along the line of the channel.

Slope

Measured in metres per kilometre, is calculated from the change in altitude between the upstream and downstream ends of the 100m stretch of river that was sampled.

3 Procedures for calculating metrics and EQRs

The following sections outline how the macrophyte metrics and EQRs are calculated. Each section comprises a step by step process allowing the calculation of observed values, reference values, calculation of the EQR then adjustment of the EQRs and subsequent combination to produce the final class.

EQRs are a ratio of observed and expected values. *Observed values* are taken from survey data collected in the field and *expected values* (also referred to as *reference values*) are calculated from the predictor variables described above. Thus River LEAFPACS2 produces a *site specific* reference value for each survey location.

The EQR scale for each metric was influenced by the data used in its development and is not the same in each case. To enable the metrics to be combined their values need to be “normalised” to the same scale. The normalised EQRs enable the combination of metrics to produce the overall River LEAFPACS EQR and the assessment of macrophyte status. It is recommended that the results from individual metrics are not be used in isolation.

The class boundaries for River LEAFPACS2 are:

Status class boundary	EQR
High/Good	0.8
Good/Moderate	0.6
Moderate/Poor	0.4
Poor/Bad	0.2

Once the final EQR has been calculated, an assessment of the statistical confidence of these values can be made. This is referred to as Confidence of Class - the procedure allows the calculation of statistical confidence of a given EQR falling into any of the five status classes. The Confidence of Class reflects the position of a given EQR value relative to the range of EQR values appropriate to a given class and takes account of the variability between sites in a water body and the variability between surveyors in collecting data. It does not measure the confidence with which an impact is detected.

3.1 River LEAFPACS2 calculator spreadsheets

The procedures for calculating the macrophyte metric EQRs, the overall EQR and the Confidence of Class can be carried out manually using a calculator and spreadsheet such as MS Excel. However, the task can be made simpler by using a spreadsheet calculator. An MS Excel spreadsheet has been produced with a series of worksheets for data input and calculation of all components of the classification, including Confidence of Class. Instructions for use are provided within the spreadsheet calculator. The most recent version of the spreadsheet calculator can be found on the UKTAG website.

NB As revisions are likely to be made and the calculator updated over time, it is important to check that the most recent version is being used.

- Calculator spreadsheets provided on the UKTAG website are:
- River LEAFPACS2 metric calculator, which enables the calculation of metrics from raw survey data
- River LEAFPACS2 EQR calculator which enables the calculation of EQRs and Confidence of Class

3.2 Calculating EQR for the metrics

A worked example of the following calculations is provided in Appendix B.

Calculation of the observed value for each parameter

(i) **Observed RMNI** (River Macrophyte Nutrient Index)

For each 100m survey, all the macrophyte taxa present that are listed in Appendix A (Table 1) are assigned the corresponding RMNI species score in column 2 of the table.

The **observed** value of the metric, RMNI, is calculated using the equation:

$$\text{Observed value of RMNI} = \frac{\sum_{j=1}^n (C_j \times R_j)}{\sum_{j=1}^n C_j}$$

where:

R_j is the river macrophyte nutrient index score for taxon **j**;

j represents a taxon listed in Appendix A, Table 1, with an RMNI score listed in column 2. **j** has a value of 1 to n, indicating which of all the listed taxa present in the survey (total number = n) it represents;

C_j is the taxon cover value for taxon **j**, determined in accordance with Appendix A (Table 2).

(ii) **Observed NTAXA** (Number of macrophyte taxa)

The observed value for NTAXA is given by the sum of the number of taxa listed in Appendix A (Table 1) that are present in the river *and* identified in column 3 of the table as being truly aquatic (i.e. hydrophytes).

Note that when there are several morphologically distinct taxa present belonging to a single aggregate (e.g. *Ranunculus* section *Batrachian*), no members of which can be identified to species level, these should be recorded as separate species for the purposes of calculating this metric.

(iii) **Observed NFG** (Number of functional groups)

To determine the observed value for NFG, each taxon included in the observed NTAXA metric (i.e. listed in Appendix A, Table 1, and identified in Column 3 of that Table as aquatic), is assigned to the corresponding macrophyte functional group number in Column 4 of Table 1.

The observed value for NFG is given by the sum of the number of different functional groups of taxa present in the survey.

(iv) **Observed ALG** (Percentage cover of green filamentous algae)

To calculate the observed value of ALG:

a) use the mid-point of the percentage cover range associated with the cover score, for each recorded algal taxon, as indicated in Appendix A (Table 2).

b) add up the individual percentage cover values of all taxa in Appendix A (Table 1) which are identified as filamentous algae in column 5.

A direct visual assessment of the overall percentage cover of green filamentous algae at the site is an acceptable alternative, but note that this cannot then be entered against the taxa in the metric calculator spreadsheet.

The observed value for the metric ALG represents the total coverage of the stream bed by green filamentous algae, and will range from 0-100.

Calculation of the reference value for each metric

The reference values described below were derived using a combination of (a) information from a network of river sites identified as being subject to no or very minor alterations likely to affect their macrophyte communities and (b) modelling.

Reference values are *site specific* and should, if possible, be calculated for each surveyed stretch in a water body, using the following equations. It is essential that the predictor variables are expressed in the same units as defined in Section 2.2.

(i) **Reference RMNI** (River Macrophyte Nutrient Index)

$$\text{Reference RMNI} = 5.239 + [1.384 \times \text{Log}_{10}(\text{Alk} + 1)] + [-0.68 \times \text{Log}_{10}(\text{S}+1)] + [0.711 \times \text{Log}_{10}(\text{D} + 1)] + [-1.074 \times \text{Log}_{10}(\text{HSo} + 1)]$$

(ii) **Reference NTAXA** (Number of macrophyte taxa (which are not helophytes))

For rivers in England, Scotland and Wales:

$$\text{Reference NTAXA} = 10.026 \times \text{EXP} (\text{Log}_{10} (S+1) \times -0.426)$$

For rivers in Northern Ireland:

$$\text{Reference NTAXA} = [10.026 \times \text{EXP} (\text{Log}_{10} (S+1) \times -0.426)] \times 0.75$$

(iii) **Reference NFG** (Number of functional groups)

For rivers in England, Scotland and Wales:

$$\text{Reference NFG} = 6.304 \times \text{EXP} (\text{Log}_{10} (S+1) \times -0.377)$$

For rivers in Northern Ireland:

$$\text{Reference NFG} = [6.304 \times \text{EXP} (\text{Log}_{10} (S+1) \times -0.377)] \times 0.78$$

In the above equations:

Alk is the annual mean reference alkalinity for the site or water body expressed as a concentration of CaCO₃ in mg/l;

HSo is the altitude, in metres, above mean sea level of the furthest upstream point of any tributary of the river shown on a 1:50,000 scale map;

S is the drop in altitude, in metres per kilometre, between the upstream and downstream ends of sampled part of the river; and

D is the distance, in kilometres, from the upstream end of the sampled part of the river to the source, as defined above.

(v) **Reference ALG** (Percentage cover of green filamentous algae)

The cover of green filamentous algae in reference sites could not be modelled satisfactorily using the environmental predictors used to model the composition and richness metrics. Consequently a **global reference value** is used, based on the median ALG value of the population of reference sites.

$$\text{Reference ALG} = 0.05\%$$

3.3 Calculation of the ecological quality ratio (EQR) for each metric

The “raw” EQRs for the individual metrics are calculated using the following equations:

(i) **RMNI EQR**

$$EQR_{RMNI} = (\text{observed value of RMNI} - 10) \div (\text{reference value for RMNI} - 10)$$

(Where 10 is the worst possible RMNI value)

(ii) **NTAXA EQR**

$$EQR_{NTAXA} = \text{observed value of NTAXA} \div \text{reference value for NTAXA}$$

(iii) **NFG EQR**

$$EQR_{NFG} = \text{observed value of NFG} \div \text{reference value for NFG.}$$

(iv) **ALG EQR**

$$EQR_{ALG} = (\text{observed value of ALG} - 100) \div (\text{reference value for ALG (i.e.0.05)} - 100)$$

(Where 100 represents the worst possible value of ALG, and global reference value of 0.05 is used)

3.4 Adjustment of the ecological quality ratios

The “raw” EQR values of different metrics are not directly aligned with each other because these metrics are measured and modelled with different levels of precision. Therefore the “raw” EQR values obtained from the equations above must be standardised before the combined LEAFPACS EQR can be calculated. The EQR for each metric is adjusted according to its value, as shown in the tables below:

i) RMNI EQR adjustment

EQR_{RMNI}	Adjusted EQR ($^A EQR_{RMNI}$)
>1.00	1.00
≥ 0.85 and <1.00	$((EQR_{RMNI}-0.85)/(1-0.85))*0.2+0.8$
≥ 0.70 and <0.85	$((EQR_{RMNI}-0.7)/(0.85-0.7))*0.2+0.6$
≥ 0.52 and <0.70	$((EQR_{RMNI}-0.52)/(0.7-0.52))*0.2+0.4$
≥ 0.34 and < 0.52	$((EQR_{RMNI}-0.34)/(0.52-0.34))*0.2+0.2$
≥ 0.16 and < 0.34	$((EQR_{RMNI}-0.16)/(0.34-0.16))*0.2$
< 0.16	0.00

(ii) Diversity metrics EQR adjustment

Take the lowest of EQR_{NTAXA} and EQR_{NFG} . This value is then standardised according to the equations below, where 'EQR' represents the lower of the two diversity EQRs:

Lowest of EQR_{NTAXA} and EQR_{NFG}	Adjusted diversity EQR ($^A EQR_D$)
≥ 0.83	$((EQR-0.83)/(1-0.83))*0.2+0.8$
≥ 0.66 and < 0.83	$((EQR-0.66)/(0.83-0.66))*0.2+0.6$
≥ 0.49 and <0.66	$((EQR-0.49)/(0.66-0.49))*0.2+0.4,$
≥ 0.32 and <0.49	$((EQR-0.32)/(0.49-0.32))*0.2+0.2,$
< 0.32 and > 0.15	$((EQR-0.15)/(0.32-0.15))*0.2$

(iii) ALG EQR adjustment

EQR_{ALG}	Adjusted EQR ($^A EQR_{ALG}$)
> 0.975	$((EQR_{ALG} - 0.975) \div (1 - 0.975)) \times 0.2 + 0.8$
≥ 0.925 and ≤ 0.975	$((EQR_{ALG} - 0.925) \div (0.975-0.925)) \times 0.2 + 0.6$
≥ 0.825 and ≤ 0.925	$((EQR_{ALG} - 0.825) \div (0.925-0.825)) \times 0.2 + 0.4$
≥ 0.625 and ≤ 0.825	$((EQR_{ALG} - 0.625) \div (0.825 - 0.625)) \times 0.2 + 0.2$
< 0.625	$(EQR_{ALG} \div 0.625) \times 0.2$

3.5 Combining the ecological quality ratios for the different metrics

The EQR for the combined metrics ($EQR_{LEA FPACS}$) is determined as follows:

Step 1: Combine composition (RMNI) and diversity metrics

- a) If ${}^A EQR_D < {}^A EQR_{RMNI}$, then combined ecological quality ratio for the composition and diversity parameters ($EQR_{C\&D}$) is calculated from:

$$EQR_{C\&D} = ((0.5 \times [{}^A EQR_D]) + {}^A EQR_{RMNI}) \div 1.5$$

- b) If ${}^A EQR_D > {}^A EQR_{RMNI}$, then

$$EQR_{C\&D} = {}^A EQR_{RMNI}$$

Step 2: Determine $EQR_{LEA FPACS}$

- a) If $EQR_{C\&D} < {}^A EQR_{ALG}$ then:

$$EQR_{LEA FPACS} = EQR_{C\&D}$$

- b) If $EQR_{C\&D} > {}^A EQR_{ALG}$, then:

$$EQR_{LEA FPACS} = (Z \times {}^A EQR_{ALG} + EQR_{C\&D}) \div (Z + 1)$$

where:

$Z = 2 \times (1 \div (\text{Exp}(\text{Ln}(2600000000) + \text{reference RMNI} \times \text{Ln}(0.0166)) + 1 \div 0.5))$

Exp is the mathematical exponential function (e^x); and

Ln is the logarithm to the base of e.

4 Application of the method for the purposes of classification

When using the method for the purposes of classifying the ecological status of a water body, the mean value for the ecological quality ratio ($EQR_{LEAFPACS}$) measured across multiple sites within a single survey season, or a single site in multiple years should be used.

4.1 Confidence of Classification

To determine the confidence of the classification the uncertainty of the EQR is determined. This uncertainty arises from a combination of within-water body spatial and temporal variability in the biological community and variation between surveyors in assessing this community in the field. For the purpose of classification too few replicate surveys are available to measure this directly. Thus the method estimates the uncertainty using data from other water bodies, using an approach described by Ellis & Adriaenssens (2006). The spatio-temporal variability (the standard deviation) of the survey EQR is estimated as a function of the mean Survey EQR in a water body.

To estimate uncertainty it is assumed that after a logit transformation the EQR uncertainty is normally distributed around the true EQR value, with the predicted standard deviation. Then the confidence of class is computed using the Standard Normal Distribution.

4.2 Combination of macrophytes and phytobenthos for classification

Annex V of the WFD refers to macrophytes and phytobenthos as a single biological quality element. Where both sub-elements are classified independently using LEAFPACS2 and DARLEQ2, they are combined for reporting purposes by taking the worst of either as the combined result.

It is however recognised that there will be situations where macrophyte surveys are either not possible or are compromised, and possibly also situations where diatom assessments are inherently unreliable.

Analysis carried out for the UKTAG (UKTAG 2013) has confirmed that a DARLEQ2 based assessment alone would generally give a reliable classification if alkalinity is $< 75 \text{ mg L}^{-1} \text{ CaCO}_3$ (because the diatom-based status is consistently lower than the macrophyte-based status over this range of alkalinity and will thus define the overall classification), whilst a LEAFPACS2 based assessment alone is adequate at $>200 \text{ mg L}^{-1} \text{ CaCO}_3$ (because the macrophyte-based status is then consistently lower than the diatom-based status). In the middle range, both components are necessary (because neither one is consistently lower than the other) although, on average, an assessment based on DARLEQ2 alone will be a more reliable guide than LEAFPACS2 alone at alkalinities up to $\sim 120 \text{ mg L}^{-1} \text{ CaCO}_3$, whereas LEAFPACS2 alone will be a more reliable guide at alkalinities above this.

5 References

Ellis, J., and V. Adriaenssens.(2006) Uncertainty estimation for monitoring results by the WFD biological classification tools. Environment Agency, Bristol.

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UKTAG(2013) Final recommendations on new and updated biological standards. September 2013.

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APPENDIX A

Table 1: River LEAFPACS taxon list and associated values/characteristics for metric calculations

Taxon	RMNI	Aquatic taxa (hydrophyte) for NTAXA & NFG	Functional Group	Filamentous alga for ALG metric
<i>Acorus calamus</i>	9.49			
<i>Alisma lanceolatum</i>	8.47			
<i>Alisma plantago-aquatica</i>	7.82			
<i>Anthelia julacea</i>	2.7			
<i>Apium inundatum</i>	4.34	X	8	
<i>Apium nodiflorum</i>	8.64	X	8	
<i>Azolla filiculoides</i>	9.71	X	1	
<i>Baldellia ranunculoides</i>	4.34	X	4	
<i>Batrachospermum sp.</i>	5.46	X	19	
<i>Berula erecta</i>	8.24	X	8	
<i>Bidens cernua</i>	8.13			
<i>Bidens tripartita</i>	8.39			
<i>Blindia acuta</i>	1.09	X	22	
Blue-green algal scum/pelts	5.1	X	3	
<i>Bolboschoenus maritimus</i>	7.65			
<i>Brachythecium plumosum</i>	2.92	X	21	
<i>Brachythecium rivulare</i>	3.56	X	21	
<i>Bryum alpinum</i>	3.83			
<i>Bryum dixonii</i>	5.22			
<i>Bryum pseudotriquetrum</i>	2.71			
<i>Butomus umbellatus</i>	8.89	X	13	
<i>Calliergon cuspidatum</i>	3.49			

<i>Callitriche brutia</i> var <i>hamulata</i>	4.51	X	6	
<i>Callitriche hermaphroditica</i>	5.75	X	5	
<i>Callitriche obtusangula</i>	8.04	X	6	
<i>Callitriche platycarpa</i>	7.56	X	6	
<i>Callitriche</i> sp.	6.67	X	6	
<i>Callitriche stagnalis</i>	6.47	X	6	
<i>Callitriche stagnalis/platycarpa</i>	6.21	X	6	
<i>Callitriche truncata</i>	6.47	X	6	
<i>Caltha palustris</i>	4.2			
<i>Carex acuta</i>	7.19			
<i>Carex acutiformis</i>	8.21			
<i>Carex aquatilis</i>	3.9			
<i>Carex elata</i>	4.54			
<i>Carex lasiocarpa</i>	3.41			
<i>Carex paniculata</i>	7.49			
<i>Carex recta</i>	5.42			
<i>Carex riparia</i>	9.06			
<i>Carex rostrata</i>	2.64			
<i>Carex vesicaria</i>	3.68			
<i>Catabrosa aquatica</i>	8.7			
<i>Ceratophyllum demersum</i>	9.73	X	5	
<i>Chara globularis</i>	3.3	X	2	
<i>Chara</i> sp.	3.85	X	2	
<i>Chara vulgaris</i>	3.77	X	2	
<i>Chiloscyphus pallescens</i>	4.78			
<i>Chiloscyphus polyanthos</i>	4.05	X	23	
<i>Cinclidotus fontinaloides</i>	5.37	X	22	
<i>Cladophora aegagropila</i>	5.66	X	19	
<i>Cladophora glomerata</i>	7.5	X	19	A

Cladophora glomerata/Rhizoclonium hieroglyphicum	8.66	X	19	A
Collema dichotomum	4.42	X	3	
Cratoneuron filicinum	5.02			
Dermatocarpon sp.	3.51			
Dichodontium flavescens	2.94			
Dichodontium palustris	1.68			
Dichodontium pellucidum	3.07			
Dichodontium flavescens/pellucidum	3.00			
Draparnaldia	3.04	X	19	
Drepanocladus fluitans	3.73			
Elatine hexandra	4.17	X	11	
Eleocharis acicularis	5.35	X	4	
Eleocharis palustris	4.54			
Eleogiton fluitans	2.06	X	15	
Elodea canadensis	7.65	X	5	
Elodea nuttallii	9.44	X	5	
Equisetum fluviatile	3.92			
Filamentous green algae	7.61	X	19	A
Fissidens polyphyllus	3.84	X	22	
Fissidens crassipes	6.2	X	22	
Fissidens curnovii	3.94	X	22	
Fissidens osmundoides	3.06	X	22	
Fissidens rivularis	5.95	X	22	
Fissidens rufulus	4.7	X	22	
Fissidens serrulatus	5.27	X	22	
Fissidens sp.	5.8	X	22	
Fissidens viridulus	4.66	X	22	
Fontinalis antipyretica	5.4	X	21	
Fontinalis squamosa	3.66	X	21	

<i>Glyceria declinata</i>	6.66			
<i>Glyceria fluitans</i>	5.25			
<i>Glyceria fluitans</i> agg	5.81			
<i>Glyceria maxima</i>	9.64			
<i>Glyceria notata</i>	8.28			
<i>Glyceria x pedicillata</i>	7.12			
<i>Gongrosira incrustans</i>	7.46	X	20	
<i>Groenlandia densa</i>	7.96	X	5	
<i>Heribaudiella fluviatilis</i>	5.49	X	20	
<i>Hildenbrandia rivularis</i>	6.03	X	20	
<i>Hippuris vulgaris</i>	5.94			
<i>Hottonia palustris</i>	6.93	X	7	
<i>Hydrocharis morsus-ranae</i>	8.77	X	1	
<i>Hydrodictyon reticulatum</i>	8.79	X	19	A
<i>Hygroamblystegium fluviatile</i>	5.41	X	21	
<i>Hygroamblystegium</i> sp.	6.55	X	21	
<i>Hygroamblystegium tenax</i>	5.27	X	21	
<i>Hygrobiella laxifolia</i>	2.76	X	23	
<i>Hygrohypnum duriusculum</i>	3.33	X	21	
<i>Hygrohypnum eugyrium</i>	4.28	X	21	
<i>Hygrohypnum luridum</i>	2.80	X	21	
<i>Hygrohypnum ochraceum</i>	2.96	X	21	
<i>Hyocomium armoricum</i>	1.96			
<i>Hypericum elodes</i>	2.66			
<i>Iris pseudacorus</i>	6.92			
<i>Isoetes lacustris</i>	3.02	X	4	
<i>Juncus articulatus</i>	3.10			
<i>Juncus bulbosus</i>	1.89	X	4	
<i>Jungermannia atrovirens</i>	2.28	X	23	

<i>Jungermannia exsertifolia</i>	3.87	X	23	
<i>Jungermannia obovata</i>	2.97	X	23	
<i>Jungermannia paroica</i>	4.00	X	23	
<i>Jungermannia pumila</i>	3.29	X	23	
<i>Jungermannia</i> sp.	2.41	X	23	
<i>Jungermannia sphaerocarpa</i>	3.08	X	23	
<i>Lemanea fluviatilis</i>	4.51	X	19	
<i>Lemanea</i> sp	4.53	X	19	
<i>Lemna gibba</i>	10.00	X	1	
<i>Lemna minor</i>	8.80	X	1	
<i>Lemna minuta</i>	9.21	X	1	
<i>Lemna</i> sp.	9.30	X	1	
<i>Lemna trisulca</i>	8.21	X	1	
<i>Leptodictyon riparium</i>	7.57	X	21	
<i>Littorella uniflora</i>	1.96	X	4	
<i>Lobelia dortmanna</i>	2.72	X	4	
<i>Luronium natans</i>	4.37	X	4	
<i>Lythrum salicaria</i>	7.33			
<i>Marsupella aquatica</i>	3.17	X	23	
<i>Marsupella emarginata</i>	1.06	X	23	
<i>Marsupella</i> sp.	1.24	X	23	
<i>Mentha aquatica</i>	6.27			
<i>Menyanthes trifoliata</i>	3.14			
<i>Mimulus guttatus</i>	5.79			
<i>Mimulus</i> sp./hybrid	5.60			
<i>Monostroma</i> sp.	6.86	X	3	
<i>Montia fontana</i>	3.35			
<i>Myosotis laxa</i>	4.82			
<i>Myosotis scorpioides</i>	6.83			

<i>Myosotis secunda</i>	4.74			
<i>Myosotis</i> sp(p).	7.00			
<i>Myriophyllum alterniflorum</i>	3.44	X	7	
<i>Myriophyllum spicatum</i>	8.26	X	7	
<i>Myriophyllum</i> spp indet	5.89	X	7	
<i>Myriophyllum verticillatum</i>	7.53	X	7	
<i>Nardia compressa</i>	1.05	X	23	
<i>Nardia scalaris</i>	2.73	X	23	
<i>Nardia</i> sp.	1.40	X	23	
<i>Nitella flexilis</i> (agg.)	4.39	X	2	
<i>Nitella opaca</i>	4.31	X	2	
<i>Nitella</i> sp.	4.59	X	2	
<i>Nitella translucens</i>	4.17	X	2	
<i>Nostoc commune</i>	5.14	X	3	
<i>Nostoc parmelioides</i>	4.12	X	3	
<i>Nostoc</i> sp.	4.66	X	3	
<i>Nostoc verrucosum</i>	4.71	X	3	
<i>Nuphar lutea</i>	8.42	X	12	
<i>Nymphaea alba</i>	5.69	X	12	
<i>Nymphoides peltata</i>	9.37	X	10	
<i>Octodicerias fontanum</i>	6.54	X	22	
<i>Oenanthe aquatica</i>	6.06	X	8	
<i>Oenanthe crocata</i>	6.22	X	8	
<i>Oenanthe fistulosa</i>	8.27			
<i>Oenanthe fluviatilis</i>	8.57	X	8	
<i>Orthotrichum rivulare</i>	4.71			
<i>Palustriella commutata</i>	4.61			
<i>Pellia endiviifolia</i>	6.50			
<i>Pellia epiphylla</i>	3.34			

Pellia sp.	4.67			
Persicaria amphibia	8.20	X	10	
Persicaria hydropiper	6.97			
Phalaris arundinacea	7.52			
Philonotis caespitosa	2.74			
Philonotis fontana	2.66			
Phragmites australis	7.70			
Platyhypnidium lusitanicum	4.35	X	21	
Platyhypnidium riparioides	5.16	X	21	
Porella cordaeana	4.95	X	23	
Porella pinnata	4.91	X	23	
Potamogeton alpinus	4.96	X	16	
Potamogeton berchtoldii	7.35	X	14	
Potamogeton compressus	8.33	X	14	
Potamogeton crispus	8.02	X	17	
Potamogeton filiformis	6.00	X	15	
Potamogeton friesii	8.19	X	14	
Potamogeton gramineus	4.24	X	16	
Potamogeton lucens	8.54	X	17	
Potamogeton natans	5.69	X	16	
Potamogeton nodosus	7.05	X	16	
Potamogeton obtusifolius	5.84	X	14	
Potamogeton pectinatus	9.59	X	15	
Potamogeton perfoliatus	8.16	X	17	
Potamogeton polygonifolius	1.71	X	16	
Potamogeton praelongus	7.81	X	17	
Potamogeton pusillus	7.47	X	14	
Potamogeton trichoides	7.24	X	14	
Potamogeton x bottnicus	6.41	X	15	

Potamogeton x cooperi	6.07	X	17	
Potamogeton x fluitans	6.51	X	16	
Potamogeton x gessnacensis	3.88		16	
Potamogeton x lanceolatus	4.24	X	17	
Potamogeton x nitens	6.17	X	17	
Potamogeton x olivaceus	5.44	X	17	
Potamogeton x salicifolius	6.36	X	17	
Potamogeton x sparganifolius	3.87	X	16	
Potamogeton x suecicus	6.02	X	15	
Potamogeton x zizzii	4.19	X	16	
Potentilla palustris	2.88			
Racomitrium aciculare	1.89	X	22	
Ranunculus (sect Batrachian) sp. or hybrid indet	7.33	X	18	
Ranunculus aquatilis var aquatilis	5.67	X	18	
Ranunculus aquatilis var diffusus	7.65	X	18	
Ranunculus circinatus	9.42	X	5	
Ranunculus flammula	2.56			
Ranunculus fluitans	7.97	X	18	
Ranunculus hederaceus	5.47			
Ranunculus omiophyllus	3.43	X	11	
Ranunculus peltatus var baudotii	9.06	X	18	
Ranunculus peltatus var peltatus	6.22	X	18	
Ranunculus penicillatus ssp. penicillatus	6.29	X	18	
Ranunculus penicillatus ssp. pseudofluitans	7.92	X	18	
Ranunculus penicillatus ssp. pseudofluitans var vertumnus	5.87	X	18	
Ranunculus sceleratus	9.86			
Rhodochorton violaceum	4.14			
Riccardia chamaedryfolia	4.91			

Riccardia multifida	5.25			
Riccia sp.	4.86	X	1	
Rivularia	4.77	X	20	
Rorippa amphibia	9.20			
Rorippa nasturtium-aquaticum agg.	8.42			
Rorippa palustris	7.32			
Rumex hydrolapathum	8.65			
Sagittaria sagittifolia	9.24	X	12	
Scapania sp. (aggregated)	2.14	X	23	
Scapania subalpina	3.21	X	23	
Scapania uliginosa	2.66	X	23	
Scapania undulata	2.05	X	23	
Schistidium agassizii	2.23			
Schistidium rivulare	5.16			
Schoenoplectus lacustris	8.44	X	13	
Schoenoplectus tabernaemontani	7.43			
Scirpus sylvaticus	6.45			
Scorpidium revolvens	4.29			
Sium latifolium	7.08			
Sparganium angustifolium	2.26	X	13	
Sparganium emersum	8.32	X	13	
Sparganium erectum	8.34			
Sparganium natans	3.59	X	13	
Sparganium emersum/erectum	8.33			
Sphagnum denticulatum	4.84			
Sphagnum sp(p)	1.07			
Spirodela polyrhiza	8.99	X	1	
Spirogyra	6.45	X	19	A
Stigeoclonium tenue	6.62	X	19	A

Stigonema sp.	4.32	X	19	
Tetraspora lubrica/gelatinosa	6.72	X	3	
Thamnobryum alopecurum	4.22	X	21	
Tolythrix penicillata	2.96	X	3	
Triglochin palustris	4.07			
Typha angustifolia	7.57			
Typha latifolia	8.87			
Ulva flexuosa	9.52	X	19	A
Utricularia intermedia	2.74	X	9	
Utricularia minor	3.77	X	9	
Utricularia sp.	3.23	X	9	
Utricularia vulgaris s.l.	3.72	X	9	
Vaucheria sp(p)	8.41	X	19	A
Veronica anagallis-aquatica	8.45			
Veronica beccabunga	7.31			
Veronica catenata	9.32			
Veronica catenata x anagallis-aquatica	8.34			
Veronica scutellata	2.35			
Zannichellia palustris	9.01	X	15	
Zygnematalean alga	6.45	X	19	A

Table 2: River LEAFACS cover values for macrophyte taxa

Column 1	Column 2	Column 3
Percentage cover range (% of channel area)	Taxon cover value	Mid-point percentage
< 0.1	1	0.05
0.1 < 1	2	0.5
1 < 2.5	3	1.7
2.5 < 5	4	3.8
5 < 10	5	7.5
10 < 25	6	17.5
25 < 50	7	37.5
50 < 75	8	62.5
≥ 75	9	87.5

APPENDIX B: Worked example

The following data were obtained from a survey of a large, lowland calcareous river.

The first column has the taxon name, the second column shows the taxon cover value of that taxon in the sample; the third column has the RMNI score for that taxon (see Appendix A, Table 1), the fourth column records whether the taxon is regarded as a true aquatic (Hydrophyte TAXA = 1) or not (Hydrophyte TAXA = 0), the fifth column shows the functional group to which the taxon, if a true aquatic, belongs, and the final column indicates the percentage cover associated with any taxon classified as a green filamentous alga.

Species	Taxon cover value	River macrophyte nutrient index score	Hydrophyte TAXA	Macrophyte functional group number	ALG % cover
<i>Apium nodiflorum</i>	3	8.64	1	8	
<i>Callitriche obtusangula</i>	1	8.04	1	6	
<i>Cladophora glomerata</i>	4	7.50	1	19	3.8
<i>Fontinalis antipyretica</i>	2	5.40	1	21	
<i>Hildenbrandia rivularis</i>	4	6.03	1	20	
<i>Lemna minor</i>	2	8.80	1	1	
<i>Oenanthe crocata</i>	1	6.22	1	8	
<i>Phalaris arundinacea</i>	6	7.52	0		
<i>Phragmites australis</i>	3	7.70	0		
<i>Ranunculus fluitans</i>	8	7.97	1	18	
<i>Rumex hydrolapathum</i>	1	8.65	0		

In addition, the following environmental data were derived:

Variable	Value
Slope (S)	0.9 metres km ⁻¹
Distance to source (D)	58.5 kilometres
Altitude of source (HS ₀)	140 metres
Alkalinity (Alk)	217 mg/l CaCO ₃

RMNI

The observed RMNI is calculated as follows:

1. Calculate taxon cover value \times river macrophyte nutrient index score for all relevant taxa present in the sample
2. Sum the results of step 1, above = **263.28**
3. Sum the taxon cover values for all relevant taxa present in the sample = **35**
4. Calculate the observed value of RMNI as $263.28 \div 35 = 7.52$

The reference value is calculated using the applicable equation in section 3.2. This results in a reference value of 7.24.

$$EQR_{RMNI} = (7.52 - 10) / (7.24 - 10) = \mathbf{0.90}.$$

EQR_{RMNI} is adjusted using the applicable equation in section 3.4, to give ${}^A EQR_{RMNI} = \mathbf{0.86}$

Number of taxa

The observed number of aquatic plant taxa (NTAXA) is **8** (as only hydrophytes are included).

The reference value for NTAXA is calculated using the applicable equation in section 3.2. This results in a reference value of **8.9**.

$$EQR_{NTAXA} = \text{observed value of NTAXA} \div \text{reference value for NTAXA} = \mathbf{0.90}$$

Functional group diversity

The observed number of functional groups (NFG) for this river is 7. There are 8 aquatic plant taxa (hydrophytes) because the helophytes *Phalaris arundinacea*, *Phragmites australis* and *Rumex hydrolapathum* are excluded. The remaining species belong to different functional groups, except *Oenanthe crocata* and *Apium nodiflorum* which share the same functional group. Consequently, there are seven functional groups.

The reference value for NFG is calculated using the applicable equation in section 3.2. This results in a reference value of **5.68**.

$$EQR_{NFG} = \text{observed value of NFG} / \text{reference value for NFG} = \mathbf{1.23}$$

Since $EQR_{NTAXA} < EQR_{NFG}$ the former is adjusted using the applicable equation in section 3.4, to give ${}^A EQR_D = \mathbf{0.88}$

EQR_{NFG} plays no further role in classification.

Algal cover

The observed cover of green filamentous algae (ALG) is 3.8%

The reference value for ALG is fixed at 0.05.

$$EQR_{ALG} = (\text{observed value of ALG} - 100) \div (\text{reference value for ALG} - 100) = 0.962$$

EQR_{ALG} is adjusted using the applicable equation in section 3.4, to give ${}^A EQR_{ALG} = 0.75$.

The complete results for this river are, therefore, as follows:

Parameter	Observed value	Reference value	EQR	${}^A EQR$
RMNI	7.52	7.24	0.90	0.86
NTAXA	8.00	8.9	0.90	0.88
NFG	7.00	5.68	1.23	
ALG	3.8	0.05	0.96	0.75

Calculating the EQR for the combined LEAFPACS parameter

Step 1:

The value of ${}^A EQR_{RMNI}$ is 0.86. ${}^A EQR_D$ has a value of 0.88.

The ecological quality ratio for the combined composition and diversity parameters ($EQR_{C\&D}$) is calculated using the applicable equation in section 3.5.

$$\text{Since } {}^A EQR_{RMNI} < {}^A EQR_D \quad EQR_{C\&D} = {}^A EQR_{RMNI} = 0.86$$

Step 2:

The value $EQR_{C\&D}$ is compared with ${}^A EQR_{ALG}$. Since the value of $EQR_{C\&D}$ is $> {}^A EQR_{ALG}$ further adjustment of $EQR_{C\&D}$ is required. Thus

$$EQR_{LEAFPACS} = (Z \times {}^A EQR_{ALG} + EQR_{C\&D}) \div (Z + 1)$$

where:

$$Z = 2 \times (1 \div (\text{Exp}(\text{Ln}(2600000000) + \text{reference RMNI} \times \text{Ln}(0.0166)) + 1 \div 0.5) = 1.0$$

Therefore:

$$EQR_{LEAFPACS} = (1 \times 0.75 + 0.86) \div (1 + 1) = 0.81$$

The face value classification of this site would be **High**, although with an EQR of 0.81 it effectively lies on the High/Good boundary.

$EQR_{LEAFPACS}$ for the waterbody would be reported as the mean of $EQR_{LEAFPACS}$ values for each individual site surveyed.