Regarding individual macrophyte species, those unique to one or other site are given in Table 5.8. Unfortunately, a number of the 17 species unique to the upstream site and some of the 14 unique to the downstream site are not truly aquatic, mostly favouring damp stream banks (however, this does not mean that they are necessarily unaffected by the change in riverine nutrient status between the two sites). A number of moss species are present upstream but absent downstream; *Pohlia carnea* is not an aquatic species, but both *Amblystegium fluviatile* and *Fissidens crassipes* require at least occasional inundation and may be affected (directly or indirectly) by the increase in phosphorus levels. It is not possible to discern from the recorded habitat data whether suitable microhabitat is available for these species at the downstream site. *Pellia epiphylla* is also present upstream but absent downstream; this species is thought to have a low tolerance to increased nutrient levels (with a Trophic Rank of 25), and it is perhaps surprising to find it even at the upstream site. The increase in phosphorus concentrations between the two sites must be suspected as a contributory factor in its absence downstream, but again the availability of suitable microhabitat downstream is not known.

Iris pseudacorus and *Nasturtium officinale* are both present upstream but absent downstream. The soft muds of the upstream site are a more suitable substrate for *Iris* and could help to explain its absence downstream, where gravels predominate. *N. officinale* fairs well in faster flowing water, such as that prevalent downstream, so its absence at the downstream site is more likely to be due to some other factor. Increased competition from species geared to higher nutrient concentrations (see below) could be a contributory factor.

Both *Enteromorpha* and *Cladophora* appear at the downstream site after being absent upstream. However, SRP levels at the upstream site (median levels of 100 ug l^{-1} in 1978 and 1979) would appear to be higher than those considered by most authors to be required for maximum growth of *Cladophora*, suggesting that some other factor is limiting growth upstream (perhaps the lack of a firm substrate). For instance, Wong and Clark (1976) found 60 ug l^{-1} TP to be the minimum concentration required for maximum growth in *Cladophora*; in contrast, however, Pitcairn and Hawkes (1973) reported restricted growth at 1 mg l^{-1} TP, so the situation is not completely clear.

Of the other species unique to the downstream site (such as *Potamogeton crispus*, *P. pectinatus*, *P. perfoliatus*, *Polygonum amphibia* and *Zannichellia palustris*), it is unlikely that upstream SRP levels were low enough to prevent growth completely since these species have wide trophic ranges; however, SRP levels may have been sufficiently low to put them at a competitive disadvantage. Many of these species thrive in hypereutrophic conditions and might be better placed to compete at the higher SRP concentrations prevalent downstream. Of the species thought by Newbold (1992) to be obligate to specific trophic bands (see Section 3.1), only *Zannichellia palustris* and *Potamogeton pectinatus* feature on the Windrush as being present at only one (the downstream) site.

Table 5.8 Macrophytes unique to one or other site on the River Windrush.

Taxa	Trophic Rank[1]	Plant Score[2]
Intake @ Worsham (upstream)		
Lunularia cruciata	-	-
Pellia epiphylla	25	6
Amblystegium fluviatile	-	6
Fissidens crassipes	-	10
Pohlia carnea	-	10
Equisetum arvense	-	-
Filipendula ulmaria	-	-
Nasturtium officinale	97	7
Nuphar lutea	138	6
Petasites hybridus	-	-
Petasites japponicus	-	-
Rorippa palustris	-	-
Symphytum officinale	-	-
Other tree genera	-	-
Carex hirta	-	8
Iris pseudacorus	60	3
Typha latifolia	146	4
Newbridge G/S (downstream)		
Enteromorpha	X136	3
Cladophora glomerata agg	112	3
Amblystegium riparium	126	2
Bidens cernua	-	-
Polygonum amphibia	141	3
Ranunculus circinatus	98	6
Rorippa amphibia	112	4
Alisma plantago-aquatica	X109	3
Elodea canadensis	71	5
Potamogeton crispus	137	4
Potamogeton pectinatus	149	1
Potamogeton perfoliatus	135	7
Polygonum sp(p)	-	-
Zannichellia palustris	150	5

[1] After Newbold and Palmer (1979), revised by Newbold and Holmes (1987)
[2] After Standing Committee of Analysts (1987)

Summary

Summarising the spatial analysis results, only two pairs of sites out of 133 in the water quality database were identified as being worthy of detailed analysis. One of these pairs was found to be incompatible in terms of habitat, such that detailed comparison of communities was not possible. The other site pair exhibited differences in communities that may be at least partially attributable to differences in SRP (or otherwise sedimentary phosphorus, for which SRP could act as a surrogate).

A number of site pairs failed only the last selection criterion of temporal compatibility with macrophyte surveys. Collection of additional data at these sites is likely to prove worthwhile. Site pairs most likely to yield valuable information are those where significant differences in SRP were consistently found towards the end of the 1980-89 time series. They are:

1. River Derwent at:
   a) Ouse Bridge
   b) Workington

2. River Frome at:
   a) u/s Louds Mill
   b) u/s Pallington Lakes
   c) Winfrith Heath
   d) Holme Bridge

3. River Moors at:
   a) u/s Palmersford STW
   b) Fir Grove Farm

4. River Piddle at:
   a) Puddletown
   b) West Mills

The habitat at sites on all rivers would need assessing from available data on the English Nature macrophyte database to discern whether they are comparable. Further water quality data for recent years would then be required for all sites to assess whether the observed differences in SRP are still in evidence. If this is the case, macrophyte surveys would then be required. It should be pointed out that it is not necessary for the same macrophyte sites to be used again - macrophyte surveys could be undertaken at the water quality sites in order to maximise spatial compatibility - but keeping the same macrophyte sites would make the data more amenable to temporal analysis, if this was deemed to be useful at a later date.

In addition to these site pairs, there is a number of pairs listed in Appendix F where significant differences in SRP levels have been found but where no spatially compatible macrophyte sites exist. These are also candidates for further data collection similar to that described above, but new macrophyte survey sites would have to be assigned (preferably coinciding with water quality sites).

6. IMPLICATIONS FOR WATER COLUMN ORTHOPHOSPHATE (SRP) STANDARDS

The review of published literature undertaken as part of this project highlights the fact that few comprehensive studies have been undertaken to link changes in riverine macrophyte communities to specific levels of phosphorus. In many published studies, changes to, or differences in, macrophyte communities are well documented but changes in the environmental levels of phosphorus are only inferred. This type of work provides little relevant information in the current context. It is clear, however, that different macrophyte communities (and individual species within these communities) are associated with different environmental phosphorus concentrations, with some species disappearing as levels increase and others becoming more competitive and dominating. This argues strongly against the imposition of a uniform phosphorus standard across all river types, and for the development of river type-specific or site-specific standards.

Many physico-chemical habitat variables other than phosphorus can have as great or greater influence on riverine macrophyte communities. A number of workers have concluded that phosphorus has a relatively minor influence on macrophytes in the systems they have studied. However, the identification of key influencing factors in any one study will greatly depend on the range of conditions under scrutiny. Clearly, the effect of phosphorus may appear minimal when comparing communities from widely different habitats, but if the range of environmental conditions is restricted to a particular river type, within which can be found a wide range of ambient phosphorus concentrations (from background levels to excessively enriched), the importance of phosphorus is likely to be paramount. In terms of protecting specific communities or individual species from detrimental effects due to phosphorus, the latter type of study provides more useful information.

Most changes to communities associated with increased phosphorus levels seem to occur through the competitive exclusion, by algae (planktonic, filamentous, epiphytic) or other macrophytes, of species adapted to thrive in lower phosphorus concentrations. In most river systems, algal species with anchorage mechanisms, such as epiphytes and filamentous algae, are more likely to have an impact than planktonic species due to the typically low residence times prevailing. Evidence of direct inhibition of growth due to elevated phosphorus levels is sparse, although it cannot be ruled out as a significant mechanism in real systems. The main effect of implementing environmental phosphorus standards would therefore seem to be control over the competitiveness of species (macrophytes or algae) that tend to dominate when phosphorus levels are elevated. It should be noted that a system does not have to be currently phosphorus-limited for phosphorus standards to have protective value, since existing limiting factors may be subsequently relieved. Phosphorus concentrations therefore need to be controlled such that they would tend to restrict the growth of "nuisance" species if phosphorus becomes limiting.

Changes in species and community status are likely to occur continuously across the whole spectrum of phosphorus levels encountered in the environment. The imposition of class boundaries or target levels inevitably places unnatural boundaries on this continuum of change. The key issue in protecting macrophyte interest is whether target levels are appropriately spaced to ensure that no significant impact can occur within any one class, or without a breach of a target level.

Some riverine literature indicates changes in communities over similar SRP concentrations to those used in the proposed series of English Nature target levels. In particular, Carbiener and Ortscheit (1987) have described communities characteristic of different SRP ranges in aquifer-fed rivers in Germany, concluding that SRP and total ammonia are the key determining factors. This work would support the imposition of standards of the order of EN target levels Class 1 (0.02 mg l^{-1}) and Class 2 (0.06 mg l^{-1}), at least for certain river types, and provides an argument for a more stringent target level to protect ultra-oligotrophic communities (in rivers such as the Cocker). This German work also points to other research undertaken in Europe that might be of value, although this would require extensive translation.

Nuisance growths of algae in rivers seem to be able to occur at very low phosphorus levels. Cartwright *et al.* (1993) suggested a guideline value of 0.03 mg l^{-1} Total P as an annual average, roughly equivalent to the most stringent value proposed in the EN series of target values (ie 0.02 mg l^{-1} SRP as an annual average). They further suggested that this might need to be reduced for very slow-moving waters. This is in line with proposals by Clyde River Purification Board (1991), who recommend a tentative guideline of 0.03-0.04 mg l^{-1} TP in free-flowing streams, but a more stringent standard of 0.012 mg l^{-1} in slower-flowing rivers where significant phytoplankton growth can occur. Many lowland rivers will have higher natural phosphorus concentrations than this and it would be unreasonable to expect them to be able to comply. However, it does highlight the fact that filamentous algal problems can occur even at natural phosphorus concentrations. In these circumstances, it is likely that other factors are having a greater influence on algal growth than phosphorus, eg poor macrophyte management, high light availability and reduced current velocities.

Threshold phosphorus concentrations for lentic macrophyte species and communities appear to range from 0.01 mg l^{-1} through the English Nature Class 1 (0.02 mg l^{-1}), Class 2 (0.06 mg l^{-1}) and Class 3 (0.1 mg l^{-1}) target values (Jupp and Spence 1977, Moss 1980, Hinton 1989). The major causal mechanism would seem to be increased turbidity from high phytoplankton densities, a phenomenon not likely to be a problem in UK rivers with any appreciable flow; however, some lowland rivers approach a lentic character and may be affected in a similar way. Results from lentic waters should therefore not be discounted in the riverine context.

The application of water column SRP standards, such as those proposed by English Nature, have the potential to restrict the growth of certain types of plant that tend to dominate communities at elevated phosphorus concentrations. These comprise all algal species and also macrophyte species depending solely or mainly upon water column phosphorus for their nutrient requirements. Included would be epiphytic algae, filamentous algae, phytoplankton (in rivers sufficiently sluggish to allow their occurrence in significant densities), non-rooted macrophytes and rooted macrophytes with rudimentary vascular systems. Such standards also have potential (although there is little hard evidence for this) in reducing or preventing direct inhibition, caused by elevated water column orthophosphate, of any valued macrophyte species that utilise this phosphorus source.

The disadvantage with water column SRP standards is that many macrophyte species either use sedimentary phosphorus only (particularly emergent species) or have the ability to use it for the majority of their phosphorus needs if water column phosphorus is in short supply (submerged, partially emergent and floating species that are rooted and have well-developed vascular systems). Certain vigorous rooted macrophytes, which could detrimentally dominate communities in conditions of elevated phosphorus concentrations, are therefore unlikely to be directly controlled by the introduction of water column standards alone. Similarly, if certain desirable rooted species are being inhibited directly by sedimentary phosphorus concentrations, a reduction in water column concentrations brought about by water column SRP standards would not help directly.

The fundamental problem is that more than one form of phosphorus is important in determining the distribution of riverine macrophyte communities. The only way, therefore, of comprehensively protecting macrophytes is to establish standards for both the water column and the sediment. In the short-term, the absence of data on sedimentary phosphorus levels precludes this, but it should not be ruled out for the future. The use of Total Phosphorus in the water column as a surrogate for sedimentary phosphorus is a possibility, but would be confounded by the effect of current velocity, which would ultimately determine sediment composition. The use of water column TP in isolation (ie in the absence of SRP standards) would give no indication of the amount of phosphorus immediately available in the water column to algae and to macrophytes that can utilise this nutrient source effectively.

Water column standards could succeed in influencing sedimentary phosphorus levels through the restriction or reduction of external loading to the river system (which would need to be considered in terms of Total Phosphorus). However, the extent to which this would happen will vary considerably from site to site, depending upon local conditions. For rivers where the community is as yet unimpacted by cultural eutrophication, the imposition of suitable water column SRP standards is likely to be successful in maintaining present concentrations and preventing phosphorus accumulation in riverine sediments, since any increased loads should be reflected in water column SRP and detected by non-compliance. For rivers where cultural eutrophication has already taken place, the effectiveness of water column standards at reducing phosphorus levels in the system as a whole will further depend upon the phosphorus capacity of the sediment and the response of the sediment to reduced external P loads. If the sediment has a small phosphorus reservoir (such as in fast-flowing rivers with coarse substrates), water column standards would reduce water column concentrations, and any excess phosphorus accumulated in the system is likely to be eliminated rapidly. Alternatively, if the sediment has a large phosphorus reservoir (such as in many slow-flowing lowland rivers), reductions in sedimentary phosphorus concentrations are likely to lag well behind improvements in water column SRP levels. Furthermore, high internal loading from the sediments could maintain high water column concentrations even though the external load has been reduced.

The literature on lakes has indicated that the timescale for natural sediment restoration, given a suitable reduction in the level of phosphorus input, is highly variable. As indicated in Section 2.4, a number of models have been produced to predict the extent of internal loading in lakes. The rate of loss from the sedimentary phosphorus reservoir in rivers is dependent on a number of factors, including sediment redox potential, sediment phosphorus concentration (largely determined by phosphorus input history and substrate type), water column phosphorus concentration, the degree of resuspension and current velocity. The process should be amenable to modelling as has been done in lakes, given a quantitative knowledge of phosphorus behaviour and the range of environmental conditions that are encountered in various river types. However, the riverine system is much more variable than the lake environment, necessitating a more complex model. Such an approach would offer a way of estimating the timescales for realising the benefits of applying standards in rivers with different physico-chemical characteristics, and whether more radical management is likely to be necessary (such as dredging).

In as far as water column SRP is utilised, riverine macrophytes and algae generally respond to chronic concentrations of nutrients rather than extreme episodic events. This is because the main response to nutrients, ie growth, occurs over non-episodic time periods (of the order of weeks or months). For this reason, it is sensible to express water column SRP standards as some sort of mean value rather than an upper percentile. This thinking is borne out by the literature, which consistently cites phosphorus levels as an annual or longer term mean rather than an upper percentile. A summer "growing season" mean may be appropriate to restrict the excessive growth of nuisance species; however, Clyde River Purification Board propose the imposition of a monthly mean standard (1991). Application of an annual mean in conjunction with a growing season mean would prevent high winter phosphorus loads, which would help to restrict sedimentary accumulation of phosphorus in slow-flowing rivers.

The Limit of Detection (LoD) on routine SRP analysis is an issue that needs some consideration. It varies from one NRA region to another and, although large improvements have been made in recent years in response to the blue-green algal monitoring programme, may be inadequate in certain regions to confidently assess compliance with the most stringent EN target level (ie 0.02 mg l^{-1} SRP as an annual average). As a general rule of thumb, a LoD of 10% of the annual mean will give adequate confidence on the true value of the mean. However, some regions may be operating on a LoD of up to 50% (ie 0.01 mg l^{-1}) of the Class 1 target level mean.

7. CONCLUSIONS

7.1 Relating to the review of available literature

Comprehensive studies linking macrophyte community status to environmental phosphorus levels are few and far between. However, some evidence has been found of differences in macrophyte communities associated with orthophosphate levels of the order of the upper target values proposed by English Nature (Classes 1 and 2). There is also some evidence to suggest that a more stringent target level might be appropriate for ultra-oligotrophic waters (see Section 6).

The main mechanism for impacts of phosphorus upon community status would appear to be competitive exclusion, although direct toxic effects cannot be ruled out in all cases. "Nuisance" species in this respect can be algae (epiphytic, filamentous or planktonic) or higher plants. It would appear that filamentous algal growths that are potentially damaging to macrophyte communities could arise over nearly the entire range of proposed EN target values if other environmental factors are favourable. Less information is available on epiphytic algae, although these may be a significant cause of competitive exclusion when phosphorus levels are increased.

Relationships between macrophyte communities and phosphorus levels are often confounded by other major determinants of macrophyte status, including ambient light levels (influenced by turbidity, colour and shading of the water surface), current velocity and substrate type, and also by the complex dynamics of phosphorus cycling. These confounding factors limit the usefulness of much of the information presently available. In designing studies to detect the effects of phosphorus, site selection to minimise these confounding effects is vital.

Since the effects of phosphorus on aquatic macrophyte communities are poorly understood and shrouded by a variety of confounding factors, and in the light of the trend towards higher SRP levels exhibited by many rivers, it would seem sensible to take a precautionary approach in UK waters of greatest conservation interest. The target levels proposed by English Nature, although not supported by an abundance of technical evidence, reflect the need to control SRP levels closely in nutrient-poor waters, whilst bringing the most excessively nutrient-enriched waters to a reasonable trophic level.

In riverine SSSIs/pSSSIs with greatly elevated phosphorus levels, special macrophyte interest exists **despite** the hypereutrophic conditions, not because of them. It is not known whether the special interest at such sites is sustainable in the long term or whether effects as yet undocumented are occurring, in either the macrophyte community or the ecosystem as a whole. In all plant communities there is a tendency for dominance by a few common species (macrophytes and algae) when nutrient levels are increased to excessively high levels, resulting in reduced diversity. Reductions in phosphorus levels to a more natural trophic level are likely to result in reduced dominance and an increase in species diversity.

If one form of phosphorus is to be used to define standards for river water, it is argued that Soluble Reactive Phosphorus would be the most appropriate. Ideally, SRP standards would be supported by sediment standards in order to gain better control of the phosphorus cycle as a whole, although this is not practical at present due to a lack of sediment data and a lack of knowledge of the relationships between sedimentary phosphorus and macrophyte communities.

Water column SRP standards are likely to be amenable to directly restricting the growth of algae, unrooted macrophytes and certain rooted macrophytes (with rudimentary vascular systems) that might interfere with macrophyte interest. The potential of such standards in controlling the growth of vigorous rooted macrophytes, particularly emergent species, is doubtful. There is likely to be some indirect control on sedimentary phosphorus levels, and therefore rooted macrophyte growth, through the control of phosphorus loads brought about by SRP standards. However, where reductions in phosphorus inputs are required, the extent of this control will vary depending upon the nature and size of the existing sedimentary phosphorus reservoir.

In rivers where reductions in phosphorus loadings are deemed to be necessary, the timescales for reductions in water column and sedimentary phosphorus concentrations will vary greatly depending upon the history and nature of the site. Large sedimentary phosphorus reservoirs and strong internal loading of phosphorus into the water column are likely to occur in slow-flowing lowland rivers.

7.2 Relating to the analysis of historical data

The historical water quality and macrophyte data analysed during this project were highly incompatible on both spatial and temporal bases, resulting in the rejection of most possible comparisons on the basis of simple technical criteria. Analysis of historical data on water quality and macrophytes has highlighted the need for a more coordinated approach to monitoring, in order to maximise the usefulness of the data in detecting cause and effect.

Comparison of adjacent sites on the River Windrush highlighted changes in SRP from median values of around 0.100 mg l^{-1} to around 0.200 mg l^{-1}. This coincided with changes in the macrophyte community that could be attributable to differences in SRP levels; however, some changes in habitat were evident between the sites such that habitat could not be ruled out as a causative factor.

Although the results of historical data analysis were disappointing, it is felt that there is still scope to obtain valuable information. The water quality database used in this study is quite limited in relation to the scale of the NRA monitoring network and also the English Nature macrophyte database.

Owing to the large number of constraints on the use of historical data, they can normally only be used to support more focused research. Ultimately, there is no substitute for integrated monitoring programmes aimed specifically at detecting effects on macrophytes due to changes in phosphorus levels.

The English Nature methodology for macrophyte surveying was designed to give a detailed species inventory of instream and bankside plants and not for the detection of water quality impacts. A methodology designed specifically for impact monitoring is likely to prove more cost-effective in the current context, although it is clear that comprehensive botanical surveys should and must continue for species inventory purposes.

8. RECOMMENDATIONS

8.1 Establishment of Special Ecosystem Use Classification

8.1.1 Definition of standards

It is recommended that orthophosphate (as Soluble Reactive Phosphate) is used as the phosphorus parameter for water quality standards within the Special Ecosystem Use Class.

No changes are suggested to the Class 4 (0.2 mg l^{-1} SRP) and Class 5 (1.00 mg l^{-1}) target levels proposed by English Nature (see Table 1.1), since there is little ecological information available to support or refute their position. It is suggested that the proposed Class 3 target level (0.11 mg l^{-1}) is brought into line with the DoE definition of "sensitive waters", under the EC Urban Waste Water Treatment Directive (ie 0.1 mg l^{-1} SRP).

It is recommended that the Class 1 (0.02 mg l^{-1}) and Class 2 (0.06 mg l^{-1}) target levels are left unchanged. However, consideration should be given to an additional target level to protect ultra-oligotrophic communities, which it is recommended would be set at 0.01 mg l^{-1}. If this is done, the original Class 1 target level (0.02 mg l^{-1}) is likely to require some adjustment (perhaps to 0.03 mg l^{-1}).

It is recommended that SRP standards are applied as "growing season" means in addition to annual means, and that failure to comply with either constitutes non-compliance. A pragmatic approach would have to be taken to defining the "growing season"; April to September inclusive is proposed.

8.1.2 Setting target levels

In light of the lack of knowledge on the sensitivity of specific macrophyte communities to environmental phosphorus levels, and the trend towards higher SRP levels exhibited by many rivers, it is recommended that SSSI and pSSSI waters should be designated target levels on the basis of water quality history. This should be undertaken with a view to maintaining SRP concentrations at, or restoring them to, natural or pre-cultural background levels. Such a precautionary approach can be justified on the basis that the waters in question are of high ecological importance and represent only a small proportion of the total length of river.

Where a statistically significant positive trend or increase in SRP levels can be identified using historical data, it is recommended that the target level is set to coincide with the SRP concentration at the beginning of the time series. However, it is recognised that the possibilities for this will vary depending upon the data that is available for each river and the time period that it covers. Indirect evidence for increases in phosphorus concentrations through time should also be considered, although such methods are likely to require more research (see Section 8.2).

Where no increase in SRP concentrations over time can be determined and none is suspected, the target level should be set to coincide with the current SRP levels (allowing for between-year variability).

For SSSI and pSSSI rivers with annual mean SRP values of greater than 0.20 mg l^{-1} (the Class 4 target level), it is recommended that the target level should be at least Class 4. This still represents a trophic state above that likely to be natural for any UK river, and is therefore not unreasonable as a minimum target for sites of special conservation interest. Such a move is likely to increase the diversity of the macrophyte community through the reduced competitiveness of species (macrophyte and algae) that tend to dominate at elevated phosphorus levels. No macrophyte species are likely to be lost from the community through reductions to this level, since there are no species that are obligate to phosphorus concentrations higher than this. Where a large reduction in SRP concentrations is required, intermediate "milestones" are likely to be useful in monitoring progress towards the final target level.

Where large reductions in phosphorus inputs to slow-flowing lowland rivers are required, sedimentary phosphorus concentrations and internal loading are likely to be high. In such situations, after monitoring the behaviour of phosphorus in the sediment, in-stream management such as dredging may be required to meet the target level.

It should be remembered that setting target values that would result in N:P ratios of less than around 15:1 is unlikely to bring about beneficial changes in macrophyte communities without reductions in nitrogen levels, since nitrogen becomes limiting at ratios lower than this.

It should be recognised that other waters of high conservation value exist outside of the SSSI network, and it is recommended that the NRA be encouraged to designate such waters under the Special Ecosystem Use Class as part of their commitment to riverine conservation under Section 16 of the Water Resources Act. Sites in particular need of such protection would include high quality oligotrophic waters, especially those containing rare species or communities known to be sensitive to eutrophication.

8.1.3 Compliance monitoring

Consideration should be given to the within-year variability of SRP data in order to assess the certainty associated with compliance with designated target levels at a range of sampling frequencies.

A minimum sampling regime should be agreed with the NRA for monitoring phosphorus within designated (SSSIs and pSSSIs) river stretches. This should formalise both the temporal and spatial sampling frequency and the Limit of Detection. It is recommended that a frequency of at least one sample per month is specified, with a Limit of Detection of 0.002 mg l^{-1} that may be relaxed outside of Class 1 (ie target level of 0.02 mg l^{-1}) waters. In rivers where a major reduction in SRP is deemed to be required, occasional monitoring of sedimentary phosphorus (interstitial water and sediment-bound fractions) should also be undertaken to assess changes in sediment quality.

It is recommended that a regular (annual or biennial) joint review of water quality status, trends and compliance within SSSIs and pSSSIs is undertaken by

English Nature and the NRA. This should involve a regular exchange of water quality data (from the NRA) and macrophyte data (from English Nature), so that full use is made by both parties of the information being gathered.

8.2 Monitoring to determine cause and effect

8.2.1 General

More information should be gathered concerning the relationship between phosphorus and macrophyte communities/species, in order to place standards on a sound ecological foundation.

A programme of focused and planned field monitoring should be undertaken to relate changes in macrophyte communities, on both temporal and spatial bases, to differences in environmental phosphorus levels (in both the water column and the sediment). This is the only way to ensure that macrophyte and water quality data of the appropriate type and quality are obtained whilst minimising the effect of, and collecting sufficient information on, all major confounding variables. When designing a monitoring programme, it should be remembered that changes in the macrophyte community (positive or negative) may take a number of years to become manifest, and the time series of water quality data used should reflect this.

The NRA has an extensive monitoring network which should be utilised fully when considering new monitoring for the detection of effects of phosphorus on macrophyte communities. It may be possible through negotiation to modify the NRA water quality monitoring programme as part of a collaborative programme of work, thereby reducing costs. Sites should be selected by agreement and water/sediment monitoring schedules defined.

Monitoring the effects of phosphorus on rare species in real systems is hampered by the patchy distribution of rarities. It is important that if such monitoring is undertaken, the species under scrutiny are locally abundant in the study area.

8.2.2 Detailed site comparisons

Care should be taken over the selection of monitoring sites for detecting impacts, since much can be done to eliminate the confounding effects of influencing variables other than phosphorus. For spatial comparisons, sites should be as similar as possible in all respects other than phosphorus concentrations. For temporal analysis at one site, efforts should be made to ensure that changes in environmental conditions (other than changes in phosphorus) are avoided where possible. Data should be collected on all major influencing variables (such as substrate type, turbidity, current velocity, depth and shading), to assess the extent to which they are likely to be responsible for observed community differences. A range of separate study areas will be necessary in order to encompass the full range of habitats encountered in the UK.

Suitable sites for monitoring effects would be immediately upstream and downstream of a phosphorus-laden discharge, where the habitat characteristics upstream and downstream are similar. Ideally, the input would be relatively clean with respect to other polluting substances; a high quality sewage effluent would probably be appropriate.

Opportunities for monitoring both detrimental effects and recovery will arise from riverine discharges where phosphorus-stripping equipment is to be installed. Phosphorus-stripping greatly changes phosphorus loads but has relatively minor effects on associated sanitary determinands. This allows the effect of reduced phosphorus loads on macrophyte communities to be studied in virtual isolation from other environmental changes, in addition to studying the response of the sediment reservoir. Detailed spatial comparisons (ie upstream and downstream) would be possible prior to phosphorus-stripping, as well as temporal monitoring of the recovery of downstream communities (relative to changes in upstream communities). As an initial step, a list of sites where phosphorus-stripping is planned should be drawn up in association with the NRA; this would include sewage treatment works identified under the EC Urban Waste Water Directive.

Further historical water quality data collection and macrophyte surveying is recommended at the sites identified in Section 5.4.1 and 5.4.2. as being worthy of further investigation.

8.2.3 Extensive spatial analysis

Collection of data from a wide range of sites, and subsequent analysis using multivariate statistical techniques, can be revealing **if information is gathered on all major influencing variables**. Since the variability in macrophyte communities due to factors other than phosphorus is great, it would be sensible to restrict environmental variation in certain ways in order to concentrate on the effects of phosphorus. This could be achieved by undertaking a separate analysis for different habitat types (perhaps NCC river types). A number of such analyses would be necessary in order to cover the range of conditions encountered, but the results would be habitat- or community-specific.

Care must be taken to identify all major factors influencing macrophyte distribution and quantify these in a standardised way in the monitoring process. This type of multivariate approach would allow the SRP tolerance ranges of different community types to be defined. More simply, the same data could be used to define tolerance ranges of individual species.

8.2.4 Macrophyte survey methodology

For future monitoring of effects (except for where temporal comparisons with historical data are to be made), a modified macrophyte survey methodology should be considered that is geared to cost-effective detection of effects. Although some information will be lost, the ability to detect changes would not necessarily be impaired by a shortened list of species or taxa that are relatively straightforward to identify. This list would be based purely upon instream species, perhaps targeted at those known or believed to be vulnerable and those that are rare. Reduced taxonomic penetration may be sensible for some taxa. Qualitative assessments of cover or relative abundance would be useful but need to be treated with caution when interpreting data, as they are prone to large measurement errors.

Surveyors should be compelled to score both presence and absence to ensure that species are truly absent from the site. For upstream/downstream comparisons, the same sampler should be used for both sites and, where possible, for consecutive years. Efforts should also be made to standardise on survey times, so that data from site-to-site or year-to-year is as compatible as possible.

Assessment at set transects along a river stretch should be considered, in order to provide quantitative estimates of abundance, cover and even biomass. This would afford greater sensitivity than presence/absence or relative abundance scoring, and would allow a rigorous statistical interpretation. However, such quantitative measures can give widely different results at a site depending upon the timing of the survey in relation to the stage of community succession (which may be advanced or delayed in any one year). It is therefore likely that repeat surveys through the summer would be necessary in order to ensure that results are fully compatible between sites and between years.

8.3 Other research requirements

Indirect approaches to determining natural (pre-cultural) environmental levels of phosphorus in UK rivers should be reviewed, in order to identify ways of assessing the true extent of contamination in SSSIs and pSSSIs on a case-by-case basis and thereby make a more informed judgement of the improvements required to achieve a natural trophic status. Approaches would include diatom analysis, consideration of catchment characteristics (particularly pedology and hydrology) and input modelling. Concerning modelling approaches, the utility of existing tools, such as WRc's model of eutrophication risk (MINDER) and the predictive model of lake nutrient loads developed at Liverpool University, should be appraised. An arbitrary decision would need to be made concerning the temporal baseline for such work, and this needs to be given greater consideration.

The data collected from the proposed programme of monitoring (see Section 8.2) should be analysed with a view to supporting and/or modifying the proposed phosphorus standards on the basis of ecological effects.

The collation of a more extensive historical water quality database focused on specific sites of interest where macrophyte data are known to be available, should be considered as a way of providing evidence of impacts in the shorter term.

A further use of historical data, not possible within the timescales of this project, would be the pairing of a large number of macrophyte and water quality sites in order to provide accurate "tolerance" ranges of SRP for different species, building on the work of Jeffries (1989). The accuracy of these tolerance ranges will increase with the number and range of sites involved in the analysis. This would be a valuable aid to the interpretation of macrophyte data when attempting to determine cause and effect.

Consideration should be given to the use of artificial streams, which can provide extremely uniform habitat conditions between treatments and are easily manipulated. However, it should be noted that such systems can be quite unstable, unless they are of a relatively large scale and well established, and are expensive in operation.

Investigations are required into the rate at which phosphorus is eliminated from river systems under varying environmental conditions. The scope for, and utility of, modelling the riverine phosphorus cycle as a whole needs to be given serious consideration.

Sedimentary phosphorus standards should be developed to act in tandem with SRP standards, in order to gain control over the riverine phosphorus cycle as a whole. It is recognised that much of the data required for sediment standards has yet to be collected, but would be obtained from the monitoring programme described in Section 8.2).

The availability of data on phosphorus half-saturation coefficients (see Section 2.5) for riverine algal and macrophyte "nuisance" species needs to be assessed, with a view to identifying SRP concentrations (in either the water column and sediment, depending upon the species) below which reductions in growth rate might be expected. If few data are available, new laboratory investigations should be considered with a view to building up a database of information on key species.