PHYSICAL ENVIRONMENT FOR RIVER INVERTEBRATE COMMUNITIES

NRA Anglian Region
Operational Investigation
A13–38A

UNIVERSITY OF LEICESTER
Ecology Unit
May 1991

NRA

National Rivers Authority

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

River Welland Environmental Survey

1 The current river channel was compared with historical evidence from 1:2500 Ordnance Survey maps. The upper river has been subject to progressive channelisation both recently (1968-1970 capital scheme) and before the Ordnance Survey (c. 1960). Some sections have incurred a 40 % reduction of channel length since the county boundary was established, with 6 % lost from the upper river as a whole. The channel lost through meander cut-off is that with the greatest diversity of flow and cross-section.

2 Macroinvertebrate family richness in the catchment was studied from existing BMWP survey data. The general tendency is for family richness to increase downstream. Tributaries typically have a higher richness for stream size than the main river; this may be bue to one or both of water quality and habitat availability. Other than chronic enrichment, pollution is rarely a problem in the catchment and there are no notable point sources other than Market Harborough STW.

3 The River Gwash and the 'Deepings' were identified as areas of special conservation value in the catchment. The River Gwash has a stable flow regime and high water quality, flowing off limestone and regulated at Rutland Water. The Deepings streams are protected from floods by the Maxey Cut flood relief channel and contribute with many local sand/ gravel pits to form an extensive area of aquatic features. The Eyebrook is another feature of special value, for its history of negligible management.

4 The physical substrates associated with riffles, pools and runs were sampled for macroinvertebrates. Biomass was ten times higher in riffles or pools than in runs. Runs had a greater proportion of highly productive families but the absolute biomass was only half that of riffles and pools. Assuming a 25:25:50 ratio of channel area between riffles, runs and pools, the effect of channelisation is to reduce macroinvertebrate biomass by 80 % and their secondary production by at least 50 %, or corresponding enhancements on restoration.

5 The distance between riffles on unmanaged rivers is correlated with channel width, which is in turn correlated with mean discharge. This project found that riffle spacing was correlated with discharge on the River Welland, where most of the rifles are those which have re-formed after dredging. The appropriate length for riffles was also correlated with discharge, albeit less strongly. This predictive capacity allows restoration which is most likely to be augmented rather than eroded by subsequent floods.

6 The macrophytes of the main river were surveyed at thirty sites. Trends in the distribution of species were revealed, against which the results of site surveys can be compared. A 'damage rating' (Haslam and Wolseley 1981) was calculated, which showed some short-lived effect of Market Harborough STW.

Functional habitat classification

7 Habitat-based conservation maanagement offers rapid surveys and immediate comparison of conservation and flood defence recommendations. The large number of aquatic macroinvertebrate species and our patchy knowledge of their individual habitat requirements means that the identity of important habitats must at present be determined empirically.

8 The identity of habitats important to the macroinvertebrate community was investigated on the River Welland.

- Forty-two 'potential habitats' were defined. Potential habitats were the combinations of flow and physical/macrophyte substrates which were distinct to the investigator.

- Samples were taken from several instances of each potential habitat on an 8.4 km study reach.

- Macroinvertebrates were identified to the furthest practical level, usually species.

- The samples were classified using a divisive hierarchical method (TWINSPAN, Hill 1979a). 'Functional habitats' were identified by stepping through the classification until samples from different habitats mixed between groups (AAABBBB to ABB and AABB).

- A final list of 15 functional habitats was suggested as a basis for site assessment.

9 The procedure was repeated on the River Wissey, with different water quality and enginnering history. The final list included 15 functional habitats, which were comparable with those obtained on the River Welland. The importance of proper 'replication' of each habitat was stressed, taking samples from a range of instances rather than from the same site.

10 Biological and habitat surveys were carried out on the River Kym, which lacks riffle-associated habitats due to successive impoundment by weirs and bridge foundations. The results of the biological survey were exactly predictable from the Welland results, given knowledge of the habitat status of the river. Explicit biological data were not used in forming recommendations for conservation management of the Kym, so the habitat survey (one working day) proved an acceptable surrogate for the biological survey (15+ working days, including species identification).

11 The assessment of channel conservation value can be carried out at habitat level, with considerable economic benefit. Recommendations for restoration of degraded channels can be readily made in a form comprehensible to all professionals involved. A draft methodology for using functional habitats in conservation management is given in the Recommendations section of this report.

RECOMMENDATIONS

River Welland

Specific recommendations for management of the River Welland are given in the main text of this report (Sections 1.7, 2.5, 3.5). Four main areas were identified as important to the conservation value of the river and are summarised below:

1. Preservation and enhancement of the riffle system. Rivers with extensive series of riffles and pools are not common in Anglian Region, due in part to their naturally-low gradient and in part to canalisation or serial impoundment. The Welland is the least affected in both these respects but prior channel modification has compromised the riffle system in some places.

2. Enhancement of margins. The 1968-1970 flood alleviation scheme which set the current character of the margins did not have regard for physical diversity. The margins are an important source of conservation interest and their development should be actively encouraged. In many places, the reinstatement of a marginal shelf may be the first priority for conservation enhancement.

3. Riparian vegetation. The effectiveness of the lowland river corridor as a conservation feature is greatly enhanced by the presence of trees. Inhibition of aquatic macrophyte growth by shading improves channel capacity. The status of riparian trees along the Welland should be investigated and enhanced, with benefit to both conservation and channel maintenance.

4. Chemical water quality. The aquatic flora of the river is dominated during the growing season by *Cladophora glomerata*. This greatly reduces the abundance and diversity of other plants, important to conservation both in their own right and as habitats. Eutrophication, the cause of *Cladophora* overgrowth, is an issue which should be addressed fully if proper benefit is to accrue from this and other R & D projects.

Functional habitat methodology

Some specific recommendations relating to functional habitats are made in the main text of this report (Sections 5.5, 6.5, 7.5). General procedures are described here for determination of the functional habitat set of a catchment; and the subsequent use of functional habitats in site assessment. Reference is made to locations in the main text for further information.

Decide the scope of the functional habitat procedure within the catchment. The method should only be applied to the part of the catchment for which underlying trends in physical conditions and macrophyte distribution are known, or will be obtained. Then irrelevant conclusions from subsequent site assessment (liverworts absent from the lower Thames) will not lead to inappropriate recommendations (encourage the liverwort flora of the lower Thames).

The first stage of the method is a 'once-only' determination of functional habitats for the catchment, which is described below with reference to sections of this report.

1. Compile a full list of 'potential habitats'. Potential habitats are the combinations of flow and physical/macrophyte substrate which are distinct to the investigator (examples Section 5.2). It may be most efficient to use existing biological data to identify the sites with highest species richness and visit these in the first instance.

2. Take samples from several instances of each potential habitat. The purpose of replication is to ensure that the full 'within-habitat' species variation is represented in subsequent data (discussed Section 6). Samples are intended to be equivalent quantitatively although taken by a range of methods. Decisions will often be made intuitively – in the fieldwork for the current project we took a pondnet-full of submerged macrophytes, a riffle substrate core of 12-cm radius, etc.

3. Identify all macroinvertebrate types in each sample to the furthest practical level (examples Sections 5.2, 6.2). We found that chironomids were important in the classification; they were identifiable to genus in most cases with practice but no prior experience.

4. Classify the samples according to their species composition using TWINSPAN. The options which were used in the current project are shown in Sections 9 and 11 of the Annex to this report. Functional habitats are identified by stepping through the classification until replicates between habitats mix, or until only one habitat is represented (method Section 4, application Sections 5.3, 6.3).

5. Consider the list of functional habitats critically. There may be some which although separate in the classification, do not contribute positively to a list of habitats for active conservation. *Potamogeton lucens* was originally identified as a functional habitat on the River Welland but was distinguished by species absence alone. Gravels above and below riffles bore distinct sets of species but would not figure separately in recommendations for enhancement.

This schedule does not describe how to choose a 'study reach' for sampling. During development of the method, limited study reaches were used (Sections 5.1, 6.1) – but if habitat distribution trends are properly considered when drawing conclusions from site assessment, there is no such limitation to the initial survey. The richer sites identified in point 1 above will be a preferred starting point, while sites with known or suspected water quality problems should be avoided.

The second stage of the method is the application of functional habitats in site assessment. In reactive surveys, the impact of channel modification on macroinvertebrate richness will be anticipated. When considering enhancement measures, the procedure will identify key habits which are absent or poorly-represented. A possible procedure for site assessment is described below.

1. Determine whether the method is appropriate. Functional habitat management is an efficient means of obtaining species richness but some sites are of high conservation status due to the presence of individual species or communities. The management of such sites should continue to address the specific requirements of target species.

2. Review the management history of the site and reports from previous biological studies and river corridor surveys. If the site investigation is reactive then obtain details of the proposed work; if strategic then make sure that potential threats and the resources available for enhancement are known.

3. Obtain large-scale maps of the site. The 1:2500 series Ordnance Survey should be available in-house or from HMSO. Note that these surveys were carried out in the 1960s. Updated plans may be available in connection with past channel modification or if the survey is in reaction to proposed engineering.

4. Survey the site, making note on the maps of each functional habitat. There may be features of special relevance, given the information collected in point 2 above.

5. The form and scope of recommendations will clearly depend on the reasons for the survey, but the underlying objective should be to achieve maximum representation of the functional habitats. Important habitats of unusual extent or frequency may confer a benefit to the catchment which outweighs the need for local habitat richness.

The same set of functional habitats cannot be applied to all parts of all rivers. National river classifications based on macrophytes have identified groups of sites defined by similar relief and geology. If the appropriate habitat set for a river can be predicted from such readily-available information, this will reduce the number of times that the first stage described above has to be carried out; and so make the functional habitat approach an attractive national strategy. The possibility of knowing habitat sets for river types rather than individual rivers is currently being researched.

Methods of assessing chemical water quality through macroinvertebrate data continue to become more sophisticated. Precise predictions can be made of what should be living in a river, which allows the detection of detrimental agents. Macroinvertebrates have habitat requirements which can be as limiting as their water quality requirements, so the 'detrimental agent' may be wholly or partly a lack of habitats. The role of functional habitats is being investigated in relation to water quality, so that the precision of predictive tools such as RIVPACS is more fully used.

Detailed taxonomic identification is important to the determination of valid functional habitats. Specialist knowledge probably exists among in-house biologists but at present each investigator would have to become widely proficient or use an external contractor. The location of specialist skills, and a mechanism for 'commissioning' between regions would further the consistent, accurate typing of biological specimens in this and other contexts.

INTRODUCTION

Rivers and their associated 'corridors' (Eckstein 1984) are an established focus for conservation interest in England and Wales. In lowland areas they are often the only sites of significant wildlife value in an otherwise bleak landscape (Holmes 1981); and the National Rivers Authority is in a strong, recognised position to promote their conservation.

Rivers are permanent features which encourage ecological richness through the availability and physical action of water. These attributes also mean that in a developed landscape the need for physical management of many rivers is essential and continuous. Changes in land-use often require alterations to channel design, whilst a periodic need for channel maintenance remains as the legacy of past decades' major channelisation works (Brookes *et al.* 1983, Coles *et al.* 1989). Weedcutting is also carried out on many rivers to maintain channel capacity (Westlake and Dawson 1982) and for amenity purposes. Against this background of a considerable biological resource – and disturbance of that resource – accurate, concise, conservation recommendations are needed by river managers in Britain for several reasons:

1) A series of Acts of Parliament and parliamentary Select Committees have given the river authorities (at present the National Rivers Authority and Internal Drainage Boards) ever-stronger duties and powers to promote nature conservation (Hellawell 1988, Anon. 1989). This requires information about conservation priorities and methods.

2) Future European Community Directives on ecological quality will require a unified approach to conservation and water quality issues. If quantitative ecological objectives are to be defined, met and maintained, then similarly quantitative and goal-oriented methods for conservation assessment must be employed.

3) Public opinion is increasingly unsympathetic towards development works such as river engineering, where they do not harmonise with the environment (Shoard 1980, Williams and Bowers 1987) – many river engineers share this opinion and require information to become good conservationists.

4) Engineers are re-discovering that river management which encourages natural development of the river can be economic in terms of both capital works outlay and subsequent maintenance costs. An ecological input to the planning stage of river works is therefore now regularly sought (Gardiner 1988).

5) The resources available for conservation enhancement measures, including the mitigation of historic damage, are now considerable. The demands placed on accuracy of ecological information for enhancement are greater than those for reactive surveys.

In the United Kingdom, ecologists have been involved in river management for almost a century. Most emphasis was initially placed on water pollution control (Carpenter 1928, Butcher *et al.* 1931, Hynes 1960) followed by the maintenance and development of fisheries (Hartley

1947, Le Cren 1958). Attention has also more recently been given to the conservation of running-water ecosystems in their own right (Morgan 1972), particularly in the face of engineering alterations (Newbold *et al.* 1983).

Macroinvertebrates have been the basis for a series of methods for the biological assessment of river water quality. Biotic score systems, which employ the differing tolerances of invertebrate groups to organic pollution, have been developed and improved (Woodiwiss 1964, Chandler 1970, Chesters 1980, National Water Council 1981, Armitage *et al.* 1983). Sensitive, high-scoring groups belong to communities more characteristic of upland river conditions, which leads to biological misclassification of clean lowland rivers as polluted (Jones and Peters 1977). For this reason, biotic scores can be used as a relative measure between years, or between neighbouring sites; but their use as an absolute measure or to set 'targets' in the context of water quality must take account of the influence of environmental conditions on species composition.

The River Invertebrate Prediction and Classification (RIVPACS) methodology (Wright *et al.* 1989) estimates the macroinvertebrate fauna to be expected at a site from a set of environmental variables; and this can then be compared with results from one or more seasons' sampling. Shortfalls in the actual species list may reflect poor chemical water quality, or may be due to environmental conditions at the site. The set of variables used to predict species presence includes 'continuous' measures such as channel dimensions and streambed particle size; but does not allow for the richness of specific habitat resources, including macrophytes. Simple measures of habitat richness have been included in the interpretation of biotic indices (Extence *et al.* 1987) and more detailed habitat investigations are being carried out at a subset of the sites used in the RIVPACS database (Wright *et al.* in press).

Macroinvertebrates remain the basis for biological assessment of water quality: the increasing need for accuracy towards the maintenance of quality targets means that information on their habitat preferences is a priority for research.

The ecological approach to river conservation management has developed more recently along similar lines as the approach to water quality control. It also was based initially on chemical criteria (Barnden 1984) but its importance has grown through the realization that particular rivers and river zones have ecological richness and rarity value (Ratcliffe 1977). Two problems were the lack of detailed national information to provide a context for site characteristics and the unsuitability for rivers of existing survey methods (Hattey 1977).

Classification schemes have been developed which enable sites to be viewed in a national context, recognising those which are of particular importance. The most widely-used classification is based upon aquatic vascular plants (Holmes 1989), which reflects their relative ease and speed of identification (Holmes 1983) and a considerable knowledge of their ecology (for example, Haslam and Wolseley 1981, Haslam 1982). The Waterways Bird Survey carried out annually by the British Trust for Ornithology using a standard methodology (Taylor and Murray 1982) and surveys by the Royal Society for the Protection of Birds provide a considerable database for breeding birds. RSPB surveys often consider in addition birds associated with the watercourse but not breeding. The database used in the RIVPACS project provides both a national and river-type context for macroinvertebrate site results (Wright *et al.* 1989).

The information provided by biological monitoring of water quality and by fisheries survey programmes was inadequate for conservation purposes. In the past decade the concept of a unified method of 'river corridor' surveys has been developed (Brooker 1982, 1983, Eckstein 1984) and a general methodology (Nature Conservancy Council 1985) acts as the basis for survey procedures. River corridor surveys have often been carried out as a matter of policy prior to any river management; and the information is incorporated into detailed site plans or maintenance schedules (Ash and Woodcock 1988). Programmes for fuller coverage of main river have been initiated, such as the NRA Anglian Region 'Rivers Environmental Database'.

The interests of conservation can now be effectively integrated into river management in a qualitative manner. The information generated by corridor surveys has helped conservationists in the water industry to make consistent, meaningful recommendations to engineers (for example, Barham 1990). General principles can also be formalised in 'codes of practice' – the ecological guidance of people whose work has an impact upon the river environment (Water Space Amenity Commission 1983, Newbold *et al.* 1983, Lewis and Williams 1984, Andrews and Williams 1988). There has been a difficulty in making quantitative ecological information similarly accessible to those involved in formulating river management.

Ecologists and river engineers have looked at the river in different ways: ecologists talked in terms of species names while engineers dealt in quantitative characteristics of river channels and flows. Recently, practitioners of both disciplines have tended to develop awareness of each other's methods and objectives. Engineering works have a direct mechanical effect on the flora and fauna which should be addressed where rare or sensitive species are present. The indirect influence through modification of physical habitat features is more pervasive, but by the same token is the most realistic method for conservation enhancement. Physical features have been considered individually in river corridor surveys (Coles *et al.* 1989) but this has not taken account of their frequency on semi-natural river channels. Geomorphological assessments consider a range of channel characteristics, but discuss the direct biological implications of channel design briefly, if at all (Brooks in press). The appropriate frequency of physical features is important to both the conservationist (as optimum habitat) and the engineer (as a characteristic of stable channel design) and as such, needs to be addressed by both as a prerequisite of satisfactory river management.

The first phase of the current project studied the River Welland in the east midlands of England – a lowland river typical of those which have a history of engineering management. The immediate objective was to provide information for habitat conservation management, especially with regard to aquatic macroinvertebrates. This would complement a concurrent study of fish habitat requirements (Smith 1989) and the existing policy of river corridor surveys prior to engineering work. Attention was focussed on non-macrophyte substrates; as being both the most consistent features of the river and the features most predictably affected by engineering works.

The use of habitat assessment in place of detailed biological surveys (Brooker 1983) is attractive in terms of both relevance (to divers species groups) and cost; but has been criticised on the grounds of a lack of information on habitat/wildlife relationships (Eckstein 1984). There has been considerable progress in the availability of information for many groups of plants and animals, where the importance of habitat has been emphasised (for example, Dawson and

Haslam 1983). The second phase of the current project addressed the full range of aquatic macroinvertebrate habitats, with three linked objectives:

1) To determine the range of 'functional habitats' on the River Welland which are distinct in terms of their associated macroinvertebrate species.

2) To assess the extent to which the list of functional habitats is reproduced in a different catchment.

3) To investigate the macroinvertebrate community on a heavily-modified river in the context of known effects of management on habitat availability.

RIVER WELLAND ENVIRONMENTAL SURVEY

The first phase of the project, as the 'River Welland Environmental Survey' aimed to provide objective information for conservation management of the River Welland, with particular regard to the habitats of aquatic macroinvertebrates. The study was of four main parts –

1. Catchment study – an overall assessment of existing biological data and the state of the river.

2. Non-macrophyte substrates – a quantitative study of major physical features and their associated macroinvertebrates.

3. Macrophyte survey – a general survey of the aquatic macrophytes of the catchment.

4. Habitat classification pilot study – a feasibility study with regard to determining a full list of aquatic macroinvertebrate habitats.

1. CATCHMENT STUDY

1.1 Introduction

Rivers such as the Welland are for the most part unremarkable in terms of site uniqueness or species rarity; but are nonetheless an important conservation resource. The stream network provides a considerable linear conservation feature in the landscape, with a continuum of environmental conditions which as a whole supports considerable biotic diversity. A general appraisal of the history and current state of the River Welland was carried out to enable the consideration of other results in the context of the whole catchment; to help select the appropriate sites for further studies; and to identify features of special conservation interest.

1.2 Channel length

There is a natural tendency for most alluvial river channels to meander. The River Welland has a wide flood plain in its middle reaches across which the channel would naturally tend to swing. Both historical and recent management has involved the removal of meanders and consequently a reduction in the length of river channel present in the Welland valley. Recent engineering has had the explicit objectives of land drainage improvement and flood relief. Past alterations would have been piecemeal encouragement of meander cut-offs and the development of mill channels.

The magnitude of channel loss on the main river was investigated using 1:2500 Ordnance Survey maps. These showed the course of the river when the county boundaries which followed the course of the channel were established; and at the time of the Ordnance Survey, which is shown on the maps. Meanders were removed more recently at many places on the Welland during a major capital improvement scheme carried out during 1968/69. The river was surveyed on foot to update channel records with respect to this and other recent works. Settlement of the original backfill in meanders leaves a distinct depression, particularly where a deep pool occurred. An example of the information from the survey is given for a stretch at Ashley (Figure 1.1). Place names used here and elsewhere in this report are located on the map which forms Appendix A.

The length of main river between Market Harborough and Rockingham was 28.9 km when the county boundary was established. The Ordnance Survey maps show reduction to 26.1 km by the early 1960s and the capital scheme removed a further 1.9 km of channel length. From Rockingham to Duddington recent alterations have been fewer, involving a reduction from 24.3 km to 23.8 km prior to the Ordnance Survey and no loss thereafter. A six percent reduction of channel length has been made over this upper section as a whole during recent years.

The full scale of historical straightening is much greater. The Ordnance Survey maps show that many sections defining the county boundary had been subject to straightening of which no positive evidence remained at the time of the Ordnance Survey. In places such as Thorpe where the land has usually been used for pasture, the tortuous routes of several old channels are still evident. Sections not apparently affected by straightening prior to definition of the county

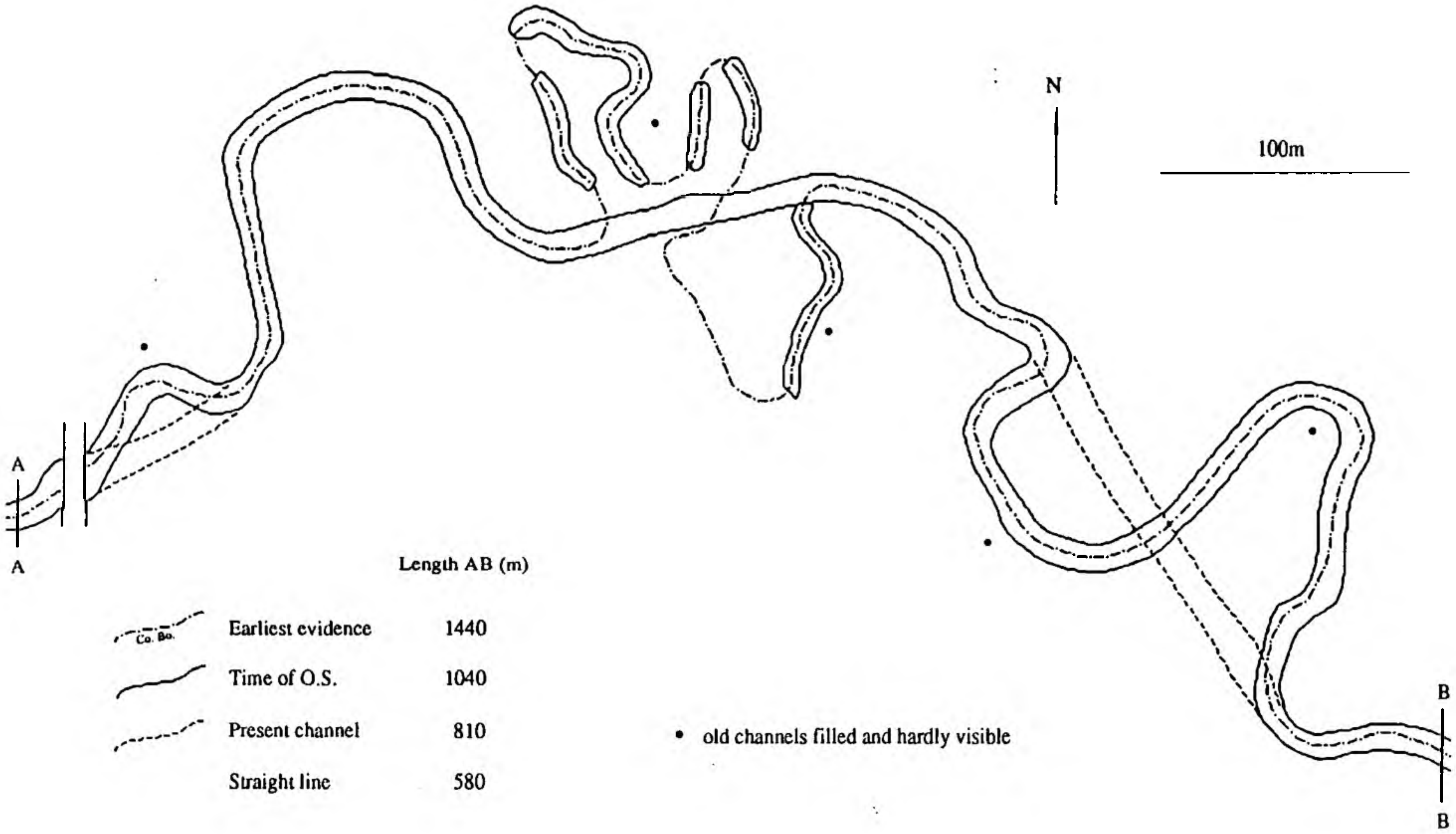


Figure 1.1 Channel loss on the River Welland at Ashley (SP 79 91)

boundary, such as the reach at Ashley, show a loss of channel to date exceeding 40 %. The impact has not been that of radical channelisation; but the losses were always of sites with considerable habitat richness, that is the most incised meanders with well-formed pools and asymmetrical cross-section.

Between Duddington and Tinwell the adjacent land becomes steeper and there is not the wide floodplain characteristic of the middle reaches. No evidence of channel loss due to straightening was seen either in the Ordnance Survey or from the field survey. Whilst wandering of the river channel on a large scale is not possible there are short sections which meander quite tightly. The major effect of the 1969 capital scheme in this section was not loss of channel length, but loss of adjacent wet habitats due to improved drainage and subsequent change to arable crops, documented by natural historians such as Messenger (1971).

At Ketton Sewage Treatment Works there is a high-flow channel which pre-dates the Ordnance Survey of the early 1960s. Such channels are being used currently as a conservation feature of engineering works, preserving the low flow channel through meanders whilst routing storm discharge in a straight line. These have been used individually, as at Ashley gauging station; and serially on previously unstraightened stretches such as the Chater downstream of Lyndon.

The third-order tributaries of the Welland are typically unstraightened, except for lower reaches which lie within the floodplain. Most main river is designed to the same specification as the Welland mainstream, with steep banks and little margin. An important exception to this rule is the Eye Brook above Eyebrook Reservoir, which has not been managed systematically. Smaller streams have been enmained and engineered only when they affected specific construction projects or estates. Since these are few in the catchment, so the physical management of first and second-order streams has been rare.

1.3 Macroinvertebrates

The macroinvertebrate community has been monitored regularly by the water authorities at a large number of sites. The information was collated to provide an overview of trends in macroinvertebrate composition through the catchment.

As a rule the samples have been taken in and around riffle areas near road bridges and sorted in the field to family level, for the determination of biotic indices of water quality. Data gathered routinely during the period 1980-1986 are reproduced as Section 1 of the Annex to this report, and summarised in Figure 1.2. For most sites only results between July and September have been considered, since this is the period during which sampling was most often carried out and allows the best comparison between sites. The River Gwash data were mainly obtained during April and because of the lower seasonal variation all results have been used.

The main trend in species richness, as reflected in BMWP scores, is an increase with stream size (Figure 1.3). This was attributed mainly to the effect of habitat availability by Ferguson (1980a), who included a measure of habitat diversity when interpreting the biotic score results in a water quality context.

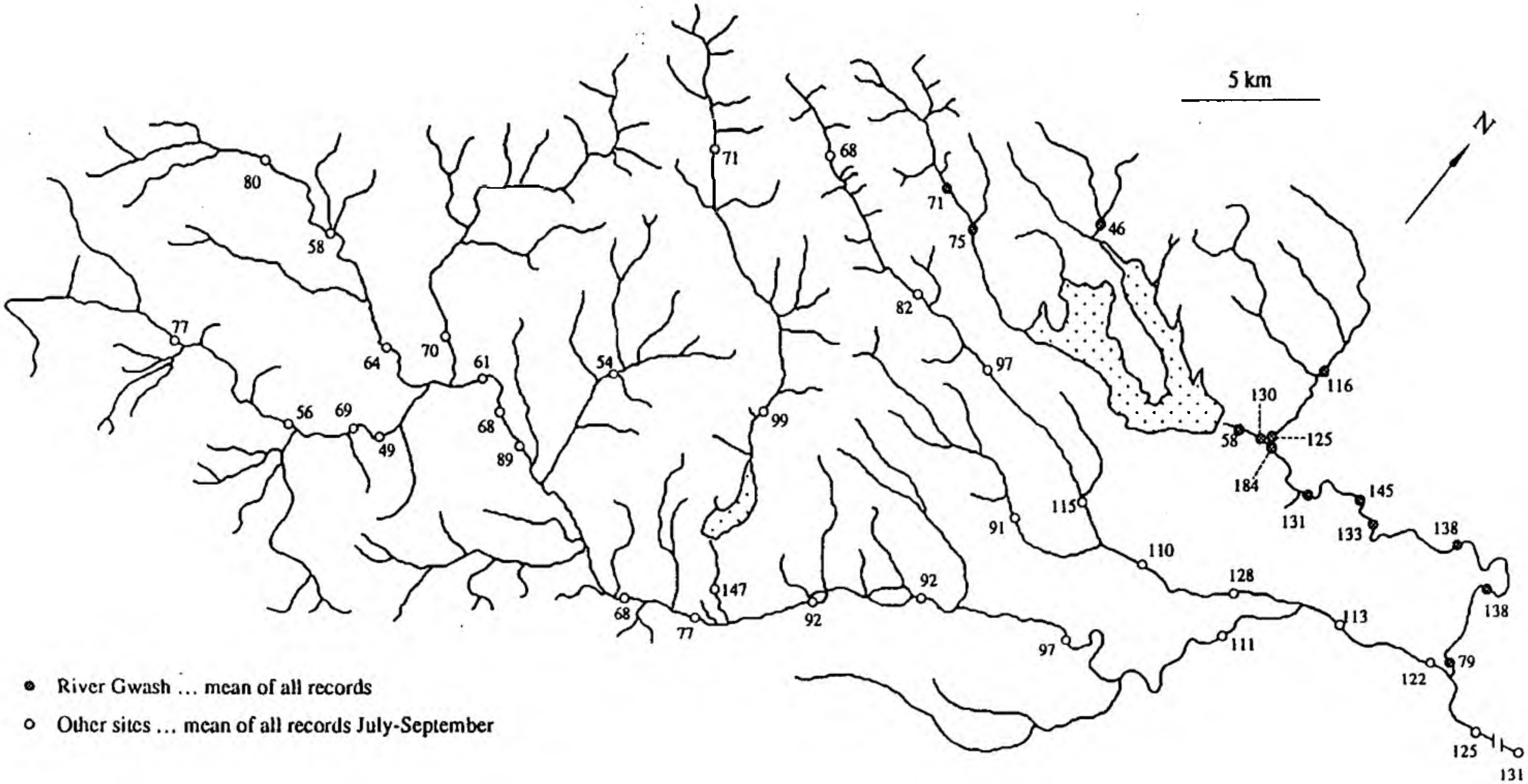


Figure 1.2 Water authority BMWP scores during the period 1980-1986

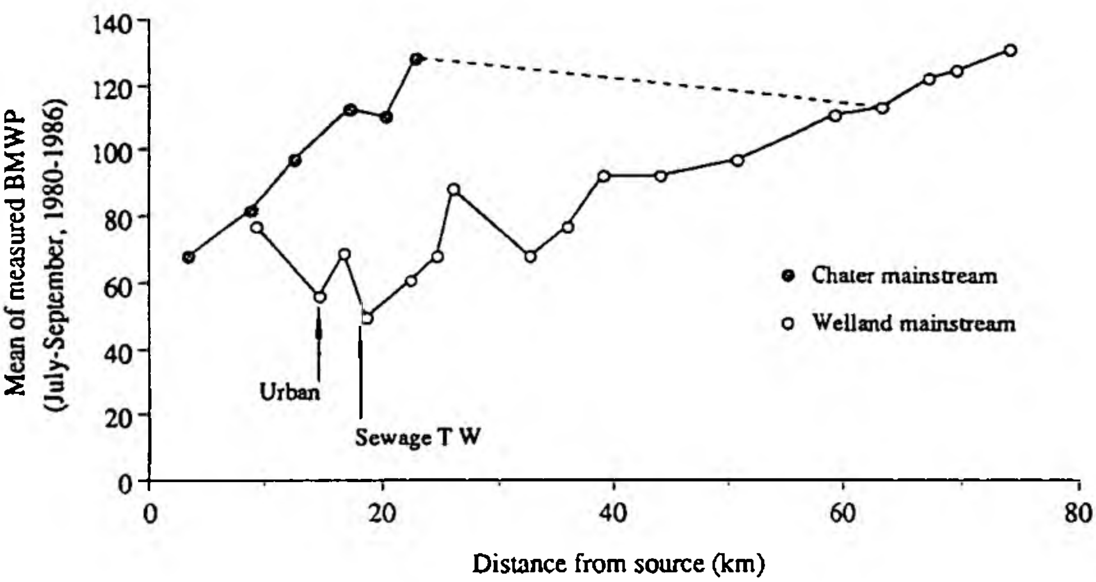


Figure 1.3 Water authority BMWP scores with distance from source

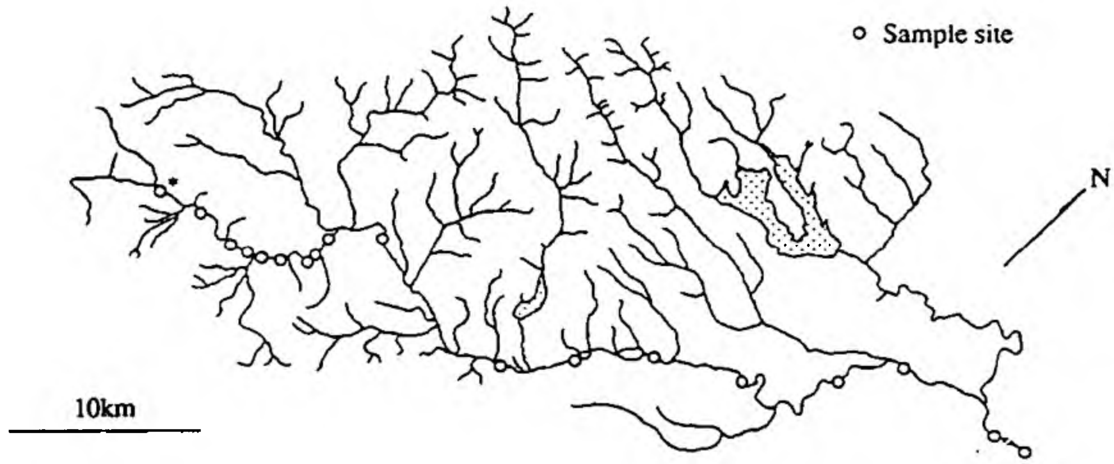
The only major urban area is at Market Harborough. Here the channel is widened and deepened for flood relief and receives considerable surface run-off. The sewage works downstream from the town has historically had an effect on the macroinvertebrate fauna as far downstream as Barrowden or beyond. A gradual improvement in the effluent from the sewage treatment works since 1979 was furthered by the commissioning of a new works in 1982, since which the fauna has recovered within a short distance from the works (Barham 1983 and see Figure 1.3).

In July 1980 an organophosphorus pollution in the vicinity of Great Bowden affected the macroinvertebrates as far as Collyweston (Ferguson 1980b); but acutely-felt point discharges of pollutants on this scale are rare. The main Welland has a lower species richness for stream size when compared with its tributaries such as the River Chater (Figure 1.3). This may well be due to the chronic effects of Market Harborough and its sewage treatment works, compounded by enrichment from agricultural run-off in the floodplain. Most parts of the tributaries have also been engineered to a lesser design, if at all.

During 1986 and 1987 a sampling programme was carried out by Anglian Water Authority at 18 sites on the upper Welland (Figure 1.4) and two on the 'wide Welland', using the methods employed in routine monitoring. Results for the 10 dates are given as Section 2 of the Annex to this report; and the total occurrence of 53 families at the 18 upper sites is shown in Table 1.1. These most recent results indicate that family richness is greatest from Weston (site code 10) downstream and that the richest site at one time is most likely to be Collyweston (site 15) or Uffington (site 17). Reference to the data from individual months emphasises the latter result for late summer sampling.

Table 1.1 Total occurrence of macroinvertebrate families at 18 sites on the Welland mainstream over 10 sampling occasions in 1986-1987 (Anglian Water data)

Family	Sites (site codes described in Figure 1.4)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Planariidae			X			X	X	X	X	X		XX		XX		XX		XX
Dendrocoelidae	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	
Oligochaeta	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Piscicolidae							X	X	X	X		X	X	X	X	X	X	X
Glossiphoniidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Erpobdellidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Asellidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gammaridae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Astacidae																X		
Baetidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Leptophlebiidae		X			X		X			X		X	X					
Ephemerellidae	X		X								X	X	X	X	X	X	X	X
Ephemeridae															X			
Caenidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Taeniopterygidae													X	X				
Nemouridae	X		X		X	X			X	X		X		X				
Leuctridae	X																	
Coenagriidae					X	X				X	X	X	X	X	X	X	X	X
Agriidae										X	X			X	X	X	X	
Sialidae	X										X							X
Rhyacophilidae																	X	
Polycentropodidae														X		X	X	
Hydropsychidae		X					X	X	X	X	X	X	X	X	X	X	X	X
Hydroptilidae									X		X	X	X	X	X	X	X	X
Limnephilidae					X					X	X	X		X			X	
Leptoceridae		X								X	X	X	X	X	X	X	X	X
Sericostomatidae														X	X			
Phryganaeidae																	X	
Elminthidae	X	X			X	X	X			X	X	X	X	X	X	X	X	X
Haliplidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dytiscidae	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gyrinidae	X										X	X						
Hydrophilidae	X	X	X	X	X	X	X	X		X	X		X	X			X	
Curculionidae																		X
Hydrometridae										X		X	X		X		X	X
Nepidae												X						
Corixidae		X		X			X	X	X	X	X	X	X	X	X	X	X	X
Gerridae	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X
Notonectidae	X			X		X				X	X	X			X	X	X	X
Aphelocheiridae																		X
Tipulidae	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	
Simuliidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Chironomidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Unionidae														X				X
Sphaeriidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Neritidae														X	X	X	X	X
Valvatidae			X	X	X							X	X	X	X	X	X	X
Hydrobiidae	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Lymnaeidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Physidae	X		X	X	X	X		X		X	X	X	X	X	X	X	X	X
Planorbiidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ancylidae	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Total	28	24	23	23	26	26	26	24	24	33	34	36	34	39	36	34	34	32
.ean (10 occassions)	11	13	10	9	10	14	12	11	11	17	17	23	23	25	26	20	27	22



- code numbers in Table 1.1 refer to these sites, starting upstream *

Figure 1.4 Eighteen sites sampled by Anglian Water Authority in 1986/87

1.4 Engineering history

The general state of the River Welland mainstream was set by a capital flood defence scheme carried out in 1968-1970. The channel from Stamford up to Market Harborough was designed to protect for a 1-in-50 year flood event. Minor maintenance was carried out in the mid-1970s and the current programme of 'rolling' maintenance began in the 1980s. This scheme involves visits to shorter sections approximately approximately every five years, which has considerable biological advantages over less frequent major dredging. Only light intervention is required at each visit, while neighbouring fallow sites are able to provide recolonisation.

Systematic records of the times and places where maintenance engineering took place were not available. The district managers and their engineers were able to provide some information on recent work before this project, which is listed in Table 1.2.

The biological survey data had shown that either Collyweston or Uffington were most suitable as sites for later studies which required a rich fauna. Collyweston was superior on the basis of its less recent dredging, which was also known to have been lighter. In addition, the Collyweston site offered a long stretch of similar river while the character of the Uffington reach changes rapidly.

1.5 The Deepings

The section between Tallington and the start of the wide river at Peakirk comprises an extensive area of diverse aquatic features. Within an area of 50 km^2 there are 28 km of river channels, 46 flooded sand and gravel workings of various ages and a network of minor channels and drainage ditches (Figure 1.5).

Table 1.2 Engineering history of the Welland, anecdotal records 1981-1987

Scope	Timing of work
Upstream of Stamford	
Rockingham Bridge → Gretton Siphon	Early 1983
Collyweston downstream	May/June 1984
Collyweston upstream	July/August 1984
Duddington upstream	September/October 1984
Great Easton	November/December 1984
Duddington (continued)	December 1984
Greene Road → Langton Brook	November 1985
Barrowden → Harringworth	1985/1986
Market Harborough	April 1986
Some sites following helicopter survey	1986
Downstream of Stamford	
Deeping Gate → Folly River	1985/1986
Gwash confluence → Uffington Bridge	Winter 1986/1987
Maxey Cut capital work	1986/1987
Stamford Town	Yearly weedcutting
Tallington → Spalding except Maxey Cut	Yearly weedcutting
'Wide Welland'	
Folly River → Crowland Bridge	1981/1982 (possibly 1982/1983)
Near tidal	1982/1983, 1985/1986 'and soon'
Far tidal	No dredging, capital bankwork as required
Welland House → Fossdyke	Stone riprap 1984/1985

Construction of the Maxey Cut bypass to effect flood relief through the residential Market Deeping area has meant that the flow of the mainstream is more characteristic of spring-fed rivers (Figure 1.6, data as Section 3 of the Annex to this report). Another result is that with a more relaxed design, engineering works in the river channels themselves have usually been restricted to weedcutting and light channel maintenance. Consequently both the habitat and biological status of this section of the Welland system are of a standard rarely found on the main river upstream. The undisturbed nature of the Deepings channels is reflected in the abundance of *Aphelocheirus aestivalis*, a water bug. This is flightless and since it is found nowhere else locally, would be sensitive to disturbance of its riffle habitat.

1.6 River Gwash

The catchment of the River Gwash, which enters the Welland at Stamford, has a different geology to that of most of the River Welland, being of limestone rather than clay. A large contribution of groundwater to the flow produces less enrichment and a more stable flow regime. The impoundment of a large part of the catchment in 1975 to produce Rutland Water further reduced the tendency to spates of the mainstream (Figure 1.7, data as Section 4 of the Annex to this report).

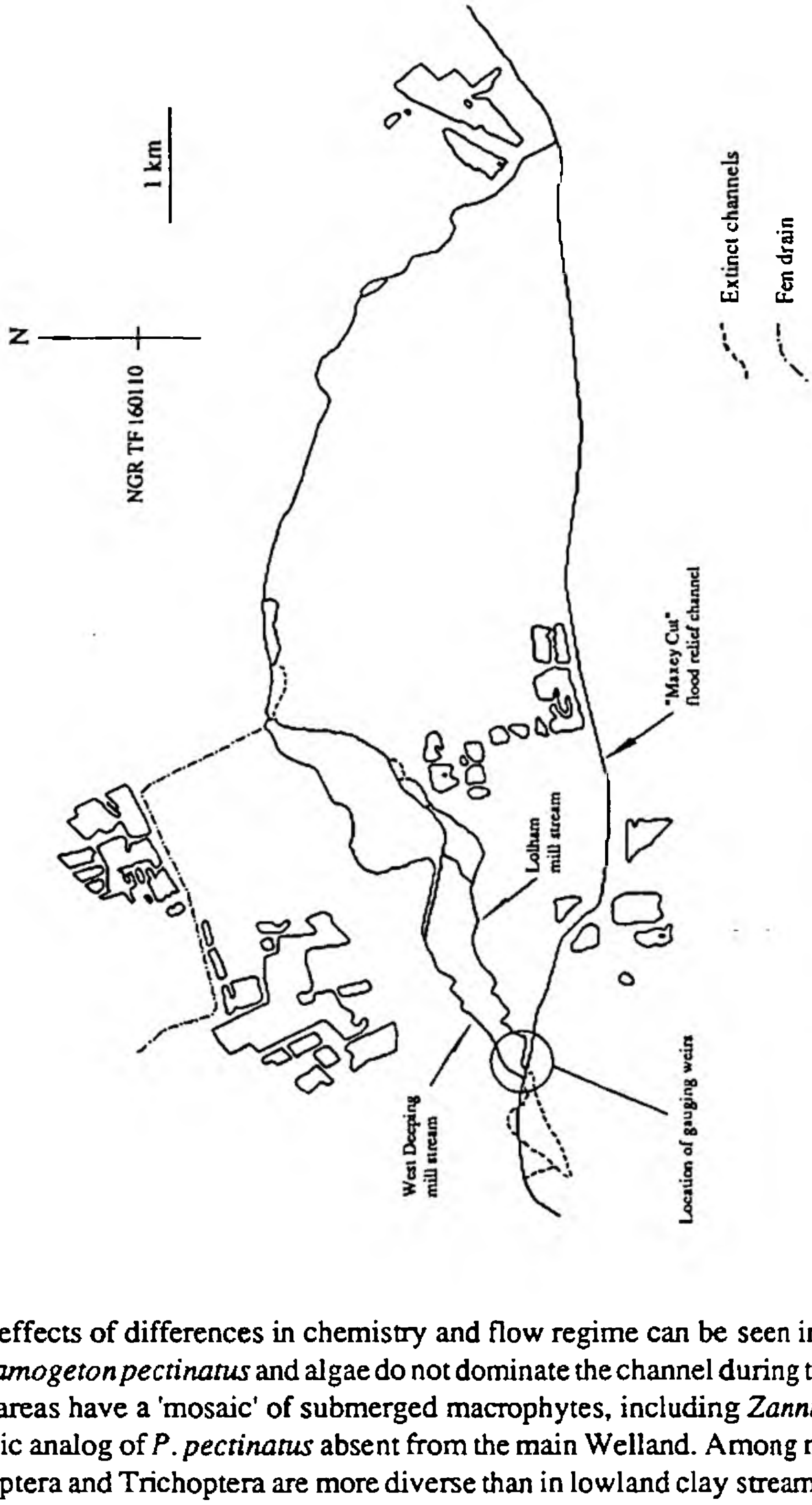


Figure 1.5 River channels and standing water in the "Deepings" system

The effects of differences in chemistry and flow regime can be seen in both the flora and fauna. *Potamogeton pectinatus* and algae do not dominate the channel during the summer months. The riffle areas have a 'mosaic' of submerged macrophytes, including *Zannichellia palustris*, a mesotrophic analog of *P. pectinatus* absent from the main Welland. Among macroinvertebrates, both Plecoptera and Trichoptera are more diverse than in lowland clay streams of the region. The river is a successful trout fishery and maintains a stock of grayling, which are restricted elsewhere in the region to other streams of good water quality such as the upper River Ise.

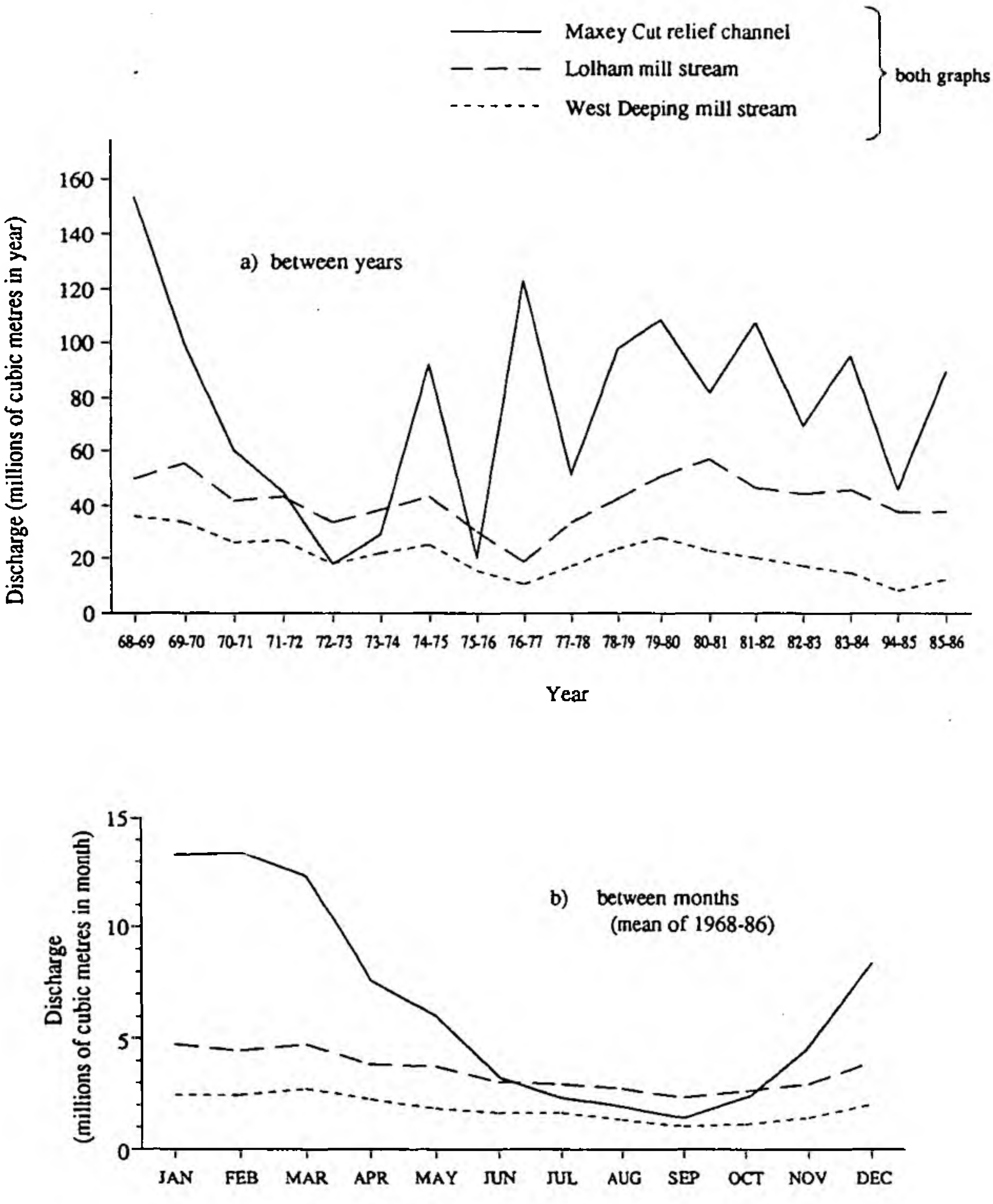


Figure 1.6 Discharge at three stations in the Deepings system during 1968-86

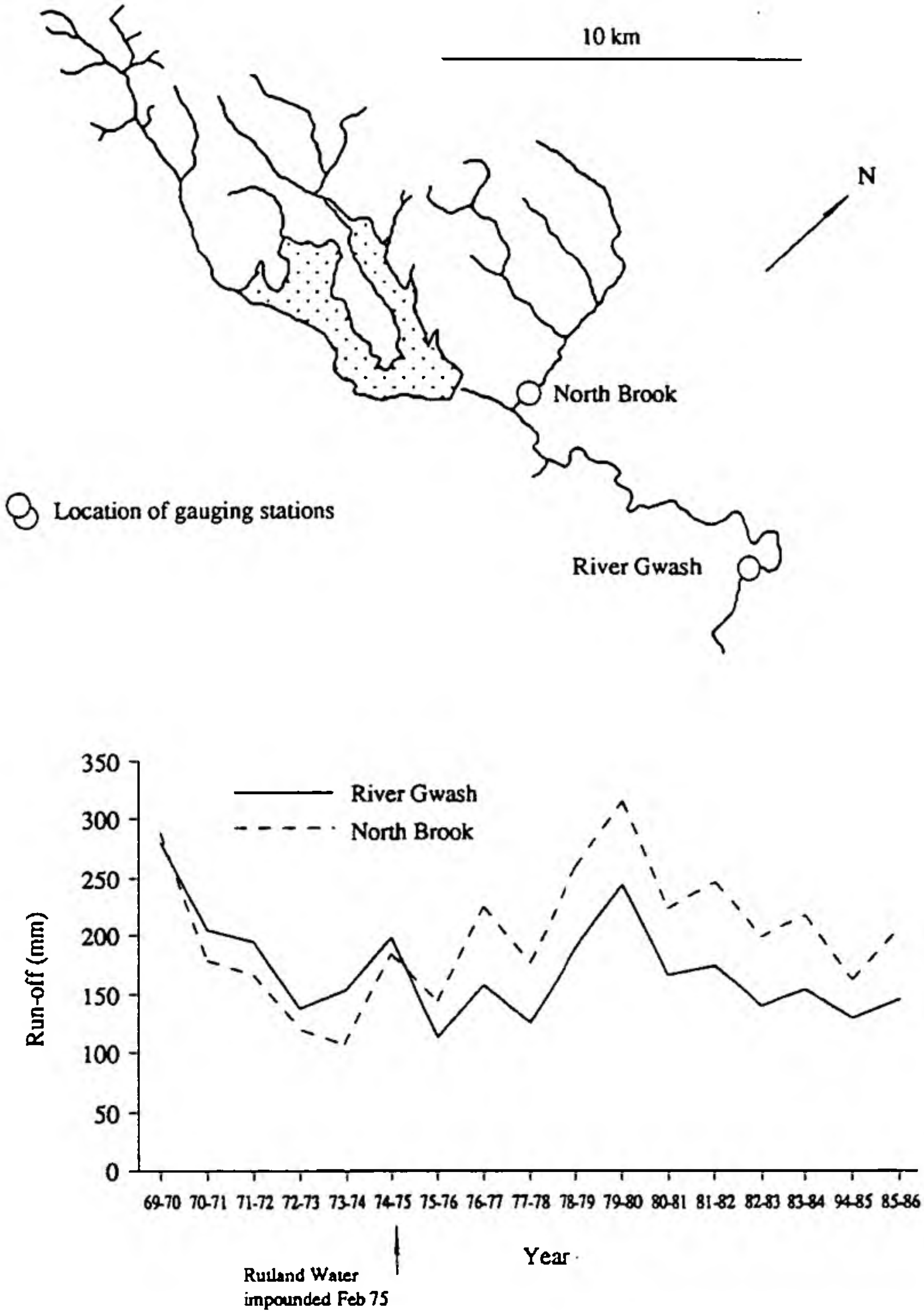


Figure 1.7 Run-off in the River Gwash catchment during 1969-1986

1.7 Recommendations

1.7.1 Channel length

There has been a considerable quantitative reduction of river channel in the Welland valley. This is most distinct in the middle reaches of the river, where mill streams have been abandoned and meanders were removed, notably during an arterial drainage scheme in 1968-1970. Straightening has also affected habitat diversity, since well-developed meanders have the greatest variety of substrate and cross-section.

Further straightening of the channel should not be considered. Flood carriers which preserve the sinuosity of the channel during normal flows have been used on the catchment – this alternative should be encouraged where locally-improved capacity is demanded.

The Eye Brook was not visited during the 1968-1970 scheme and has not been straightened to any degree. Channel maintenance has been restricted to piecemeal bushing and the removal of blockages. The stream is unpolluted and highly meandering – it represents a locally unique system which should be preserved.

The flood return period which determines channel maintenance on the main river should be reviewed. Land-use differs along the valley and if areas which require only a lesser design could be identified, this would allow considerable scope for active or passive restoration of physical diversity.

1.7.2 The Deepings

The two main features which contribute to the conservation value of the Deepings streams are their number and their relatively light management regime.

The small channels serve to interrupt the landscape and their corridors provide habitat for non-aquatic fauna. The existence of this habitat is dependent upon the streams and so the maintenance of some flow should is important.

The special value within the channels themselves lies with species which are sensitive to habitat disturbance. Here the current policy of regular light maintenance (including weedcutting) is essential, to avoid major channel modifications which might cause a loss of species.

1.7.3 River Gwash

The River Gwash supports a flora and fauna which is distinctly different from that of the main river and its other tributaries. The stability of the flow regime means that maintenance need only be reactive, at a similar level to that on the Eye Brook. Water resources use of the river should have regard for its high conservation value.

2. NON-MACROPHYTE SUBSTRATES

2.1 General introduction

Much of the variation in non-macrophyte, physical substrate for macroinvertebrates along the river channel is determined by the riffle-pool system, which is the dominant channel characteristic of most natural and semi-natural rivers (Richards 1982, see also Appendix B). Riffles are characterised by the presence of a range of substrate particle sizes other than the finest sediment, which is confined to pools during normal flows. Detritus such as leaf litter also accumulates in pools, since the flow needed for its transport is slight. On lowland rivers a third more or less distinct flow/substrate category occurs, called a run or glide, which has a bed of intermediate particle size (usually sand).

The three substrate classes (henceforth referred to as riffle, pool and run substrates) sustain different communities of macroinvertebrates. A study was carried out on the River Welland with three objectives:

1. To determine the value of the three substrates in terms of macro-invertebrate biomass and diversity, and the degree to which the communities are distinct.

2. To estimate quantitatively the effect of channel management on invertebrate biomass as a result of alteration of the physical substrates.

3. To provide a method for comparison of the current state of a reach with its predicted natural state in respect of the riffle-pool system – and so to allow quantitative recommendations for its management.

2.2 Macroinvertebrate biomass and diversity

2.2.1 Methods

Quantitative samples were taken from each of the riffle, pool and run substrate types at five sites in the River Welland catchment (Figure 2.1).

The sites were chosen to reflect the range of stream character within the catchment.

The uppermost site at Theddingworth is representative of the second-order tributaries of the River Welland, which have not been substantially managed. There are few macrophytes in the channel itself, since low flows in summer leave little of the channel permantly wetted. Shallow margins support *Phalaris*, other grasses and herbs such as *Veronica beccabunga* and *Myosotis scorpioides*.

The site at Harringworth is typical of the Welland mainstream and its larger tributaries. A major arterial drainage scheme in the late 1960s involved lowering of the bed and the removal of riparian trees. There are very few shallow margins and the channel is dominated in summer by growth of algae and of macrophytes such as *Potamogeton pectinatus* and *P. perfoliatus*.

The Collyweston sample site marks the downstream extent of the Welland as a clay river. Thereafter there is a limestone geology which gives way to alluvium and fen deposits downstream from the Uffington sample site (Ministry of Housing and Local Government 1964). *Ranunculus penicillatus* appears and becomes dominant over *Potamogeton pectinatus* in riffles between Harringworth and Collyweston.

The chemistry and runoff characteristics of the River Gwash (sampled at Ryhall) are different to those of the upper Welland. The underlying geology is limestone rather than clay and the flow is regulated in part at Rutland Water. The channel at the study site has a well-developed 'mosaic' of submerged macrophyte species, of which *Berula erecta*, *Zannichellia palustris* and *Oenanthe fluviatilis* are not found on the Welland.

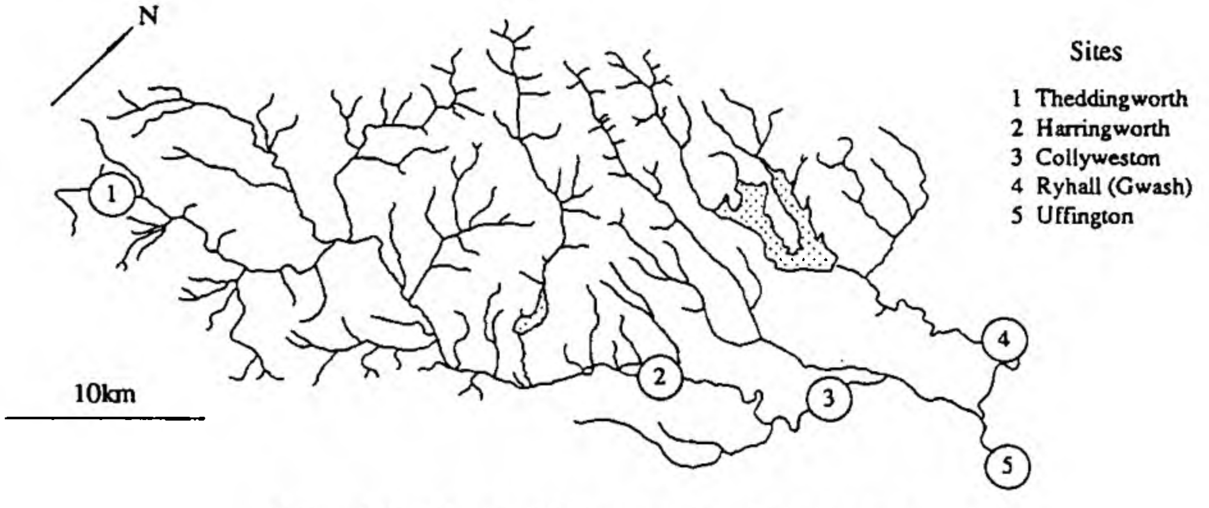


Figure 2.1 Sites at which substrate samples were taken

Ten replicate samples were taken from each of the 15 substrate/site combinations. Fine sediment samples were taken whole, either with an Ekman grab on a pole (15x15 cm, 0.022 m^2) or by scooping out the contents of an open-ended cylinder (14 cm radius, 0.062 m^2). Very fine sediment was removed on site using a 650 μ sieve. Riffle samples were taken using a Hess corer, modified such that suspended matter flowed into a hydrant net (in effect a Surber sampler, 12 cm radius, 0.045 m^2). Firmly anchored invertebrates such as the larvae of the cased caddis *Hydroptila* were then removed from the stones within the corer by hand. Samples were kept at 4 °C and live-sorted to family level or beyond within 24 hours of collection. The weight of each macroinvertebrate type in each sample was then measured, after drying in a vacuum oven at 80 °C overnight.

2.2.2 Results

The qualitative distribution of families between the three substrate/flow types is summarised in Figure 2.2. Relevant data collected elsewhere and at a later stage in the project is also presented.

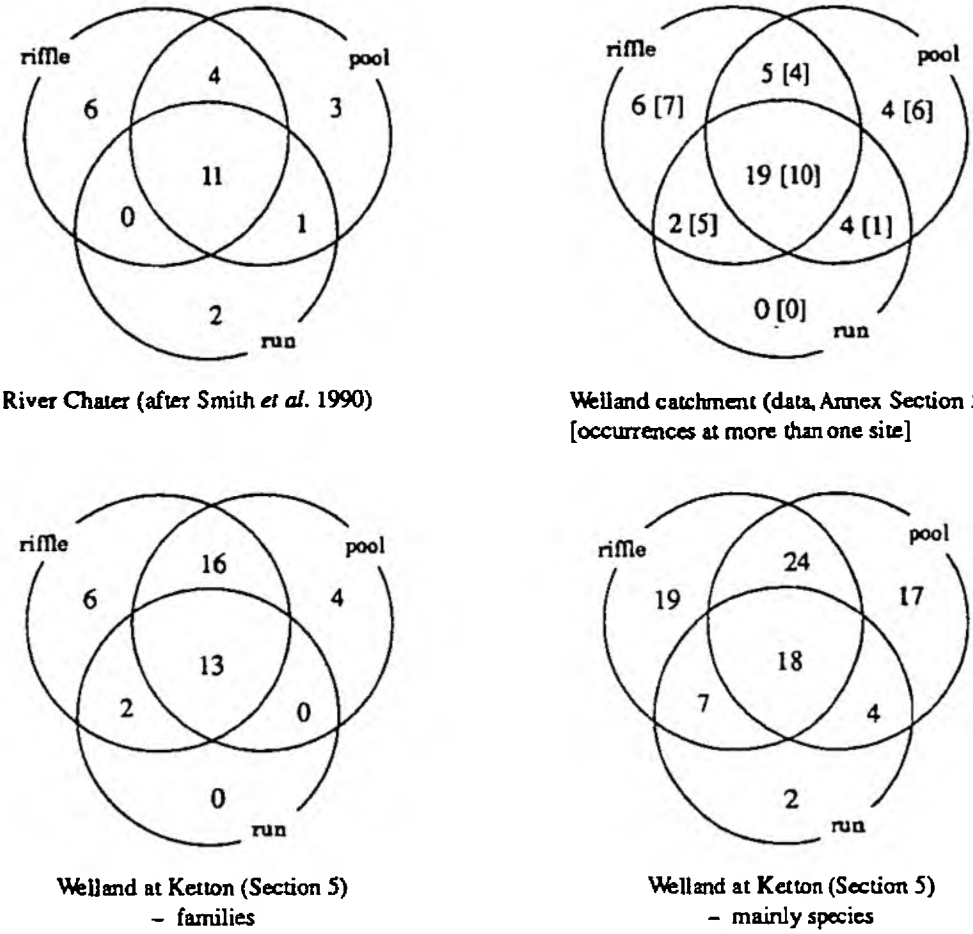


Figure 2.2 Number of taxa occurring in three substrate types

The dry weights of each family in each sample are given in Section 5 of the Annex to this report. The total biomass of macroinvertebrates in each site/substrate is shown in Table 2.1.

Table 2.1 Total macroinvertebrate dry weight (g/m^2) for three substrates at five sites

	Mean (standard error) for 10 replicate samples		
Site	Riffle	Run	Pool
Theddingworth	3.71 (0.33)	0.48 (0.12)	1.63 (0.35)
Harringworth	2.90 (0.40)	0.15 (0.03)	4.15 (1.00)
Collyweston	5.53 (0.64)	1.10 (0.12)	19.10 (2.96)
Uffington	2.32 (0.58)	0.20 (0.03)	3.78 (0.73)
Ryhall	7.97 (1.35)	0.98 (0.16)	4.49 (0.41)
Mean	4.49	0.58	6.63

Table 2.2 shows the biomass data split between taxa with slow turnover such as mayflies and beetles and those with rapid turnover such as oligochaetes and chironomids. Allocation of families to the 'high' and 'low' categories of productivity was done subjectively, from information on their life cycles.

Table 2.2 Dry weight (g/m^2) of macroinvertebrates of high and low productivity

	Riffle		Run		Pool	
	High	Low	High	Low	High	Low
Theddingworth	1.06	2.74	0.32	0.17	0.22	1.40
Harringworth	0.13	2.76	0.08	0.07	0.17	3.97
Collyweston	0.38	5.16	0.63	0.46	0.83	18.26
Uffington	0.24	2.08	0.14	0.06	1.86	1.91
Ryhall	0.58	7.39	0.51	0.46	1.01	3.46
Mean	0.48	4.03	0.34	0.24	0.82	5.80

2.2.3 Discussion

Macroinvertebrate species richness was higher in pools and riffles than in runs (Figure 2.2). The communities of runs were numerically dominated by two groups (Oligochaeta and Chironomidae) whereas riffles and pools were characterised by co-dominance of four or five families (pools by Asellidae, Oligochaeta, Erpobdellidae, Chironomidae and Sialidae; riffles by Hydropsychidae, Gammaridae, Erpobdellidae, Elminthidae and Oligochaeta). Each biotope had many taxa in common with one or both of the other two. There were always some which were restricted to riffles or pools, but rarely were any families characteristic of a sandy substrate – this was still true for identification to the level of genus/species (Figure 2.2).

The standing crop of macroinvertebrates was consistently higher for both the riffle and pool substrates than for the run substrate (Table 2.1). The contribution to secondary production of a given standing crop also depends on the turnover rates of the constituent taxa. Since it is well known that oligochaetes and chironomids form a considerable part of the 'run' fauna, it is possible for the relative value of the substrates to change when production is considered. The results show that the absolute standing crop of both fast and slow producers is least in the sand substrate although the proportion of productive types is greater (Table 2.2). Substrates of the riffle-pool system as a unit support at least twice the biomass of fast producers. This also sets a two-fold lower limit on the relative value to secondary production of riffles and pools over runs – and more, according to the importance of slow producers.

2.3 <u>Influence of channel management</u>

Runs occur naturally between riffles and pools but tend to dominate the channel after unmitigated dredging or straightening.

At several sites on the Welland mainstream the direct effects of the 1968-1970 capital scheme on bedform remained visible in 1987. For example, over a 400 m length of channel at Easton (TF 000 052), coarse material was absent from the channel but occurred on the eastern bank. The marks left by the dragline were clearly visible in the clay bed of the channel.

The effect of straightening on bed form is illustrated in Figure 2.3 for one site on a third-order tributary of the Welland. The straightening is not recent, but the new channel has no material from which high flows could form riffles. The weir installed to prevent headward erosion and to maintain low flows for fish may also prevent input of coarse load from upstream.

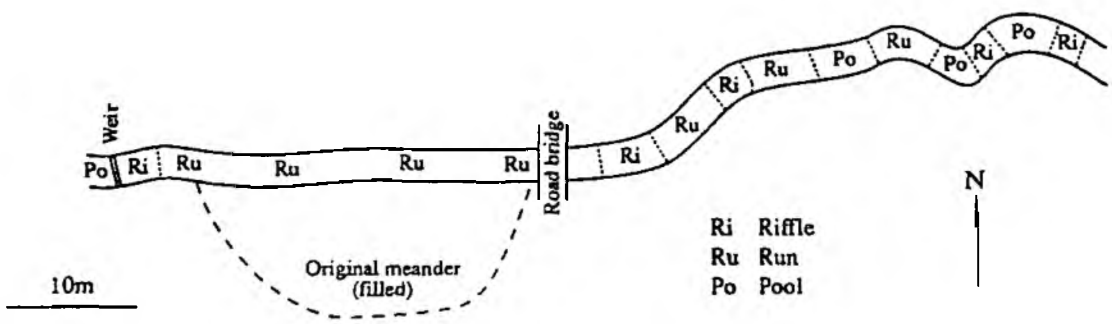


Figure 2.3 Physical changes in the River Chater after channelization above bridge (after Smith *et al.* 1990)

From biological and physical information (Sections 2.2 and 2.4 respectively) it is possible to make a quantitative estimate of the importance of the riffle-pool system to the macroinvertebrate community.

1. The biomass of invertebrates was ten times greater in riffles and pools than in runs. The proportion of taxa with high productivity (short generation time) was high in the substrate of runs, but the absolute biomass in riffle-pool substrates was twice that in runs.

2. Riffles and pools were together a prerequisite for around half of the species richness in particulate substrates – the values at bottom right of Figure 2.2 are slightly overestimated since life-stages were sometimes treated separately in the analysis from which the data are obtained.

3. The proportion of the channel in the Welland catchment occupied by riffles was quite independent of stream size – about 20-30 % by length. No quantitative assessment of the extent of pool substrate was undertaken although the same figure is probably a fair estimate.

Assuming both riffles and pools to each occupy 25 % of the channel, and by substituting the mean biomass estimates from each habitat, the result of removing the riffle-pool system is to reduce the potential macroinvertebrate biomass by 80 %, and production by 50 % at least. By the same token, reinstatement of the system could effect a five-fold increase in biomass and a two-fold or greater increase in production.

Half of the macroinvertebrate species were only found in riffle or pool substrates. This is probably an underestimate of the increase in overall species richness which would result from reinstatement of the riffle-pool system where it is absent. The methods employed in Section 2.2 did not explicitly sample the macroinvertebrates which are associated with macrophytes – many of which are in turn restricted to extremes of water velocity.

Runs are of natural value in the river because they are the main habitat of some species; they are only ecologically undesirable when, as the result of channelisation, they replace riffles and pools so that the overall habitat richness and productivity of a reach is reduced. On rivers where riffles and pools are appropriate, their maintenance or enhancement is a major requirement for effective conservation practice.

2.4 Riffle distribution

2.4.1 Introduction

Various mechanisms have been proposed for sorting of bedload into riffles during high flows (reviewed by Richards 1982), but consistent results have been reported in respect of riffle spacing. Typically, the spacing between riffles is 5-7 times channel width – which varies within a catchment of similar geology in relation to discharge. Riffles have at various times been removed during engineering work from much of the main river in the Welland catchment. The upper Welland flows through a clay geology with very little coarse material, so the river has only been able to re-form riffles where this material has been spread rather than removed. Where the channel has been over-widened, this has also reduced the competence of the river to sort such bedload as is available. In contrast, for several kilometres at Uffington the bed is composed of gravels, and there the riffle system recovered fully within three years of heavy dredging.

Reinstatement of riffles and pools is an established conservation measure, and riffles have been introduced successfully on the River Gwash, a Welland tributary. On rivers such as the Welland which are subject to severe flood events, riffle material must be placed at sites of high-flow deposition, to be augmented rather than eroded. Where the channel meanders the inflections indicate proper sites for riffles, but on a straightened channel the appropriate placement must be found by other means.

Previous studies of riffle spacing have been concerned with empirical confirmation of theoretical relationships, and so have used laboratory systems or sought the most pristine rivers. Therefore whilst it has been shown that the spacing is predictable for straight as well as meandering stretches, there is little explicit information on the spacing of riffles in rivers with a long dredging history. Channel width is a difficult quantity to define reliably but discharge measurements are readily available. Since riffle spacing should be related to discharge, a study was made on the Welland to find out whether a spacing-discharge relationship existed for a managed river.

2.4.2 Methods

Mean annual rainfall over the upper Welland varies between 650 and 750 mm/year but evapo-transpiration is fairly constant at 480 mm/year. Therefore runoff within the catchment is variable (about 170-270 mm/year), so it would be wrong to assume one figure for runoff and use catchment alone as a relative measure of discharge. Most gauging stations in the Welland catchment are low-flow weirs which cannot record accurately during flood events, and the results from these were not used in calculations. There are, however, several stations which can describe accurately the whole range of flood conditions (Figure 2.4) and mean annual runoff was calculated for those sites, using the existing data. The catchment area of each study site was measured from 1:50000 scale Ordnance Survey maps. Annual Mean Discharge (AMD) was calculated from runoff at the nearest reliable gauging station and the relative catchment areas of the study site and the gauging station.

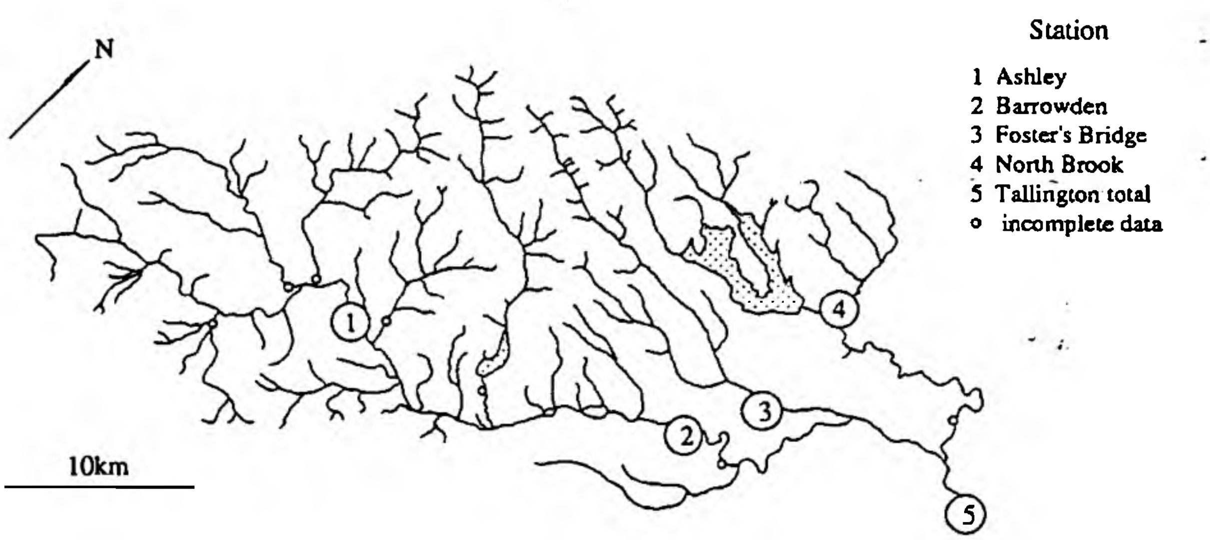


Figure 2.4 Flow gauging stations in the upper Welland catchment

A field survey of riffles and pools was carried out during the summer of 1987 at eight sites in the catchment (Figure 2.5). Sites were those at which the riffle-pool system had not been compromised by recent dredging, or by removal of all coarse bed material in the past. Riffles and pools were recorded on field sheets derived from 1:2500 scale Ordnance Survey maps.

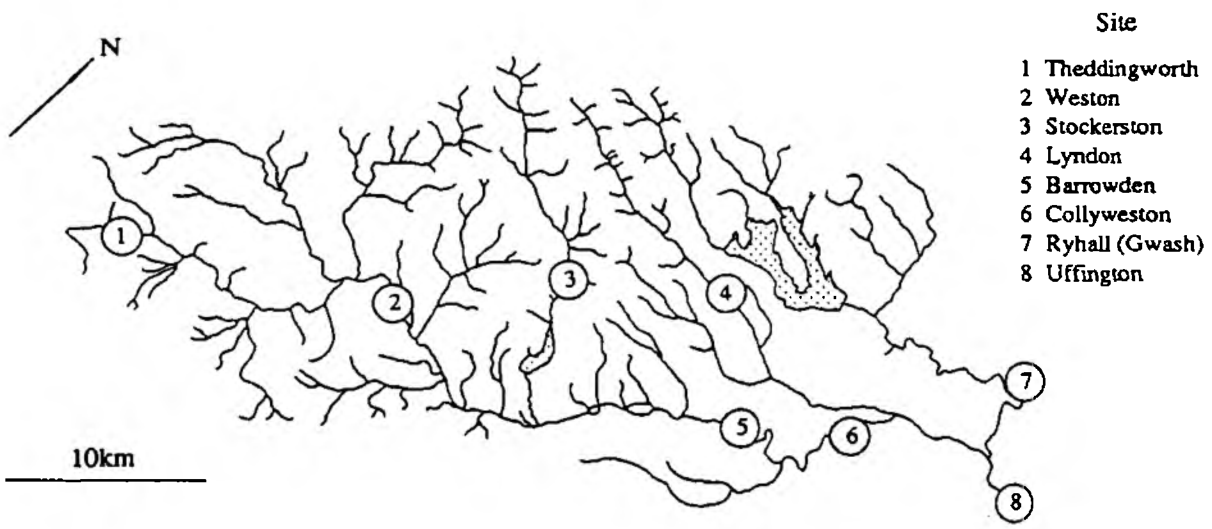


Figure 2.5 Riffle measurement sites in Welland catchment

2.4.3 Results

The data are given in Section 6 of the Annex to this report. For each site the mean riffle-spacing and percentage of the channel composed of riffles was measured (Table 2.3).

Table 2.3 Riffle characteristics and mean discharge at sites in the Welland catchment

Site	AMD	LEN	N	ΣR	IRD (S.E.)
Theddingworth	3.8	2195	91	29.1	24.9 (1.41)
Lyndon	8.2	3338	100	19.6	33.6 (1.91)
Stockerston	10.2	4799	132	28.0	36.0 (1.67)
Ryhall	35.5	3706	58	21.4	75.7 (5.14)
Weston	36.2	1988	23	27.7	84.5 (9.96)
Barrowden	76.6	3194	31	28.8	108.3 (12.00)
Collyweston	85.2	4142	24	21.6	172.9 (21.20)
Uffington	139.2	2263	12	19.5	187.5 (37.32)

AMD : annual mean discharge (10^6 m^3) IRD : mean riffle spacing (m)

Σ R : total riffle length as % of total channel length (LEN, expressed in metres)

N : number of riffles

The relationship between riffle spacing and stream discharge is shown in Figure 2.6. The distribution of riffle spacing was skewed, so the raw data were log-transformed. Skewness would certainly be expected on a naturally meandering river, with short inter-riffle distances arising on meander arms which have become overlong. The use of log(AMD) as the independent variable offers a better fit than AMD (*cf* Smith *et al.* 1990).

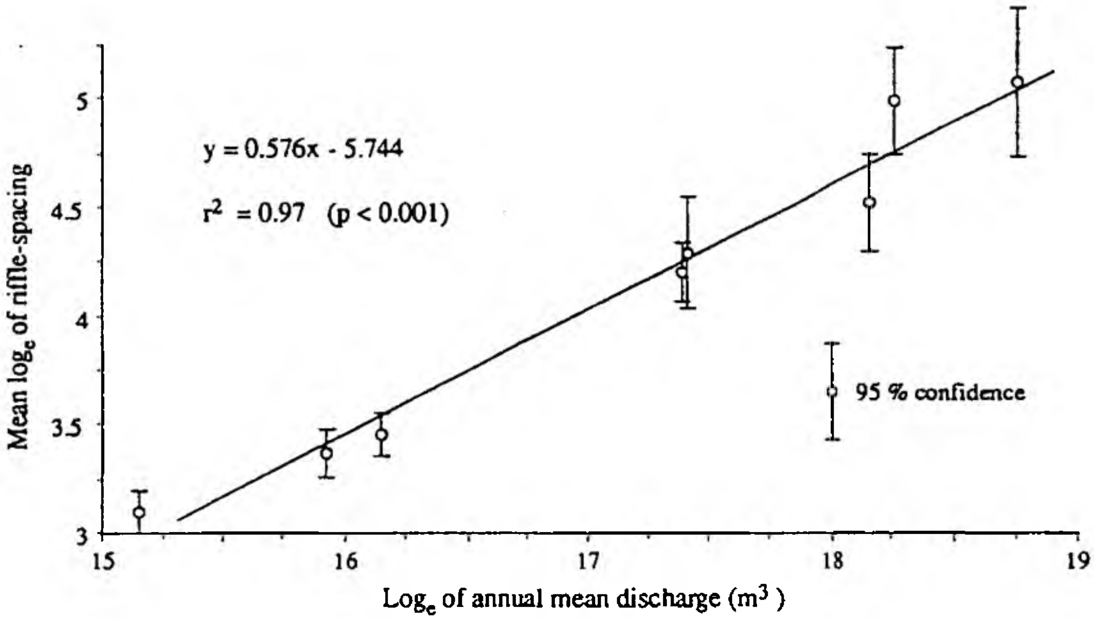


Figure 2.6 Relationship of riffle-spacing to discharge

Riffle length also was correlated with discharge (Figure 2.7) after log-transformation to normalise the distribution of the data.

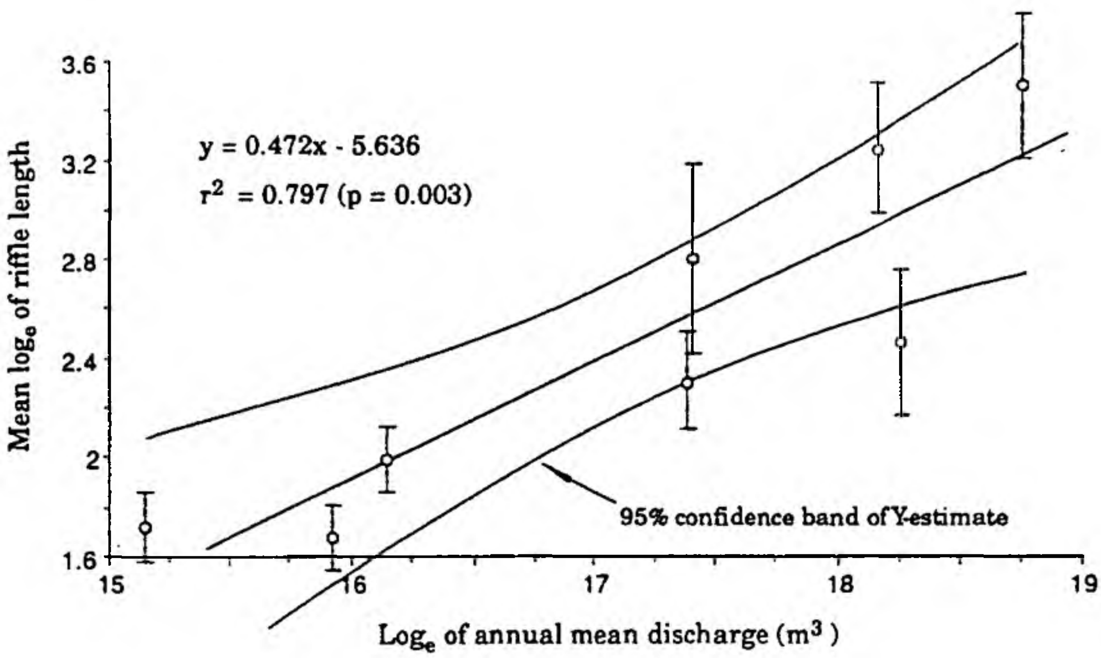


Figure 2.7 Relationship of mean riffle length to discharge

2.4.4 Discussion

Riffle spacing

Even though most of the riffles at study sites must be those which have been formed after dredging, the same form of spacing-discharge relationship which occurs on unmanaged rivers was found (Figure 2.6). The parameters of the regression will differ between catchments, depending upon gradient and geology, but only a short field survey and reference to existing discharge data is required to define the relationship. The appropriate frequency of riffles for any stretch of the river can then be calculated. Stretches of river failing to support an appropriate number of riffles can then be identified from a field survey. Shortfall in the frequency of riffles may be for four main reasons.

- The river does not naturally form a riffle-pool system
- Absence of coarse bedload from the channel
- Channel wider than expected from stream size
- Impoundments

Rivers at the extremes of gradient or bedload particle size do not form riffle series. The Welland – and much of the main river in England and Wales – falls within the set of conditions under which a riffle-pool system is appropriate.

The next two listed conditions are most likely to be the result of previous unsympathetic engineering practices. If riffles are disturbed during dredging they shoud re-form during high flows over a period of years. This cannot happen where coarse material has been removed or where the competence of the river to sort existing material has been reduced.

The riffle-pool system will be lacking on stretches where structures such as bridge foundations or mill impoundments act as fixed heads, producing greater depth upstream. There may only be limited potential for mitigation of this effect and in many instances it would be considered environmentally undesirable to do so. Fixed heads with long upstream pools often produce diverse conditions around and below the structure; and may present a net benefit to physical and biological richness, especially when considered in the context of the whole catchment.

Riffle length

Throughout the study sites, riffles accounted for 20-30 % of channel length (Table 2.3) – if introduced riffles are not long enough then the full potential for stream restoration will not be met. Because the distance between riffles increases with stream size while the 'proportion of riffle' remains stable, there is a relationship between riffle length and discharge, which could be used as a guideline in reinstatement. The relationship on the River Welland (Figure 2.7) is not as precise as for riffle spacing; but it does provide an objective starting-point against which other considerations might be laid.

2.5 Recommendations

The presence of varied physical substrate is of major importance to both the biomass and diversity of aquatic macroinvertebrates on the River Welland. The system of alternating riffles and pools is the dominant source of such variation and should form an important element of conservation strategy and practice for the river.

2.5.1 Site assessment

Site assessment carried out reactively or for the design of enhancement measures should pay special attention to the state of the riffle system. The discharge at a site can be used to predict the mean spacing of riffles by the following relationship:

$$\log_e S = 0.576 \log_e D - 5.744$$

i.e. $$S = 0.0032\ D^{0.576}$$

- where S is riffle spacing (m) and D is the annual mean discharge (m^3)

The current state of the riffle system can be assessed by comparison with this prediction. Riffles will not be regularly-spaced at the predicted interval but the mean spacing of a number of riffles should correspond quite well.

If the number of riffles on the reach is substantially less than the predicted number, this may have arisen for three reasons:

- There is a lack of coarse bed material
- The channel is wide, so the flow is not powerful enough to sort coarse bed material
- The flow is impounded by a structure which has produced a long pool upstream

Steps for enhancement of riffle-poor reaches should be taken wherever possible.

2.5.2 Enhancement measures

The appropriate action to enhance the riffle system depends largely upon the reason for its absence.

Lack of coarse material

If there is no coarse bed material then this is probably the result of previous dredging. The material which forms riffles on the upper Welland is not abundant in the clay through which it runs. If the original bed material is evident then this should be returned to the channel; and if not, the import of suitable material should be considered.

Wherever possible the material should be used to form riffle areas in the correct positions along the channel. If the channel is sinuous, then the correct sites are at the points of inflection of meanders – otherwise, the relationship described in Section 2.5.1 provides an approximate spacing. By locating riffle material at intervals predicted from the relationship with discharge, they will be augmented by subsequent stream processes rather than eroded. The length over which to establish a riffle is also predictable from discharge, by:

$$\log_e L = 0.472 \log_e D - 5.636$$

i.e. $$L = 0.00357\, D^{0.472}$$

- where L is riffle length (m) and D is the annual mean discharge (m^3)

It should be noted that the relationship with discharge was less definite for riffle length (Figure 2.7) than for riffle spacing (Figure 2.6). Geomorphological advice should be taken on the correct grades of material and the most stable architecture for reinstated riffles.

Widened channel

High flows on the River Welland are considerable due to its clay geology. The effect of widening on stream power is most likely to be important through Market Harborough where the channel has been designed for urban flood relief. At present the low-flow component of the two-stage channel is shallow, little narrower than the floodway and is often incompletely wetted during summer. It might be redesigned independently of the main channel to have a more natural capacity in relation to the riffle-forming annual/biannual floods.

For some distance downstream from Market Harborough STW the channel is choked with emergent macrophytes, especially *Sparganium* spp. Widening of the channel may have encouraged siltation (and colonisation) during low flows to such an extent that the normal pattern of erosion/ deposition does not occur during brief flood events. The overall diversity of the channel would be improved by creating a realistically small low-flow channel, which would not be as liable to deposition during normal flows.

Impoundments

The conditions produced by impoundment exist during normal flows in the pools which accompany the riffle system, but there are at least three factors which make the impounded reaches different:

- During floods, the velocity difference between riffles and pools is reversed. Impounded pools then provide a stable region for species intolerant of rapid flow:

- The water level above fixed heads is stable for a greater proportion of the summer and may provide more stable (although less diverse) habitats during dry summers.

• The impounded reaches may be desirable as match fisheries because of their greater extent and uniformity.

The flow of the River Welland is not generally dominated by impoundments and so in the context of the catchment they probably further habitat and species richness. Fisheries interests have played a role in management the river (*eg* low-flow weirs) and the compatibility of angling and conservation can be shown to advantage.

2.5.3 Other catchments

The prediction of appropriate riffle location and size should be possible for most catchments. The relationship between riffle spacing and stream discharge is well-proven for unmanaged rivers and the results given in Section 2.4 show that riffle spacing can be predicted on a river where most of the riffles are those which have re-formed after dredging. The parameters of the relationship will vary between catchments according to geology and gradient, so the survey and correlation with discharge would have to be repeated.

The balance between impounded flow and riffle-pool morphology provides added habitat diversity on the River Welland. By contrast, some tributaries of the River Great Ouse such as the River Kym (Section 7) are predominantly impounded (by virtue of low gradient). There it could enhance the diversity of the catchment to identify some structures which can economically be redesigned to allow unimpeded passage of water.

2.5.4 Post-project appraisal

There is ample evidence to show the value of riffles to riverine communities, and the reinstatement of riffles has become a frequent tool for stream restoration. The fate of 'assisted' riffles, biologically and physically, is less well documented. There are a number of alternative strategies for reinstatement which may not be equally successful – introduced or native material, differing particle size composition, riffle construction or mere provision of material. To make the best use of resources, the success of various methods should be monitored from new and existing programmes of habitat enhancement.

3. MACROPHYTE SURVEY

3.1 Introduction

Aquatic plants are important both in their own right and as habitat features. They are used as implicit indicators of overall biological status in the River Corridor assessment programme. Work by Brierley (1985) showed that macrophyte species composition through the length of the neighbouring River Nene was fairly constant, though through canalisation the physical nature of that river is not diverse. It was important to find out if similar constancy occurred on the River Welland and if not, to establish trends against which the status of sites could be compared in future.

3.2 Methods

A survey of macrophyte species and physical characteristics was carried out from 30 bridges along the main river in July 1987. The abundance of each species was recorded on a three-point scale (scarce, frequent, abundant). The survey was repeated in August of 1990 by a student at the University of Leicester (Thorpe unpublished data) – data are included with those from the 1987 survey in Section 7 of the Annex to this report.

The results of the bridge-based survey were used to calculate the 'damage rating' described by Haslam and Wolseley (1981) as an indicator of physical or chemical disturbances to the river.

3.3 Results

A substantial core of species was found at sites throughout the river. In addition to these, some species showed upstream or downstream limits to their overall distribution (Table 3.1).

Table 3.1 Distribution of aqauatic macrophytes from 1987 bridge survey

	Widespread	
Phalaris arundinacea	*Sagittaria sagittifolia*	*Rorippa-nasturtium aquaticum*
Glyceria maxima	*Potamogeton perfoliatus*	*Mentha aquatica*
Sparganium erectum	*Elodea canadensis*	*Rorippa amphibia*
Schoenoplectus lacustris	*Nuphar lutea*	*Apium nodiflorum*
Potamogeton pectinatus	*Potamogeton natans*	*Myosotis scorpioides*
Cladophora glomerata	*Polygonum amphibium*	*Veronica beccabunga*
Enteromorpha sp.	*Juncus effusus*	*Veronica catenata*
Potamogeton crispus	*Juncus inflexus*	*Solanum dulcamara*
	With a downstream limit	
Petasites hybridus	*Callitriche stagnalis* agg.	*Glyceria fluitans*
	With an upstream limit	
Ranunculus penicillatus	*Fontinalis antipyretica*	*Carex acutiformis*
		Carex otrubae

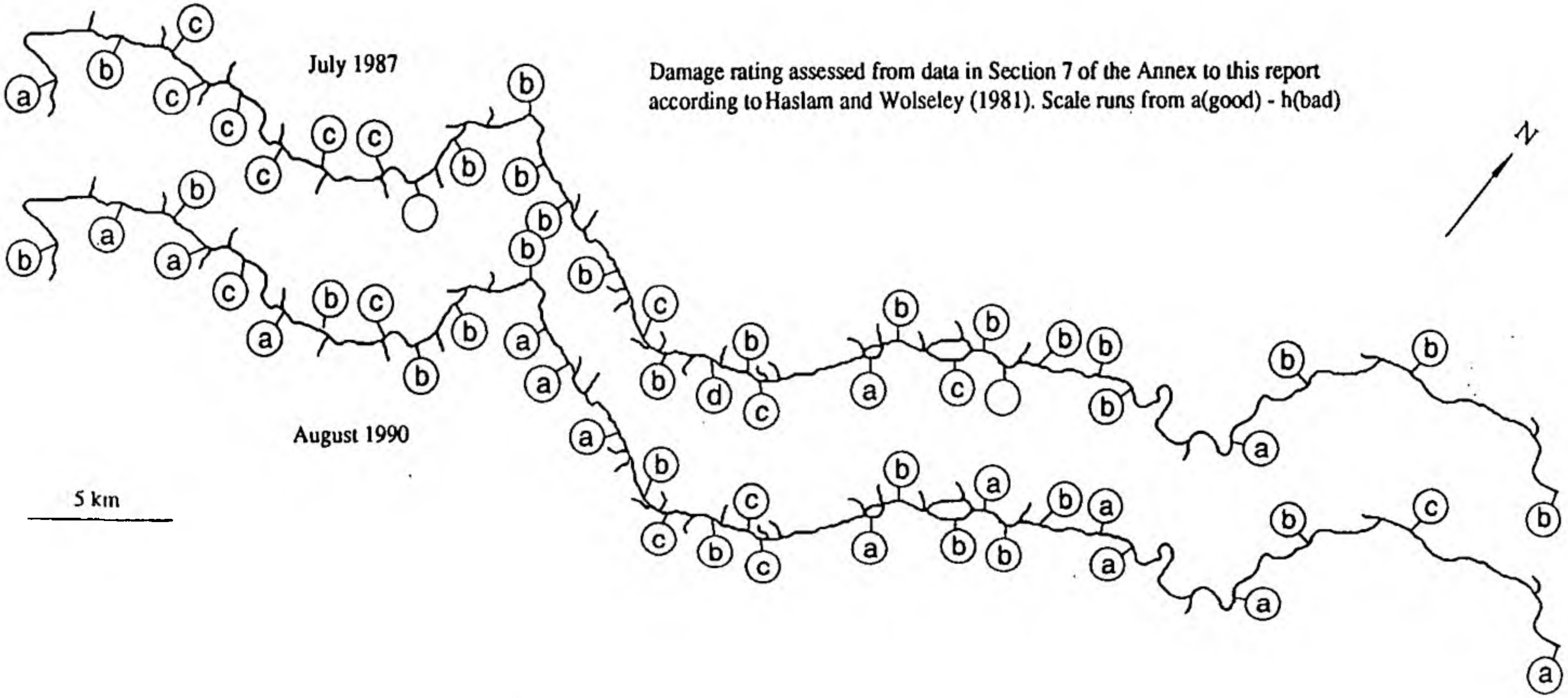


Figure 3.1 Macrophyte 'damage rating' from surveys of the Welland mainstream in 1987 and 1990

Of the widespread species, some were truly ubiquitous (such as *Phalaris arundinacea*) while many species occurred only locally (such as *Sagittaria sagittifolia*), usually reflecting the availability of appropriate habitat. An annotated species list was made of macrophytes found during the 1987 survey and during other work on the River Welland Environmental Survey (Appendix C).

The values of the damage rating (Haslam and Wolseley 1981) are shown in Figure 3.1 for both the 1987 and 1990 surveys of the Welland mainstream.

3.4 Discussion

The chemical water quality of the whole of the Welland mainstream is now consistently NWC class 1b, with the exception of a short reach downstream of Market Harborough which is class 2. This was reflected in the species of macrophytes found during the survey and thus values of the damage rating (Figure 3.1). The usual rating was 'b' or 'c' on a scale from 'a' (good) to 'h' (bad). The main feature contributing to the assessment of damage in this manner on the Welland was the abundance of *Potamogeton pectinatus* and blanket weed (*Cladophora glomerata* with *Enteromorpha* sp.). Both are indicators of enrichment. Ratings of 'e' and 'd' were reported previously at the two sites downstream of Market Harborough STW (Barham *et al.* 1988, 1990). These arose in error from essentially duplicate assessment of the 'percentage of pollution-tolerant species' element in the damage rating, which has also lead to revision of the rating for some other sites.

When using the procedure which Haslam and Wolseley (1981) provide for calculation of their damage rating, scores for the Welland relied heavily on the interpretation of *Potamogeton pectinatus* as 'intermediate' or 'much' and of blanket weed as 'much'. It is possible that the most significant factor producing differences between the two years was the interpretation of 'frequent' (=intermediate) and 'abundant' (=much) by the two surveyors. The time since the last maintenance dredging at a site was generally longer for the second survey and this may also have contributed to the apparent improvement.

The 1990 survey included sites on the River Gwash. Several species were found on the Gwash which have not been recorded recently from the Welland, such as *Oenanthe fluviatilis*, *Berula erecta*, *Mimulus guttatus*, *Zannichellia palustris* and *Hippurus vulgaris* (data in Section 7 of the Annex to this report). Both the chemistry and management history of the Gwash catchment have set it apart from the main river in terms of species composition.

The 1968-70 capital scheme had effects on the fauna and flora of the Welland mainstream which are to a degree irreversible. Some species were lost from the channel (for example, *Oenanthe fluviatilis*, *Scirpus setaceus*) but the most profound effect was the improved drainage of adjacent marshy ground described by Messenger (1971). Current practices of maintenance dredging probably do not further affect the overall status of the plant community. Only short reaches are dredged at any one time, and within these reaches not all the channel requires attention on each occasion: a result of the 'rolling' schedule of channel maintenance.

The river is enmained from Theddingworth downstream but most stretches above Market Harborough have not been extensively modified. Much of the channel is tree-lined on one or both banks and the difference in channel characteristics between shaded and unshaded parts is marked. Shaded parts have well-defined series of pools and solid, symmetrical riffles with little weed growth, while unshaded sections are dominated by asymmetric shoals with substantial bank erosion. The shoals are stabilised by macrophytes such as *Myosotis*, *Veronica*, *Glyceria* and *Phalaris* in the favourable light conditions. Downstream from Market Harborough, bankside vegetation was stripped during the capital scheme to provide access for dredging plant. Reinstatement of shade along the south bank alone would probably reduce the tendency for shoals to form whilst retaining access for maintenance.

3.5 Recommendations

3.5.1 Water quality

The abundance of *Potamogeton pectinatus* and *Cladophora glomerata* on the Welland mainstream indicates that nutrient enrichment from treated sewage and agricultural runoff has a profound effect on the flora. The general pattern of macroinvertebrates in the catchment (Section 1.3) is also influenced by water quality. The effluent from Market Harborough sewage treatment works is of a high standard, which must be consistently maintained. Long-term strategy for the catchment should recognise eutrophication as the main factor – alongside habitat richness – which influences the ecology of the river.

3.5.2 Riparian vegetation

The use of shade in weed control has been studied and recommended by Dawson and Kern-Hansen (1978). If benefits of shading include the discouragement of shoal formation in addition to the direct effect of reducing weed growth and channel roughness, the reintroduction of alders or similar shade to reaches prone to shoaling might be very cost-effective. Many sections of the Welland were stripped of trees during the 1960s capital scheme – any move to reinstate riparian trees for shade and cover would further the conservation of a range of wildlife.

4. HABITAT CLASSIFICATION – PILOT STUDY

4.1 Introduction

The simplest basis for objective habitat assessment of the river channel would be a list of habitats which each contributed to the total number of species supported by the channel.

For the purposes of building a species list it is sufficient to assemble a list of habitats intuitively, such as the nine sampled in a major survey of the River Teifi in Wales (Brooker 1982). This approach would not be appropriate in the present context, since the validity of the results could be compromised by definition of either too few habitats or too many. If a number of habitats are considered distinct in habitat assessment but actually support the same species, then the habitat status of a stretch with more than one habitat of that type is overestimated. If, on the other hand, they are considered identical but in reality support different species, then the status of a stretch with more than one habitat of the type is underestimated. Most importantly the second scenario would prevent recognition of low habitat richness and possible recommendations for enhancement.

In principle it would be possible to build a list of distinct habitats from the requirements of individual species. That approach can be discounted at present, due to the complexity of the task and the lack of detailed information. The practical solution is to let the distribution of species define the list of habitats through application of multivariate analysis to distribution data.

4.2 Method

There are many methods available for the classification of 'samples' according to their species composition. The procedure used for classification of habitats was indicator species analysis (Hill *et al.* 1975), using the computer program TWINSPAN (Hill 1979a). The advantages of indicator species analysis over other classification methods for purposes analagous to ours were discussed by Gauch and Whittaker (1981). Its main virtue for the present task was that all of the species information is used at each level of the classification. TWINSPAN uses the first dimension of an ordination to divide samples into two groups. Species showing the most preference for samples in either half are selected, and the point at which the samples are split is adjusted to provide the best separation on the basis of these indicator species. Then the ordination and subsequent splitting is repeated for each of the daughter groups, and so on.

Indicator species analysis continues to divide the sample set regardless of the degree of difference between samples, and it was noted by Hill *et al.* (1975) that "... the process has to be stopped when the user thinks fit". Usually the aim is to explain results in terms of environmental parameters and this has proved to be the limiting factor in those applications. The procedure was arrested at level 2 (4 groups) by Ormerod *et al.* (1987) in a study of macrophyte assemblages, while the macroinvertebrate community study of Wright *et al.* (1984) used 16 groups (level 4). The present work did not aim to explain distributions – by taking samples from several instances of each possible habitat, the need to apply an arbitrary stopping-point was avoided. For any branch of the classification, the last level at which 'replicates' remained together was considered to constitute only one habitat with respect to the macroinvertebrate community (Figure 4.1).

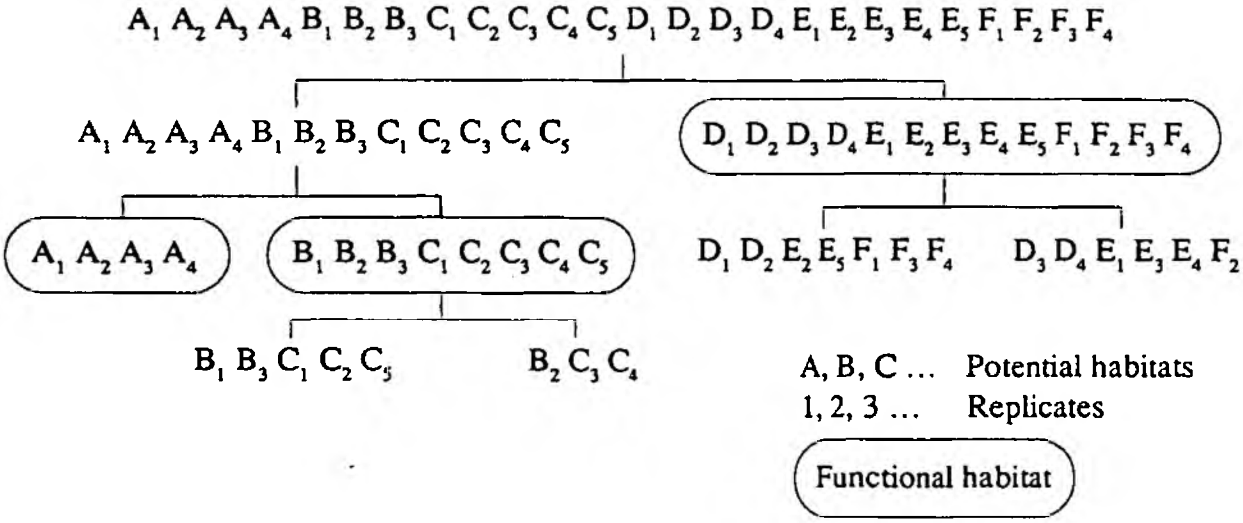


Figure 4.1 Example of habitat definition from divisive classification

In 1987, quantitative samples were taken from three substrate types (riffle, sand, mud) at five sites in the Welland catchment (Section 2.2). Replicates were taken from each site/substrate combination. Clear differences in both biomass and family richness were found: the variation was greatest between substrates, less between sites and least within replicate sets. The habitat classification process was applied to these data as a test of its effectiveness, on the basis that substrate types should separate first, then the sites and finally the replicates, since this was the sequence of increasing similarity shown previously. This report uses the binary method of numbering groups (*, *0, *1, *00, *01, *10, *11 etc.) since this provides more immediate information on their provenance than enforced decimal numbering (0, 1, 2, 3, 4, 5, 6 etc.).

4.3 <u>Results and discussion</u>

With a small number of exceptions the substrate types (i.e. riffle, sand & mud) separated as TWINSPAN groups *0, *10 & *11 (Figure 4.2). The indicator species used at each division reflect another feature of the substrates: that both riffle and mud substrates supported characteristic families, while sand supported only a small set of cosmopolitan families (Section 2.2).

The relationship between TWINSPAN and ordination can clearly be seen for substrate types, with samples from different types occupying sectors of an ordination diagram (Figure 4.3).

The pattern of division within substrate classes varied. Replicate sets from riffles tended to remain together in the classification (Figure 4.4). The first site to separate from the others was Ryhall on the River Gwash, which has a different water chemistry and flow regime from the main river. Samples from the Uffington site did not stay together in the classification but it may be significant that these were the first to be taken and sorted.

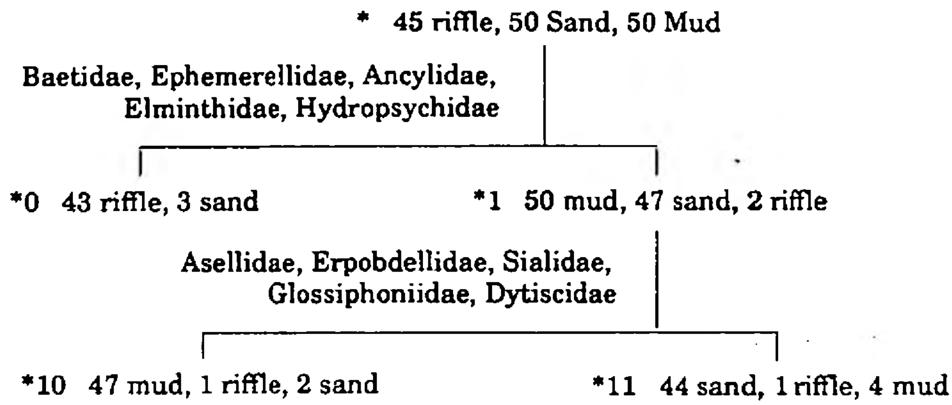


Figure 4.2 Classification of samples from three substrates at five sites in the River Welland catchment according to macroinvertebrate families

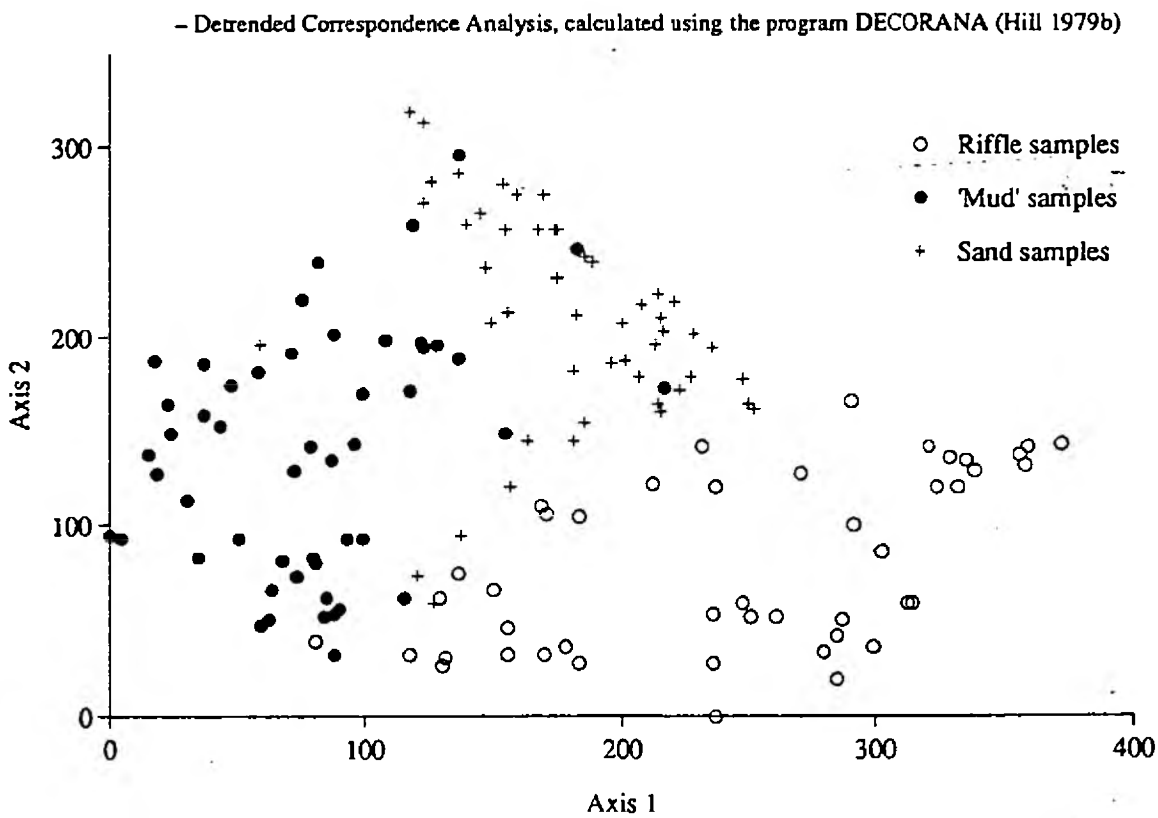


Figure 4.3 Ordination of samples from three substrate types

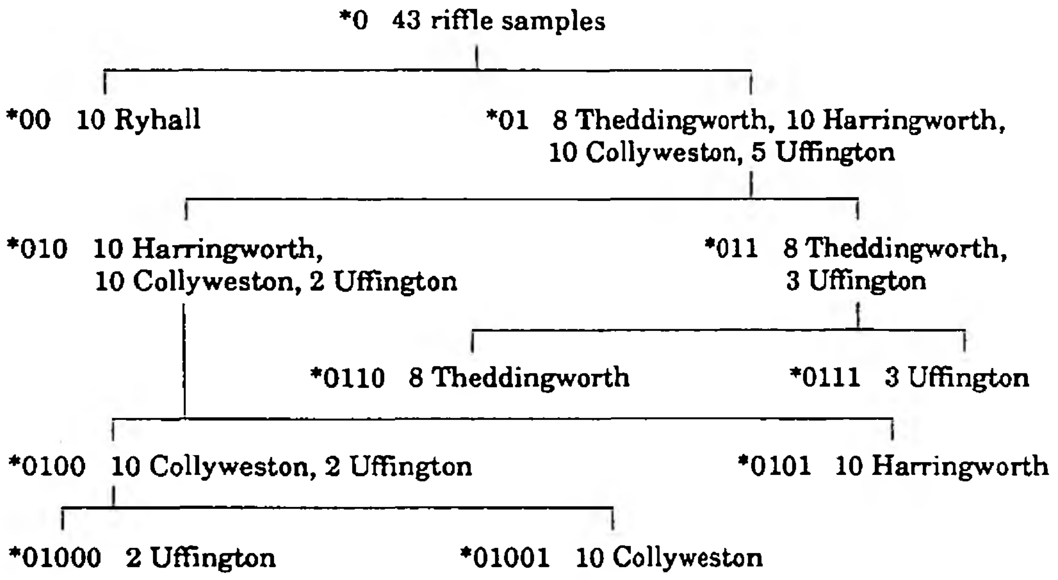


Figure 4.4 Classification of samples from riffle substrate

For mud (= silt in pool) substrates the variation between sites was less marked in comparison to the variation between replicates. Accordingly the replicates from different sites became more mixed in the classification than those of riffle substrate (Figure 4.5). In the habitat analysis "Collyweston" and "Theddingworth" would be separated with some confidence but the others would be considered as one group.

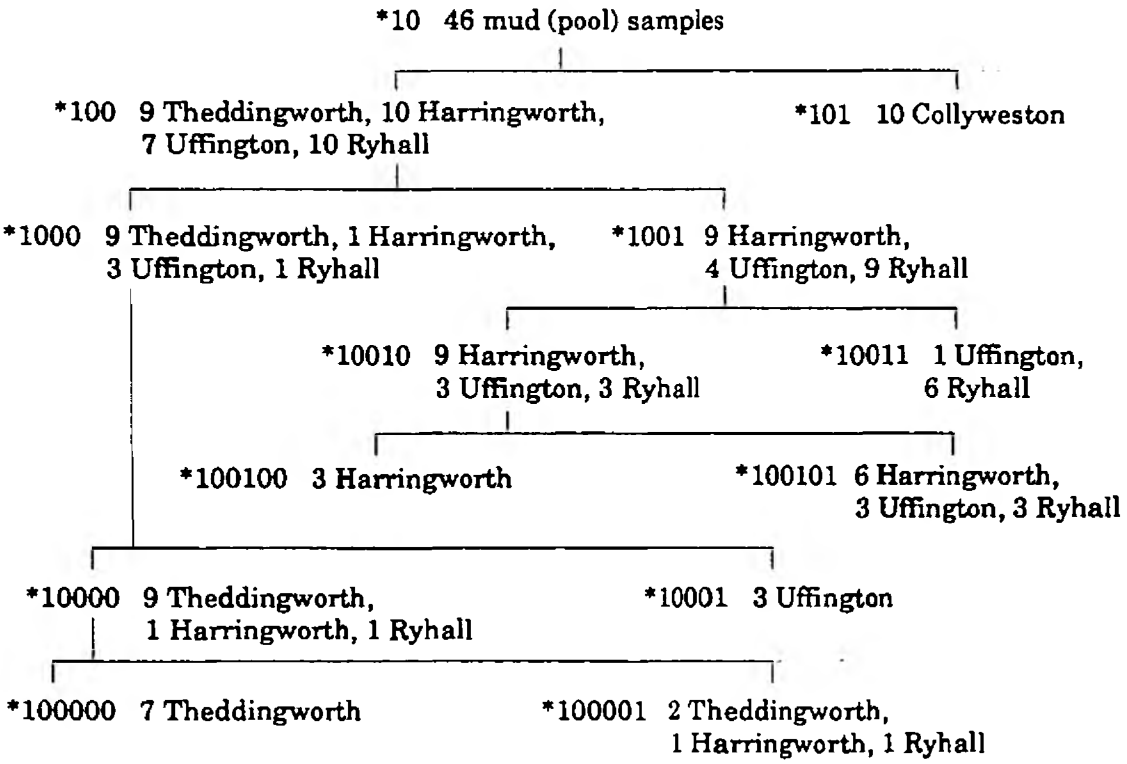


Figure 4.5 Classification of samples from mud (pool) substrate

The classification of samples from sand substrates did not reveal much more distinction between sites than between samples from the same site (Figure 4.6). In the habitat classification they would be combined as "sand", subject to a closer look at the status of "Ryhall". Higher taxa present in sand tended to be ubiquitous, although further identification of groups such as Oligochaeta and Chironomidae might have shown differences between sites.

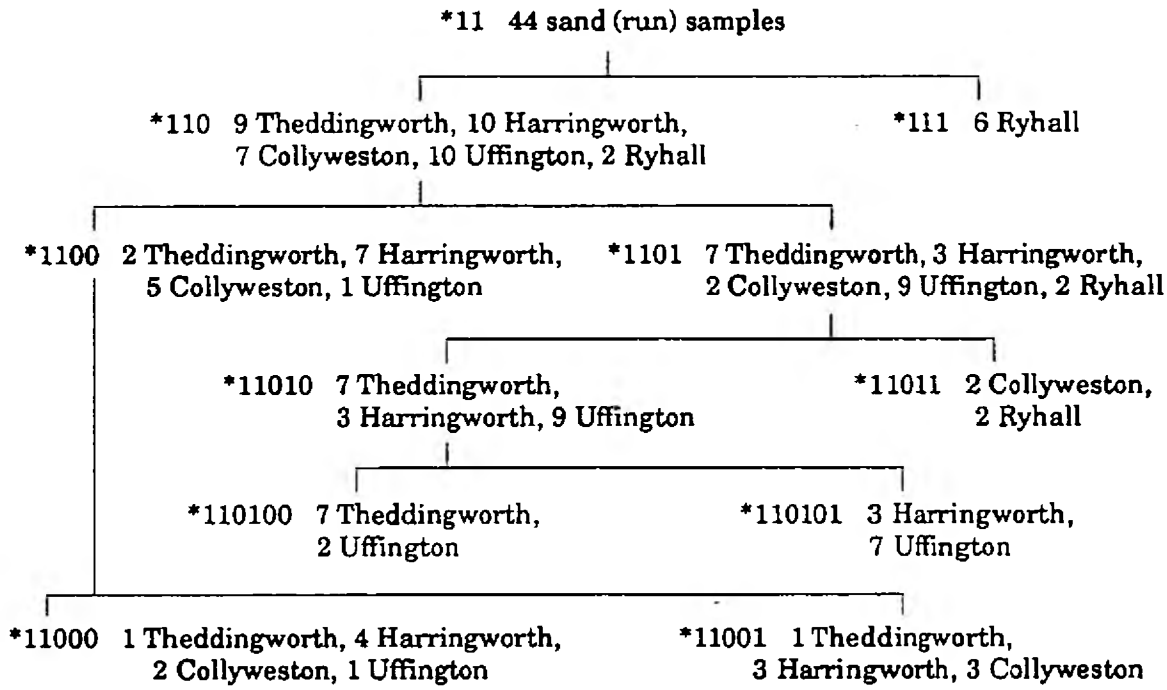


Figure 4.6 Classification of samples from sand (run) substrate

The test using data from 1987 showed that the use of replicate samples offers an alternative to an arbitrary stopping-point in TWINSPAN. The method for habitat classification based on TWINSPAN was then applied to a full range of habitat types on two rivers, as described in Sections 5 and 6 of this report.

FUNCTIONAL HABITAT CLASSIFICATION

The second phase of the study latterly formed the National Rivers Authority project 'Physical Environment for River Invertebrate Communities'. The method for classification of river macroinvertebrate habitats, introduced in Section 4, was developed and tested. The study consisted of three parts, carried out on three rivers in Anglian Region –

1. River Welland – intensive sampling over a full range of potential habitats. Classification of the samples to determine a list of 'functional habitat' groups with distinct species complements.

2. River Wissey – the procedure repeated on a contrasting river to further test the method and to find out whether the list of functional habitats is 'portable' within the region.

3. River Kym – a survey of habitats and macroinvertebrates on a river with known shortfalls in habitat availability. How much biological information is required to make valid conservation recommendations from a habitat survey ?

5 RIVER WELLAND - FUNCTIONAL HABITAT CLASSIFICATION

5.1 Study site

The general character of the River Welland has been described in Part A of this report. The study reach of 8.4 km (Figure 5.1) was between the entry of Fineshade Brook at Duddington (SK 976 002) and the entry of the River Chater at Tinwell (TF 057 001).

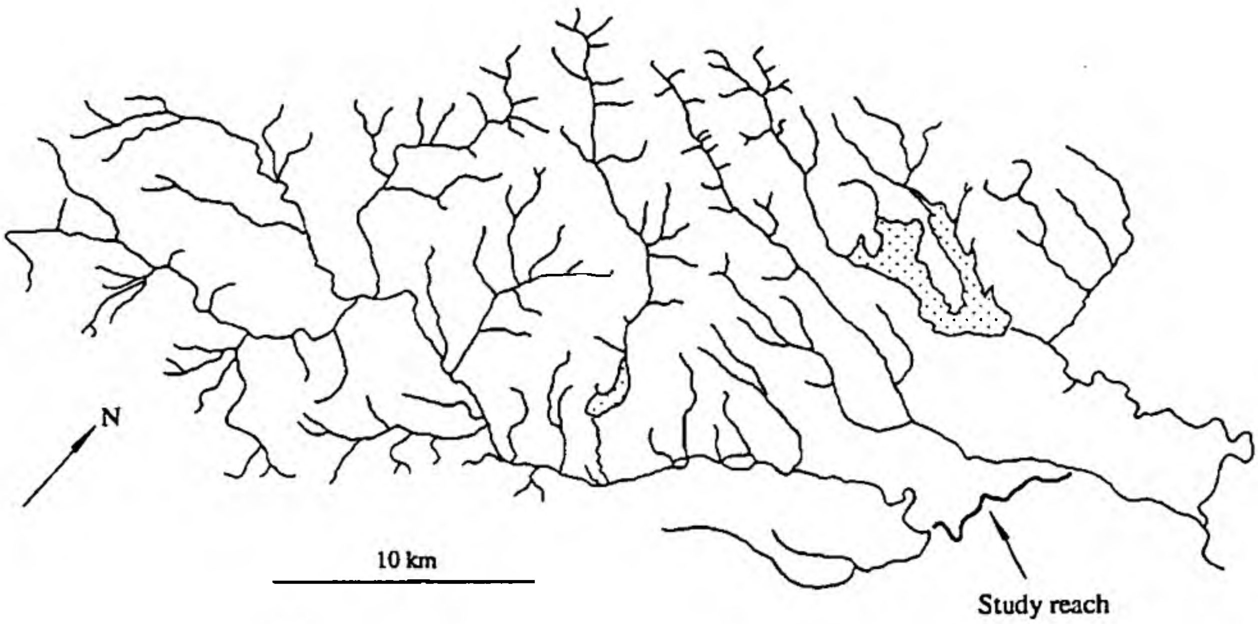


Figure 5.1 Location of study reach in upper Welland catchment

Water quality is similar along the reach. There are no notable point sources of effluent upstream except treated sewage from Market Harborough sewage treatment works, which lies 36 km above Duddington. BMWP scores from Wakerley (above the study reach) and Collyweston (downstream part of the study reach) were similar even before improvements to the sewage treatment works.

Discharge increases only slightly over the study reach. No major tributaries enter the main river between confluence with the Fineshade Brook and with the River Chater: the catchment area of the river increases by only 3 % (14 km^2) through the reach.

The study reach included sections ponded by mill and bridge structures, and sections with a meandering plan and established riffle-pool sequence. From previous work it was known that the reach held most of the perceived habitats to be found in the Welland catchment. The length of the reach ensured that replication of most habitat types was possible.

5.2 Data collection

During August 1988, 181 samples were taken from 42 potential habitats (Table 5.1). Where possible the replicates were from different examples of the same habitat, to ensure that the full within-habitat variation was included. Samples were taken to provide equivalence within the macro-invertebrate abundance groups to be used in the analysis (0-9, 10-99, 100-999, 1000+).

Table 5.1 Potential habitats sampled in August 1988

(replicates ••••)

Blanket weed
- *Cladophora* (slack •••• & flowing •••••)
- *Enteromorpha* (slack ••• & flowing •••)

Floating-leaved macrophytes
- *Potamogeton natans* (slack •••••)
- *Nymphaea alba* (slack •••••)
- *Nuphar lutea* (slack •••••)

Submerged macrophytes
- *Elodea canadensis* (slack ••••• & flowing ••••)
- *Fontinalis antipyretica* (flowing ••••• & broken •••••)
- *Potamogeton lucens* (flowing •••••)
- *Myriophyllum spicatum* (flowing ••••)
- *Potamogeton pectinatus* (flowing •••• & broken •••)
- *Potamogeton perfoliatus* (flowing •••••)
- *Ranunculus penicillatus* (flowing ••••• & broken •••••)
- *Schoenoplectus lacustris* (flowing •••)
- *Nuphar lutea* (flowing ••••)

Emergent macrophytes
- *Phalaris arundinacea* (shoots •••••)
- *Agrostis stolonifera* (shoots •••••)
- *Rorippa amphibia* (shoots •••••)
- *Glyceria maxima* (shoots ••••• & roots •••••)
- *Sparganium erectum* (shoots ••••• & roots •••••)
- *Schoenoplectus lacustris* (shoots ••• & roots ••••)
- *Carex acutiformis* (shoots ••• & roots •••)

Particulate substrates
- Silt (with leaf litter ••••• & without leaf litter •••••)
- Sand (A •••, B •••, C •••) [u/s riffle, d/s riffle, point bar]
- Gravel (above riffle ••••• & below riffle ••••)
- Riffle, i.e. broad particle size range (A •••••, B •••••, C •••••)
- Rocks (in slack •••)

Submerged and floating-leaved macrophyte species were treated separately in each of three flow types: slack ('pool'), flowing ('run') and broken water ('riffle'). A portion of the stem and leaves was enclosed in a hand-net and then cut from the rest of the plant. Samples were taken of both the shoots and the roots of reed-like emergent plants. The shoot sample was cut between the substrate surface and summer water level. 'Root' samples included the roots and that portion of the shoot lying within the substrate. The shoots of herbaceous marginal plants were sampled by severing the stem and removing the plant directly to a container. The plant was first shaken *in situ* and free-swimming invertebrates captured with a hand-net.

Particulate substrata were sampled with methods appropriate to the flow and depth of overlying water. The invertebrates of coarse material found in broken water were sampled using a Surber sampler – the contents were stirred until examination revealed that all animals had entered the net. Sandy and silty substrata found in water of greater depth were recovered intact using an Ekman grab mounted on a pole. Rocks in slack water were removed intact. Samples were stored in a cold room at 4 °C and live-sorted within two days of collection (usually within 12 hours), with subsampling of groups represented by more than 50-100 individuals.

Table 5.2 List of taxa from River Welland habitat samples

Theodoxus fluviatilis	*Valvata piscinalis*	*Potamopyrgus jenkinsi*	*Bythinia tentaculata*
Lymnaea stagnalis	*Lymnaea pereger*	*Physa fontinalis*	*Planorbis carinatus*
Planorbis planorbis	*Planorbis vortex*	*Planorbis albus*	*Planorbis contortus*
Ancylus fluviatilis	*Sphaerium corneum*	*Pisidium* sp.	*Anodonta cygnaea*
Ephemera danica	*Ephemera vulgata*	*Ephemerella ignita*	*Habrophlebia fusca*
Caenis macrura	*Caenis luctuosa*	*Baetis rhodani*	*Baetis scambus*
Baetis vernus	*Centroptilum luteolum*	*Cloeon dipterum*	*Cloeon simile*
Procloeon bifidum			
Leuctra geniculata			
Ischnura elegans	*Enallagma cyathigerum*	*Agrion splendens*	*Aeshna cyanea*
Hydrometra stagnorum	*Velia* nymph	*Velia caprai*	*Velia sauli*
Gerris nymph	*Gerris lacustris*	*Gerris najas*	*Nepa cinerea*
Notonecta nymph	*Notonecta glauca*	*Notonecta maculata*	*Corixidae* nymph
Hesperocorixa sahlbergi	*Sigara dorsalis*	*Sigara falleni*	
Elmis aenea larva	*Elmis aenea* adult	*Esolus parallelipipedus* adult	*Limnius volckmari* larva
Limnius volckmari adult	*Oulimnius tuberculatus* larva	*Oulimnius tuberculatus* adult	*Haliplus* larva
Haliplus confinis	*Haliplus fluviatilis*	*Haliplus immaculatus*	*Laccophilus hyalinus*
Platambus maculatus	*Hydroporus palustris*	*Potamonectes elegans*	*Helophorinae* larva
Dytiscinae larva	*Helophorus brevipalpis*	*Hydraena gracilis*	*Chaetarthria seminulum*
Polycelis tenuis/nigra	*Dugesia lugubris*	*Dendrocoelum lacteum*	
Piscicola geometra	*Theromyzon tessulatum*	*Hemiclepsis marginata*	*Glossiphonia heteroclita*
Glossiphonia complanata	*Helobdella stagnalis*	*Erpobdella testacea*	*Erpobdella octoculata*
Asellus aquaticus	*Crangonyx pseudogracilis*	*Gammarus pulex*	*Austropotamobius pallipes*
Sialis lutaria			
Rhyacophila dorsalis	*Hydropsyche pellucidula*	*Hydropsyche angustipennis*	*Hydropsyche contubernalis*
Hydropsyche siltalai	*Hydroptila* sp.	*Sericostoma personatum*	*Athripsodes aterrimus*
Ceraclea dissimilis	*Limnephilus lunatus*		
Simulium angustipes larva	*Simulium angustipes* pupa	*Simulium equinum* larva	*Simulium equinum* pupa
Simulium salopiense larva	*Simulium salopiense* pupa	*Simulium erythrocephalum* larva	*Simulium erythrocephalum* pupa
Simulium ornatum larva	*Simulium ornatum* pupa	Ephydridae	Tipulidae (not *Dicranota* sp.)
Dicranota sp.	Ceratopogonidae	*Anopheles* sp.	Tabanidae
Dolichopodidae	Psychodidae	*Procladius* sp.	*Macropelopia* sp.
Ablabesmyia sp.	Tanypodinae indet.	*Corynoneura* sp.	*Thienemanniella* sp.
Synorthocladius semivirens	Orthocladiinae indet.	*Cladotanytarsus* sp.	*Cryptochironomus* sp.
Demicryptochironomus sp.	*Endochironomus* sp.	*Parachironomus* sp.	*Paratanytarsus* sp.
Paratendipes sp.	*Polypedilum* sp.	*Rheotanytarsus* sp.	'*Saetheria*-like sp'
Tanytarsus sp.	*Chironomus* sp.	Chironominae indet.	*Potthastia longimana gp.*
Prodiamesa olivacea			
Tubificidae (hair chaetae)	Tubificidae (no hair chaetae)	Naididae	Lumbriculidae
Haplotaxidae			
Hydracarina			

Identification was carried out in most cases to species (Table 5.2), with the most frequent exceptions being Hydracarina (no further), Chironomidae (variously to sub-family or genus) and several other groups of Diptera (*e.g.* Ceratopogonidae and Psychodidae, no further). Nymphs of Hemiptera and larvae of some Coleoptera were often also left at a higher taxonomic level than the adults. Life stages were treated separately if they were not identifiable to the same level (e.g. Hemiptera) or if they showed markedly different morphology (e.g. Elminthidae). The data are given as Section 8 of the Annex to this report.

5.3 Data analysis

The multivariate analysis described in Section 4 was applied to the data obtained in August 1988. Pseudospecies cut levels were set at 0, 10, 100 and 1000. All other options within the calculation were set to the defaults, except that the maximum number of divisions was made large enough to run to a stopping point on each branch of the classification. The classification is summarised in Figure 5.2, and more completely presented as Section 9 of the Annex to this report (TWINSPAN output) and Appendix D (graphical representation).

The analysis produced a reduced list of habitat groups which were decided by actual species composition rather than from intuition and experience (Table 5.3), although there were some cases in which the identity of the groups was equivocal – in particular group *001, comprised of submerged macrophytes.

Table 5.3 List of habitats indicated by the classification

• Sand	• Shoots of emergent macrophytes
• Gravel u/s riffle	• Roots of emergent macrophytes
• Gravel d/s riffle	• Blanket weed in pool
• Mud with litter	• *Nymphaea* in pool *
• Mud without litter	• *Nuphar* in pool *
• Riffle substrate	• *P. lucens* in flowing water
• Rocks in pool	• *Elodea* in pool
• Marginal *Rorippa amphibia*	• *Fontinalis* in riffle
• Marginal *Agrostis*	• *Nuphar* in flowing water
• Marginal *Phalaris*	[• Other submerged macrophytes]

* unclear from the classification whether one group or two

Some qualifications (before the practical application of a functional habitat set) are indicated from the original data and from the lists of 'preferential species' reported by TWINSPAN for each dichotomy. The necessary element of interpretation can be described with reference to the groups –

"Sand". The sand samples separated cleanly from the remainder at an early stage in the classification. Replicates from sand above riffles, below riffles and from point bars then became

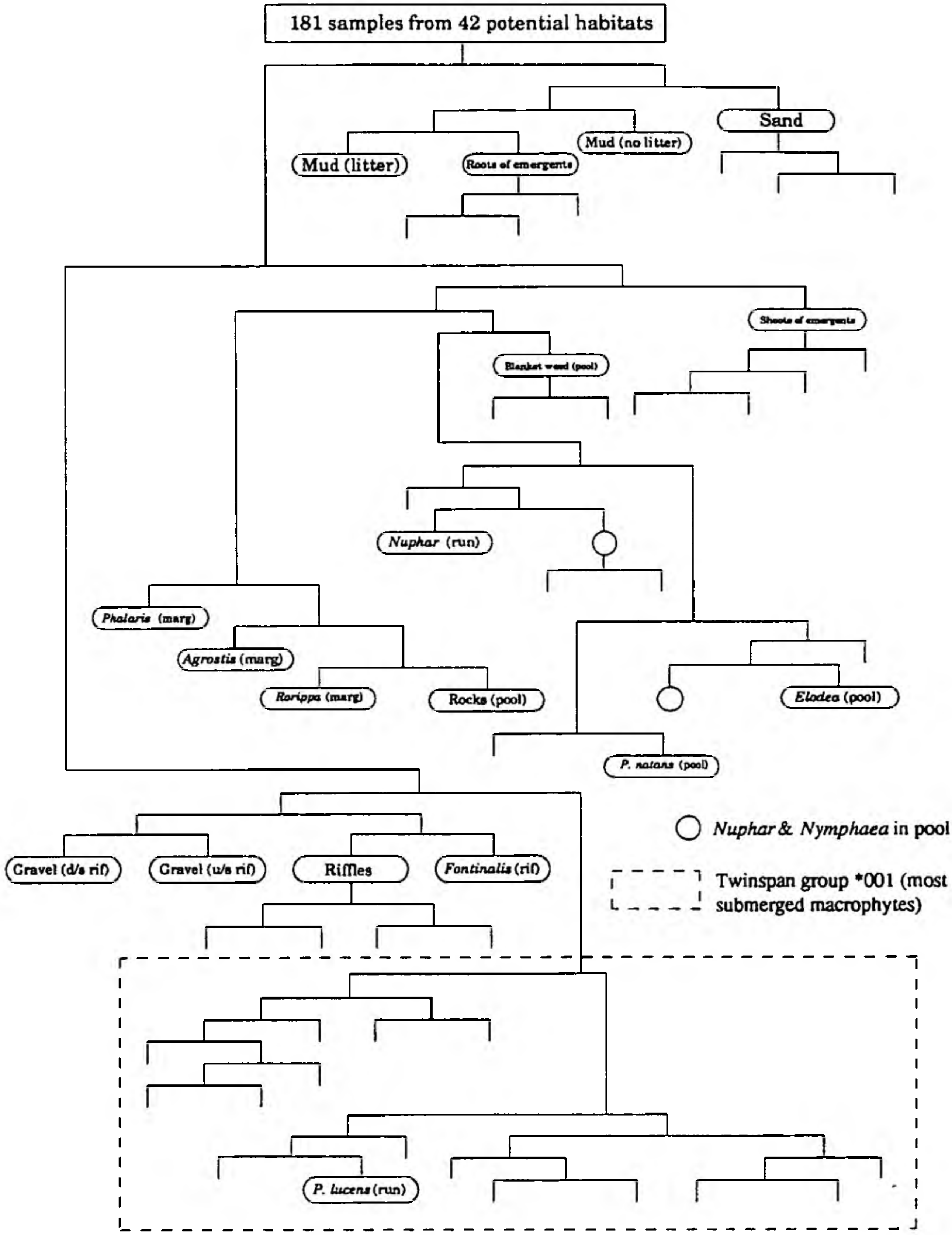


Figure 5.2 TWINSPAN classification of functional habitats

mixed, indicating 'sand' as a single habitat. The division which isolated the sand samples was almost entirely decided by absence of species from sand: 25 species present in the mud and root samples were absent from sand, whilst only one uncommon chironomid species was confined to sand samples. The proper treatment seems to be to count sand as a habitat only if it is the sole substrate.

"Mud with litter" and "Mud without litter". These separated as discrete groups of replicates in consecutive levels of the classification (Figure 5.3).

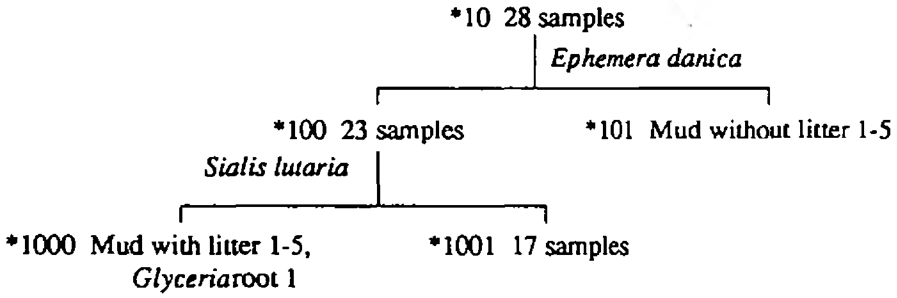


Figure 5.3 Division of 'mud' samples within the classification

Considering all the replicates, 31 taxa occurred in both mud habitats, 18 species only in mud with litter and 15 species only in mud without litter. The habitats contribute sufficient separate species to be treated as distinct.

"Gravel d/s riffle" and "Gravel u/s riffle". Four samples from each of these habitats separated out from group *0000 of the classification. In a similar way to the two classes of mud samples, there were a number of species restricted to one of the habitats (Table 5.4).

Table 5.4 Numbers of individuals in combined replicates from the gravel habitat types

Taxon	d/s rif	u/s rif	Taxon	d/s rif	u/s rif
Simulium equinum larvae	4	2	*Baetis scambus*	39	32
S. erythrocephalum larvae	8	0	*Haliplus* spp. larvae	0	4
Elmis aenea larvae	15	38	*Potamonectes elegans*	5	0
E. aenea adults	6	108	*Helophorinae* larvae	11	5
Limnius volckmari larvae	16	0	*Glossiphonia complanata*	5	9
L. volckmari adults	0	18	*Helobdella stagnalis*	0	4
Oulimnius tuberculatus larvae	17	76	*Erpobdella octoculata*	0	9
O. tuberculatus adults	0	121	*Asellus aquaticus*	27	50
Theodoxus fluviatilis	0	5	*Hydroptila* sp.	4	0
Valvata piscinalis	25	12	*Sericostoma personatum*	0	7
Potamopyrgus jenkinsi	24	8	*Athripsodes aterrimus*	0	5
Bythinia tentaculata	4	2	*Dicranota* sp.	0	13
Physa fontinalis	32	0	Hydracarina	21	92
Ancylus fluviatilis	0	16	Orthocladiinae	0	17
Sphaerium corneum	52	23	*Prodiamesa olivacea*	5	0
Ephemerella ignita	25	15	Tubificidae (hair chaetae)	55	129
Caenis luctuosa	0	8	Tubificidae (no hair chaetae)	0	114
Baetis rhodani	10	0	Lumbriculidae	25	116
			Haplotaxis gordioides	11	0

It does not seem that species found only upstream or downstream of riffles were present only due to drift from pools and riffles respectively. For example, there were several times as many Elminthidae in samples from upstream of riffles as downstream, suggesting an active upstream movement. The habitats are distinct but need not be considered separately in surveys for assessment. The quantitative enhancement of fine gravels may be a management option but their distribution around the riffle-pool system is carried out during high flows.

"Rocks in pool". This habitat was unusual in that substrate characteristic of fast water was present in a slack. It occurred in the lee of a road bridge and was present due to scouring of finer sediment during high flows. The rocks themselves originated as ballast eroded from the foundations. No such large rocks occur elsewhere in the channel and so it may be inappropriate to include "rocks in pool" in a general list of desired, appropriate habitats.

"Riffle substrate". Samples were taken to avoid rooted macrophytes since these were treated as possible habitats in their own right. Macroinvertebrates which are characteristic of coarse particles in flowing water (*e.g.* Elminthidae, Hydropsychidae) are well known, but the diversity of species taken in the riffle samples emphasised that the riffle substrate contains particles over a broad size range.

"Roots of emergent plants" and "Shoots of emergent plants". Both of these groups formed by the mixture of replicate samples from four macrophyte species. Since the provenance of the two habitats is the same, the habitats can be combined as "Emergent plants".

"Marginal *Phalaris*", Marginal *Agrostis*" and "Marginal *Rorippa*". The habit of these macrophyte species differed and so the samples were less nearly equivalent than those from, for instance, submerged macrophytes. Consequently the groups of invertebrates captured may have been influenced by the sampling method. *Phalaris* was rooted above the summer water level and the shoots nearest to the water line hung into running water. It was sampled by sweeps with a hand-net. The shoots of both *Agrostis* and *Rorippa* were cut individually, having first swept with a hand-net. There was less disturbance prior to sweeping the *Phalaris*, capturing mobile surface-dwelling bugs which may have left the other habitats before they were sampled. It was not practical to remove *Rorippa* stems without disturbing the substrate, and numerous Oligochaeta present in the *Rorippa* samples but absent from *Agrostis* probably reflect this problem. Although recognising that sampling methods affected the species composition of the samples in these cases, there were 'preferential' species not apparently related to differences in sampling. There is then not enough reason to over-ride the results of the classification and group the habitats.

"*Nuphar* in pool" and "*Nymphaea* in pool". It is unclear from the classification whether these two macrophyte species are equivalent or distinct as habitats. Aside from scarce species the fauna of the two habitats was very similar (Table 5.5). It then appears that they should be combined as one habitat.

Submerged macrophytes as habitats. Some of the sample sets from submerged macrophytes separated cleanly from other habitats in the classification but the majority, forming group *001, split thereafter in a complex manner. Within group *001, some habitats separated from the remainder clearly (*e.g.* "*Potamogeton lucens* in run" and "*Elodea* in run"), whilst the replicates

Table 5.5 Numbers of individuals in combined replicates from *Nuphar* and *Nymphaea* in pool

Taxon	*Nup.*	*Nym.*	Taxon	*Nup.*	*Nym.*
Oulimnius tuberculatus adults	0	2	*Dugesia lugubris*	33	14
Potamopyrgus jenkinsi	2	2	*Dendrocoelum lacteum*	0	1
Bythinia tentaculata	8	2	*Theromyzon tessulatum*	5	11
Lymnaea stagnalis	0	2	*Glossiphonia complanata*	2	0
Lymnaea peregra	0	2	*Helobdella stagnalis*	3	7
Physa fontinalis	59	19	*Erpobdella octoculata*	65	26
Planorbis carinatus	3	0	*Asellus aquaticus*	37	29
P. planorbis	1	0	*Crangonyx pseudogracilis*	2	0
P. vortex	94	11	Hydracarina	2	2
P. albus	0	2	Ceratopogonidae	0	1
Centroptilum luteolum	0	3	*Anopheles* sp.	0	1
Cloeon dipterum	0	4	Orthocladiinae	87	45
Nepa cinerea	1	0	*Endochironomus* sp.	1	0
Helophorinae larvae	0	4	*Paratanytarsus* sp.	1	3
Helophorus sp.	24	34	*Rheotanytarsus* sp.	5	3
Chaetarthria seminulum	1	0	*Tanytarsus* sp.	1	0
Polycelis tenuis/nigra	55	12	Naididae	2	55

of several (e.g. *Ranunculus* in riffle" & "*Fontinalis* in run") did not remain together. Different behaviour of replicates in the classification should be, and is, reflected in an ordination (Figure 5.4).

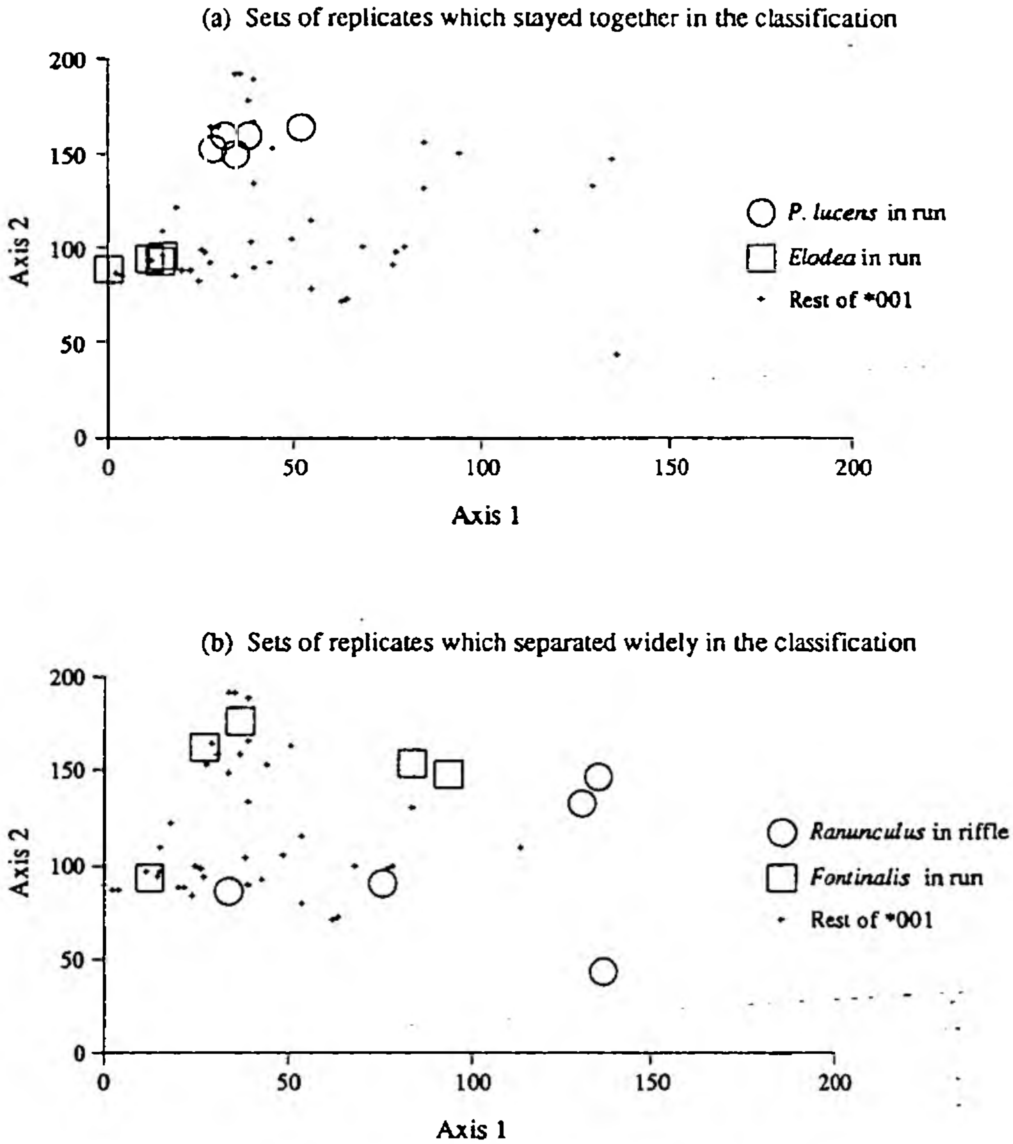
Replicate samples from *Potamogeton lucens* separated together from the main body of submerged plant samples, and strict interpretation to the classification regards it as a functional habitat. The habitat contribution of *P. lucens* to the macroinvertebrate community lies wholly 'within' that of the other submerged plants, however, since the separation is based entirely on absence of species from *P. lucens*. It then seems justified not to regard *P. lucens* as a separate functional habitat.

5.4 Discussion

When the classification method was applied to a simple set of data which involved three very distinct habitats, it resolved the differences between samples with as much clarity as would a formal statistical test (Section 4). The use of replicate samples was found to be suitable as a means of identifying objective stopping-points for TWINSPAN.

The classification applied to a large number of habitats provided a set of habitat groups which had more 'between-group' variation than 'within-group' variation with respect to their associated macroinvertebrate assemblages. In principle this list could be used in two ways to assess habitat status:

1. Provision of a habitat 'score' analagous to the BMWP score. Studies carried out by Anglian Water on tributaries of the River Nene some years ago, based on work by



Ordinations were calculated using detrended correspondence analysis (DECORANA Hill 1979b)

Figure 5.4 Ordination of habitat samples (TWINSPAN group *001)

Barham (unpublished thesis), showed that such a method produced meaningful results using simpler measures of habitat diversity. Although the absolute value of such a score would vary seasonally, comparisons between sites would identify those which most required attention.

2. Identification of specific shortfalls in habitat richness at a site and the recommendation of appropriate enhancement measures. To some extent this is current practice in river corridor surveys, but the habitat requirements of most invertebrates are not explicitly accounted for during such surveys.

The habitat list included twenty groups but some modification of the list was needed to satisfy points of common sense. The process of interpreting classification results is open to criticism in the present context since it reintroduces an element of subjective judgement which the method was designed to eliminate. While sometimes necessary (e.g. recognising *P. lucens* as a special case), such changes to the classification should be made with caution. The problem could be mitigated by the way in which habitat objectives are described, for assessment in the field and for management recommendations. For example 'The presence of at least one submerged macrophyte species is important, preferably not *P. lucens* alone' – this also recognises that additional submerged macrophyte species enhance habitat value to some extent. A scheme is suggested in outline for determining the number of distinct macroinvertebrate habitats in a length of the River Welland (Figure 5.5).

Gravel ?	☐	Run – *Nuphar* ?	☐
Riffle ?	☐	Pool – *Nuphar* or *Nymphaea* ?	☐
– with *Fontinalis* ?	☐	– *Elodea* ?	☐
Mud – with leaf litter ?	☐	– Blanket weed ?	☐
– without leaf litter ?	☐	Other submerged plants ?	☐
If none above, sand ...	☐	– how many (for info) ?	☐

Margins – 'reeds' ?	☐		
– *Rorippa* (or similar) ?	☐	Total Score	☐
– *Phalaris* ?	☐		
– *Agrostis* (or similar) ?	☐		

Figure 5.5 Checklist for assessing habitat richness for benthic macroinvertebrates (River Welland)

The final list of habitats is not far from that which would be constructed intuitively. This may indicate either that our knowledge of the habitat preferences of macroinvertebrates is equal to the practical limitations of the method; or less constructively, that the method does not in practice "... let the distribution of species define the list of habitats" (Section 4).

A large proportion of the variation in species composition is attributable to differences in substrate and flow, which are intimately linked to the riffle-pool system. We can make positive recommendations with respect to the current status and appropriate enhancement of that system (Section 2.3). The diversity of marginal vegetation, which provides another several distinct habitats, is similarly linked to the character of the bank, and of the bed around normal water level. Conservation measures in respect of the bankside are well-known (for example, Lewis and Williams 1984). This information complements that regarding macroinvertebrate biomass (Section 2) in stressing the importance of major channel features.

Attention to shortfalls in habitat availability, probably during channel maintenance, can be predicted to have a beneficial effect on species richness. While naturalness is an important objective for conservation, the status of a stretch of river can be considered in the context of the whole river. The flow at some sites on the River Welland is impounded, but the intermittent artificial ponding enhances overall habitat diversity of the catchment and adds to the visual amenity and fisheries value.

5.5 Recommendations

5.5.1 Habitat assessment

Conservation assessment on the River Welland should have strong regard for habitat richness. The checklist given in Figure 5.5 forms the basis for a macroinvertebrate habitat element in surveys, from which priorities for maintenance and enhancement can be identified.

The reach from which the list was compiled is particularly habitat-rich and shortfalls should be viewed in the context of the catchment. Macrophyte species may be absent from a reach for local reasons which respond to local management, or their absence may reflect general trends (Section 3) which will only change through catchment-scale management for water quality.

5.5.2 Margins

The classification showed that the two main sources of habitat richness were physical variation (associated with the riffle-pool system) and marginal macrophytes. The 1968-1970 capital scheme left a very poor margin which has redeveloped in few places. There is much potential for the enhancement of overall habitat value through restoration of varied margins.

The mainstream of the River Welland is an extensive length of channel which has been modified to a constant margin design over a short period (1968-1970). A systematic study of the current state of the margins would provide good information on the mode of recovery of reduced margins, whilst also producing a strong set of recommendations for enhancement.

6 RIVER WISSEY – FUNCTIONAL HABITAT CLASSIFICATION

6.1 Study site

The River Wissey is of a similar size to the River Welland. There is a high groundwater contribution to discharge in the chalk catchment and consequently it is a less eutrophic stream than the Welland, also with less tendency for spates. Results of biological monitoring by the water authority have shown that the macroinvertebrate community is different from that of the River Welland. The study reach was a 3 km length of the river upstream of the A1065 road bridge at Mundford (TL 807 944).

6.2 Data collection

During August 1989, 95 samples were taken from 19 potential habitats (Table 6.1). Sampling methods were those described for the River Welland study (Section 5.2).

Table 6.1 Potential habitats sampled in August 1989

	(••• replicates)
Blanket weed	
Cladophora glomerata (flowing •••••)	
Submerged macrophytes	
Fontinalis antipyretica (broken •••••)	*Potamogeton pectinatus* (flowing •••••)
Ranunculus penicillatus (flowing •••••)	*Potamogeton lucens* (flowing •••••)
Berula erecta (flowing •••••)	*Schoenoplectus lacustris* (flowing •••••)
Sagittaria sagittifolia (flowing •••••)	
Emergent macrophytes	
Sparganium erectum (shoots ••••• & roots •••••)	*Schoenoplectus lacustris* (shoots ••••• & roots •••••)
Veronica beccabunga (shoots •••••)	*Glyceria maxima* (shoots ••••• & roots •••••)
Particulate substrates	
Gravel (•••••)	Sand (•••••)
Silt/mud with no leaf litter (•••••)	Riffle substrate, i.e. broad particle size range (•••••)

In sampling the Welland, replicates were usually from different examples of the same habitat – this was less often possible in sampling the River Wissey. The Wissey study site was widened some years ago. Due to the stability of the flow regime, the stream edge still has a near-vertical 0.5-1 m bank and similar depth of water in most places. Emergent macrophytes (*Glyceria maxima, Sparganium erectum, Schoenoplectus lacustris*) were therefore infrequent and it was not possible to take each sample from a different stand. Submerged *Berula erecta, Schoenoplectus lacustris* and *Sagittaria sagittifolia* were also infrequent (two stands, one stand and one stand respectively).

The River Wissey is of low gradient and had a less well developed riffle-pool system than the River Welland, which led to a reduced number of potential habitats distinguished by flow.

Slow (not slack) pools were present but their substrate was very loose silt which supported no macrophytes. Only two riffles with broken water and distinctly coarser substrate occurred on the study reach, one of which was small; the other shallow and shaded on one arm of a bifurcation. The majority of the bed of the river was gravel with various proportions of sand/silt, grading through to the silty pool substrate.

Samples were stored in a cold room at 4 °C and live-sorted within two days of collection (usually within 12 hours), with subsampling of groups represented by more than 50-100 individuals. Further identification was carried out in most cases to species (Table 6.2) as described in Section 5.2. Chironomidae were treated in more detail than during the Welland study; all were identified to genus and many to species level. The data are given as Section 10 of the Annex to this report.

Table 6.2 List of taxa from River Wissey habitat samples

Valvata piscinalis	*Potamopyrgus jenkinsi*	*Bythinia tentaculata*	*Lymnaea palustris*
Physa fontinalis	*Planorbis carinatus*	*Planorbis vortex*	*Planorbis albus*
Planorbis contortus	*Ancylus fluviatilis*	*Acroloxus lacustris*	*Sphaerium corneum*
Pisidium sp.			
Ephemera danica	*Ephemerella ignita*	*Ecdyonurus insignis*	*Caenis rivulorum*
Caenis luctuosa	*Baetis rhodani*	*Baetis scambus*	*Baetis vernus*
Centroptilum luteolum	*Centroptilum pennulatum*	*Cloeon dipterum*	
Leuctra nigra	*Leuctra geniculata*	*Nemoura* sp.	
Corixidae nymph	*Sigara dorsalis*	*Sigara falleni*	*Sigara venusta*
Callicorixa praeusta			
Elmis aenea larva	*Elmis aenea* adult	*Limnius volckmari* larva	*Limnius volckmari* adult
Oulimnius tuberculatus larva	*Oulimnius tuberculatus* adult	*Haliplus* larva	*Haliplus fluviatilis*
Brychius elevatus	*Potamonectes elegans*	*Oechthebius minimus*	*Helochares lividus*
Helophorinae larva	Dytiscinae larva	Gyrinidae larva	*Hydraena gracilis*
Anacaena limbata			
Polycelis tenuis/nigra	*Dugesia lugubris*	*Dendrocoelum lacteum*	
Piscicola geometra	*Theromyzon tessulatum*	*Hemiclepsis marginata*	*Glossiphonia complanata*
Helobdella stagnalis	*Erpobdella octoculata*		
Asellus aquaticus	*Crangonyx pseudogracilis*	*Gammarus pulex*	
Sialis lutaria			
Rhyacophila dorsalis	*Polycentropus flavomaculatus*	*Agapetus fuscipes*	*Hydropsyche pellucidula*
Hydropsyche angustipennis	*Hydropsyche contubernalis*	*Hydropsyche siltalai*	*Hydroptila* sp.
Sericostoma personatum	*Lepidostoma hirtum*	*Athripsodes aterrimus*	*Athripsodes cinereus*
Mystacides azurea	*Limnephilus lunatus*	*Limnephilus rhombicus* gp	*Halesus radiatus*
Potamophylax rotundipennis	*Chaetopteryx villosa*	*Anabolia nervosa*	*Silo nigricornis*
Simulium angustipes larva	*Simulium angustipes* pupa	*Simulium equinum* larva	*Simulium equinum* pupa
Simulium erythrocephalum larva	*Simulium erythrocephalum* pupa	*Simulium ornatum* larva	*Simulium ornatum* pupa
Ephydridae	Tipulidae (not *Dicranota* sp.)	*Dicranota* sp.	Ceratopogonidae
Anopheles sp.	Tabanidae	Muscidae	Psychodidae
Rhagionidae	Dixidae	*Procladius* sp.	*Macropelopia* sp.
Ablabesmyia sp.	*Thienemannimyia* sp.	*Psectrocladius* sp.	*Corynoneura* sp.
Thienemanniella sp.	*Epoicocladius flavens*	*Rheocricotopus fuscipes*	*Synorthocladius semivirens*
Cricotopus sylvestris	*Cricotopus bicinctus*	*Nanocladius rectinervis*	*Eukiefferiella claripennis*
Eukiefferiella sp B	*Tvetenia calvescens*	*Microtendipes* sp A	*Microtendipes* sp B
Cryptochironomus sp.	*Demicryptochironomus* sp.	*Endochironomus* sp.	*Paratendipes* sp.
Polypedilum sp A	*Polypedilum* sp B	*Rheotanytarsus* sp.	*Cladotanytarsus* sp.
Tanytarsus sp.	*Chironomus* sp.	*Potthastia longimana* gp.	*Prodiamesa olivacea*
Tubificidae (hair chaetae)	Tubificidae (no hair chaetae)	Naididae	Lumbriculidae
Haplotaxidae	Lumbricidae		
Hydracarina			

The main qualitative features of the species list for the River Wissey as compared to the River Welland (Table 5.2) were a greater richness of Trichoptera and a lesser richness of Hemiptera and Odonata. The former probably reflects differences in water chemistry and flow regime, while the latter can be attributed to a paucity of pool-based habitats on the River Wissey. As stated previously, the treatment of Chironomidae identification was more detailed for the River Wissey and this is reflected in the greater number of taxa recognised.

6.3 Data analysis

The multivariate analysis described in Section 4 was applied to the data obtained in August 1989. Pseudospecies cut levels were set at 0, 10, 100 and 1000. All other options within the calculation were set to the defaults, except that the maximum number of divisions was made large enough to run to a stopping point on each branch of the classification. The classification is summarised in Figure 6.1, and presented in greater detail as Section 11 of the Annex to this report (TWINSPAN output) and Appendix E (graphical representation).

The classification suggested little grouping of the potential habitats and so the derived list of functional habitats (Table 6.3) closely resembles the original list (Table 6.1).

Table 6.3 List of habitats indicated by the classification

- Sand
- Gravel
- Silt (no leaf litter)
- Riffle substrate
- Marginal *V. beccabunga*
- *Sparganium* shoots [1]
- *Schoenoplectus* shoots [1]
- *Glyceria* shoots [1]
- *Fontinalis* in riffle
- *Cladophora* in run
- *Ranunculus* / *P. pectinatus* in run [2]
- *Berula erecta* in run [2]
- *Schoenoplectus* in run [2]
- *Sagittaria* in run [2]
- *Sparganium* roots [3]
- *Schoenoplectus* roots [3]
- *Glyceria* roots [3]

Contrast with River Welland where :
[1] Shoots of emergent macrophytes grouped
[2] Most submerged macrophytes grouped
[3] Roots of emergent macrophytes grouped
(these may have grouped on the Wissey also)

The functional habitats indicated by the classification can be considered in relation to the data and in comparison to the functional habitats derived for the River Welland (Section 5).

"Sand". The sand samples separated cleanly from the remainder at an early stage in the classification. The division which isolated the sand samples was almost entirely decided by absence of taxa from sand: 48 taxa present in the gravel samples were absent from sand, whilst only three taxa were confined to sand samples. Of those three, Simulium angustipes larvae and Naididae were surely not genuinely supported by the substrate and were present in far greater numbers elsewhere. Prodiamesa olivacea was more numerous in silt samples. The proper

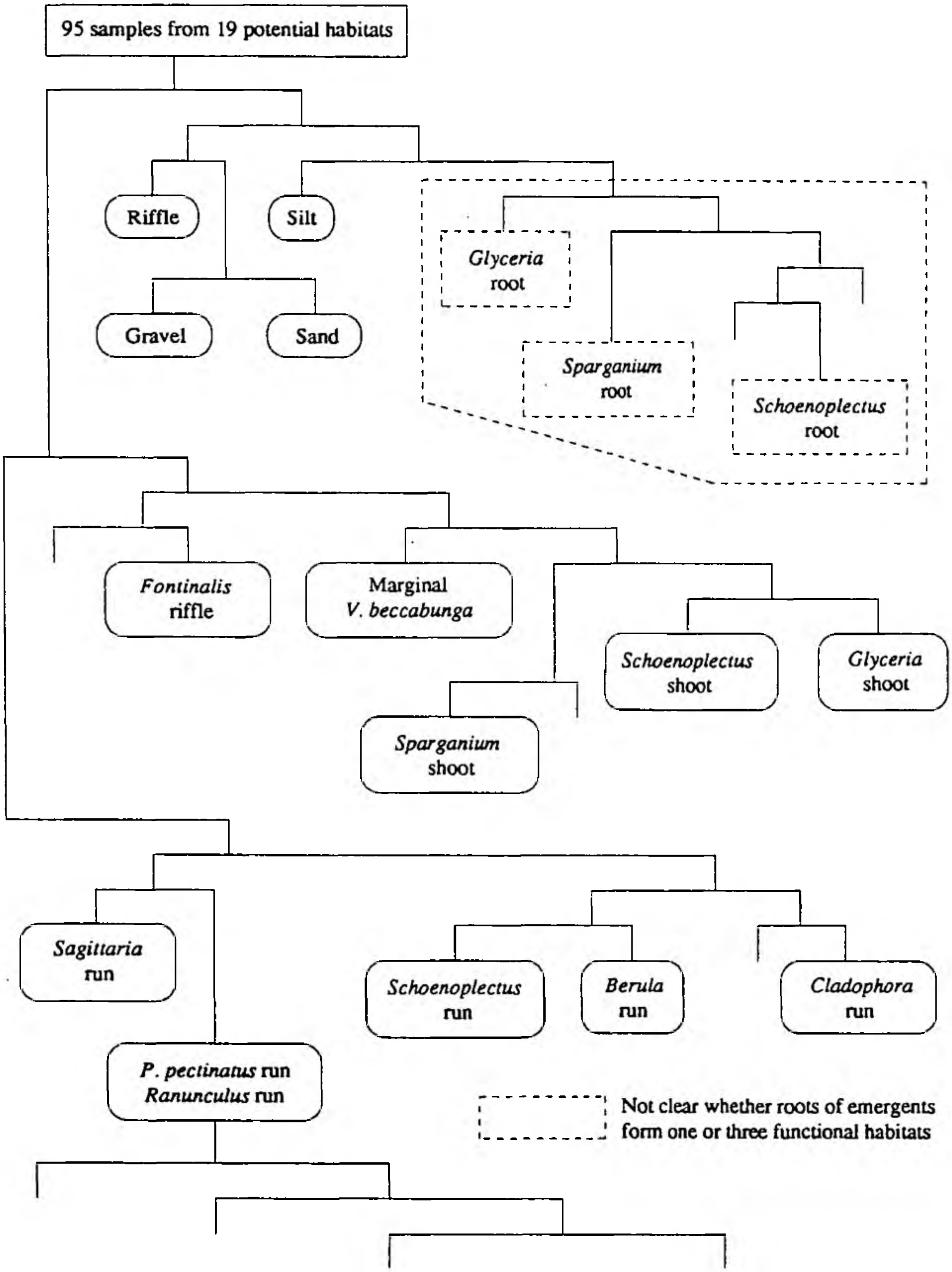


Figure 6.1 TWINSPAN classification of functional habitats

treatment, as for the River Welland, seems to be only to count sand as a habitat if it is the sole substrate.

"Silt" and "Gravel". The samples from these habitats separated from the classification at the third and fourth levels respectively. On the River Welland it was appropriate to distinguish between silt ('mud') which contained leaf litter and that which did not. None of the Wissey silt samples contained noticeable amounts of leaf litter–it was spread more evenly within the channel. The weaker riffle-pool system of the low-gradient Wissey similarly made distinction of gravel above and below riffles inappropriate.

"Riffle substrate". The riffle samples separated from the others at the third level of the classification. The riffle substrate did not support a set of taxa as large as that on the River Welland (mean 33 taxa per sample) – this was especially true of the shallow shaded riffle (Table 6.4, samples C, D and E).

Table 6.4 Macroinvertebrate taxa from River Wissey riffle samples

Taxon	A	B	C	D	E	Taxon	A	B	C	D	E
Simulium angustipes	120	22	4	6	5	*Dendrocoelum lacteum*		1			
S. equinum	256	42	9	22	6	*Glossiphonia complanata*			1	1	
S. erythrocephalum	8	16	3	6		*Erpobdella octoculata*			1		1
S. ornatum	16	2	1	2	2	*Gammarus pulex*	87	30	12	32	51
Elmis aenea larva	3	6		2	2	*Hydropsyche pellucidula*	2	2		2	2
E. aenea adult	3				1	*Polycentropus flavomaculatus*					1
Limnius volckmari larva	3	7	4	8	15	*Rhyacophila dorsalis*	1			2	
L. volckmari adult		1				*Agapetus fuscipes*	1				
Oulimnius tuberculatus larva		2				Tipulidae (not *Dicranota* sp)	1				
Bythinia tentaculata				1		*Dicranota* sp.	34	14	10	21	28
Planorbis albus			1			Hydracarina	6				1
Ancylus fluviatilis		1			1	*Polypedilum* sp. A	1	1			
Sphaerium corneum		7		4	3	*Demicryptochironomus* sp.		1			
Ephemera danica		2		1	2	*Synorthocladius semivirens*	6		1	1	
Ephemerella ignita	3	1		1		*Eukiefferiella claripennis*	1				
Baetis rhodani	1					Tubificidae (hair chaetae)	2	1	2	2	
Baetis scambus	12		1			Tubificidae (no hair chaetae)	4			2	2
Baetis vernus	1					Naididae			1		
Leuctra nigra	5	1			1	Lumbriculidae	32	16	3	19	4
Gyrinidae larva	1	1				Lumbricidae		2	1		
						Number of taxa	25	23	16	19	19

"Marginal *Veronica beccabunga*". This was the only herbaceous macrophyte found in the limited margins at the River Wissey study reach. The samples separated with the shoots of emergent macrophytes (and thence from them), except for one replicate which classified with the riffle samples.

"Shoots of *Schoenoplectus lacustris*", "Shoots of *Sparganium erectum*" and "*Shoots of Glyceria maxima*". 'Shoots of emergent macrophytes' classified as a functional habitat in the

River Welland classification, whilst the shoots of separate species remained as discrete habitats in the River Wissey classification. There are two main factors which might have contributed to the difference in classification of the habitats between the two rivers. They are not mutually exclusive –

- Habitat specificity of species found or identified only on the River Wissey
- Failure to account for the full 'within-habitat' variation on the Wissey

The species which most distinctly occurred in a subset of the 'shoots of emergent macrophytes' habitats are shown in Table 6.5 and discussed subsequently with respect to the two factors.

Table 6.5 Taxa with widely different occurrences on the shoots of emergent macrophyte species

	G. maxima	*S. lacustris*	*S. erectum*
Simulium angustipes pupa	8	1	
S. erythrocephalum larva	1	10	2
Elmis aenea larva	27		3
Planorbis vortex	7	1	4
Ancylus fluviatilis			25
Acroloxus lacustris	11	77	
Ephemerella ignita	5		16
Baetis scambus	2		11
Gyrinidae larva	46		5
Theromyzon tessulatum	11	3	2
Helobdella stagnalis			4
Crangonyx pseudogracilis	4	2	7
Psychodidae	7		
Thienemannimyia sp.	3		26
Naididae	1	25	143

Species shown are those which occur in at least four samples from at least one habitat and yet are absent from at least four samples from at least one habitat. *Ancylus fluviatilis*, which does not fulfil these criteria, is shown for comparison with *Acroloxus lacustris*.

Some of the species on the Wissey (as a less eutrophic stream) might have narrower environmental tolerances, and hence habitat requirements, than those on the Welland. The species to which this hypothesis is most applicable intuitively, namely the diverse Trichoptera, do not appear in Table 6.5. The concept of environmental tolerance in terms of habitat specificity, however, goes beyond the chemical tolerance which is most often considered. *Acroloxus lacustris* and Gyrinidae larvae were not present on the River Welland, whilst the chironomid *Thienemannimyia* may or may not have occurred within 'Tanypodinae indet.' on the Welland. Other species which do not qualify for inclusion in Table 6.5 were also new on the Wissey, such as the beetles *Anacaena limbata* and *Oechthebius minimus*, the caddis *Lepidostoma hirtum* and the chironomid *Nanocladius rectinervis*.

Whilst emergent macrophyte samples on the Welland were from different stands, those on the Wissey were often from the same stand, reflecting their availability on the study reach.

Differences in microhabitat unrelated to the identity of the macrophyte may therefore have had greater influence on the habitat classification for the Wissey. Some of the taxa appearing in Table 6.5 are characteristic of flowing water (*Elmis aenea* larva, *Ephemerella ignita, Baetis scambus*); and *Simulium erythrocephalum* larvae cannot feed without a flow of water. *Acroloxus lacustris* is widely held to be characteristic of slow-moving or still water in contrast to *Ancylus fluviatilis*. The classification of the shoots of emergent macrophytes may then have arisen from their position with respect to the current as much as from their identity. This could equally be true for the Welland, where the greater independence of the 'replicate' samples within each habitat would have led to the observed mixing of replicates from different habitats within the classification.

Both of the factors suggested as leading to separation of the emergent macrophytes may have been important. Species which were found or identified only on the Wissey do occur amongst those in Table 6.5, so this factor cannot be discounted. Most of the species in the table were found in both rivers, so the second listed factor may be at least as responsible for the observations as the first.

"Roots of *Schoenoplectus lacustris*", "Roots of *Sparganium erectum*" and "Roots of *Glyceria maxima*". 'Roots of emergent macrophytes' was indicated as a functional habitat by the River Welland classification. The classification of the roots of emergent macrophytes on the River Wissey was not clearly either as one group or as three groups. The same two factors which may have influenced division of the shoot samples could apply to the root samples, namely that the Wissey species displayed narrower habitat specificity, or that sampling failed to represent fully the 'within-habitat' variation.

The species which most distinctly occurred in a subset of the 'roots of emergent macrophytes' habitats are shown in Table 6.6.

Table 6.6 Taxa with widely different occurrences on the roots of emergent macrophyte species

	G. maxima	*S. lacustris*	*S. erectum*
Elmis aenea larva	6		3
Bythinia tentaculata	109	4	
Sphaerium corneum	13	2	1
Pisidium sp.	6	3	
Ephemera danica		1	7
Leuctra nigra	29	2	2
Polycelis tenuis/nigra	18	1	6
Lepidostoma hirtum			7
Ceratopogonidae	3	29	7
Tanytarsus/Micropsectra sp.	2	26	13

Species shown are those which occur in at least four samples from at least one habitat and yet are absent from at least four samples from at least one habitat.

Leuctra nigra and *Lepidostoma hirtum* were not present on the River Welland. Species not included in Table 6.6 were also identified only on the Wissey, namely Gyrinidae larvae, *Polycentropus flavomaculatus*, *Athripsodes cinereus* and chironomids such as *Thienemannimyia* and *Rheocricotopus fuscipes*. Of taxa identified only from the River Wissey, there were ten (including five chironomids) associated with root samples as compared with 15 (five chironomids) associated with the shoots of emergents.

Current speed was suggested as a microhabitat factor in the classification of samples from the shoots of emergent macrophytes. Several of the species listed in Table 6.5 have known requirements with respect to flow but Table 6.6 includes only *Elmis aenea* larvae. The factor may still play a role in deciding the root classification – either through indirect effects of flow *via* substrate composition, or through other environmental differences between the location of the macrophyte species.

Submerged macrophytes as habitats. "*Cladophora* in run" and "*Fontinalis* in riffle" separated from the other habitats, as they did on the River Welland. The other submerged macrophytes sampled on the Welland generally classified in a complex way. Sets of replicates from the River Wissey often remained more separate in the classification, in which case they were indicated as discrete functional habitats.

Samples from *Potamogeton lucens* did not remain together in the classification but neither did they mix with those of other sample sets in forming a functional habitat. Samples from *Potamogeton pectinatus* and *Ranunculus penicillatus* remained together in the classification to form a functional habitat which might be termed "Thread-leaved submerged macrophytes". The species which most distinctly occurred in a subset of the remaining habitats are shown in Table 6.7.

Table 6.7 Taxa with widely different occurrences on the shoots of three submerged macrophyte species

	B. erecta	*S. lacustris*	*S. sagittifolia*
Simulium angustipes pupa	24		12
S. equinum pupa	44	1	232
S. erythocephalum pupa	165	2	506
S. ornatum pupa	35		106
Physa fontinalis	12	10	1
Sphaerium corneum	7		
Ephemerella ignita	61	14	1
Leuctra nigra	10	1	
Dugesia lugubris	1		
Hydropsyche angustipennis	64	2	
Hydracarina	40	10	1
Rheocricotopus fuscipes	928	30	
Cricotopus sylvestris	198	20	24

Species shown are those which occur in at least four samples from at least one habitat and yet are absent from at least four samples from at least one habitat.

Of the three macrophytes, *Sagittaria sagittifolia* and *Berula erecta* were not present on the River Welland study reach. Their distinction as functional habitats can be ascribed to known characteristics of their fronds and of the macroinvertebrate species which they support. The submerged form of *Schoenoplectus lacustris* is covered with a gelatinous film which may prevent the attachment of *Simulium* larvae and lead to the observed absence of pupae. *B. erecta* has a different habit to the trailing leaves of *S. sagittifolia*, providing the appropriate conditions for *Ephemerella*, *Leuctra*, *Hydropsyche* and Hydracarina. *Rheocricotopus fuscipes* also had a clear preference for *B. erecta*.

The same considerations which applied to emergent macrophytes might be expected to apply to the submerged macrophytes. Two stands of *Berula erecta* were found along the study reach, with only one stand each of the submerged forms of *Schoenoplectus lacustris* and *Sagittaria sagittifolia*. *Ranunculus penicillatus*, *Potamogeton pectinatus* and *P. lucens* were plentiful and so could be sampled in the desired way, at divers locations. The character and species complement of the habitats suggests that their separation would have remained valid if more instances had been available for sampling.

6.4 Discussion

The classification provided a basis for considering the macroinvertebrate species associated with potential habitats on the River Wissey. The way in which emergent and submerged macrophytes classified as habitats differed from the corresponding River Welland classification (Section 5.3). Two possible causes for this were proposed in Section 6.3 and are reiterated here:

1. Habitat specificity of macroinvertebrate species found and identified. It is central to the classification procedure that species with strict habitat requirements have a less general distribution and so play a major role in divisions. The use of four abundance classes as pseudospecies reduces the influence of apparent habitat-specificity by rare species.

2. Failure to account for the full 'within-habitat' variation on the Wissey. To be sure that samples reflect the range of species found in a habitat they need to be taken from a range of examples of the habitat. Otherwise, environmental conditions independent of the habitat definition might decide the classification.

The first cause described above is the reason for – and logical basis of – the classification study. The second, undesirable factor could produce an unduly high number of functional habitats from the range of habitat types sampled. There were limited instances of several macrophyte habitats within the study reach on the River Wissey and consequently the replicates probably did not represent the full range of environmental conditions in which each habitat occurred. This introduced uncertainty in the interpretation of the classification (Section 6.3) and therefore into a scheme for determining the number of distinct macroinvertebrate habitats in a length of the River Wissey (Figure 6.2).

The results showed that macroinvertebrate habitats on the Wissey could be determined using a classification method. The resulting list of habitats was for the most part similar to that which had been found for the River Welland. Uncertainty in the interpretation of some results illustrated the importance of site selection. There were insufficient instances of several habitats within the study reach, which should have been extended until independent occurrences of each habitat were found.

Gravel ?

Riffle ?

- with *Fontinalis* ?

Mud/silt ?

If none above, sand ...

Run – *Schoenoplectus* ?

- *P. pectinatus* or *Ranunculus* ?
- *Berula* ?
- *Sagittaria ?*
- Blanket weed ?

Other submerged plants ?

- how many (for info) ?

Margins – *Glyceria* [1] ?

- *Sparganium* [1] ?
- *Schoenoplectus* [1] ?
- *V. beccabunga* (or similar) ?

[1] These may be equivalent

Total Score

Figure 6.2 Checklist for assessing habitat richness for benthic macroinvertebrates (River Wissey)

6.5 Recommendations

6.5.1 River Wissey

The study did not aim explicitly to recommend conservation management for the River Wissey and so no general catchment survey was carried out. At least at the Mundford study site, prior channel modifications have had a lasting effect which is of concern.

The catchment area is much less than that of the Welland at Ketton (Section 5), yet the channel has been widened throughout to a greater extent. Physical uniformity along the channel may be due in part to the shallow gradient, but may also have arisen through reduced competence after widening. If present requirements for channel capacity permit, management of the river should encourage variation of flow and the streambed through local narrowing or redistribution of bed material.

The river should support a rich marginal flora with both herbs and tall emergents but fails to do so. Margins at the study site were even less extensive than those on the middle River Welland, where bankside erosion has introduced some shelves. The introduction of physical diversity to the margins would make little difference to the overall channel capacity, whilst it would benefit the flora and other groups such as fish fry and small mammals.

6.5.2 Functional habitat methodology

Replication

The classification procedure on the River Wissey emphasised the importance of selecting a range of replicates of each habitat type. It was unclear in several cases whether habitats were truly distinct, or whether their separation resulted from environmental variation between individual sites. Sampling for future applications of the method should only be carried out after a survey of the distribution of each 'potential habitat' on the river. This will allow a representative set of samples to be taken, lengthening the initially-selected study reach if necessary.

General appraisal

No fundamental difficulties were encountered in applying the method to either of the study rivers. The main criteria for success are correct replication of habitats and the equivalence of samples from diverse habitat types. Careful preparation has been identified as the main requirement for correct replication. The abundance categories of 1-9, 10-99, etc. produce satisfactory results and give enough latitude for different sampling methods to provide equivalent values. The choice of abundance categories should be investigated further using data from the Rivers Welland and Wissey. Categories derived from the distribution of species abundance values might be more appropriate and aid the comparison of data between catchments.

Further development

The Rivers Welland and Wissey are characteristic of a small subset of the main river for which the National Rivers Authority has responsibility. Functional habitats provide an effective basis for conservation management which could be used on the majority of rivers. To do this requires that the important habitats are identified for other river types, using the method described in Sections 4-6 of this report.

7. RIVER KYM – LIMITED HABITAT SET

7.1 Study site

The River Kym, a tributary of the River Great Ouse, was used for this phase of the study. It is a clay stream like the River Welland but at Hail Weston (TL 166 625 - TL 175 619) the flow and depth are dominated by 'ponding' due to a succession of bridge foundations and a gauging station weir. The catchment area – and therefore discharge – is less than that of the Welland study reach (Section 5.1), but through past management the size of the channel is similar. Habitats associated with a riffle-pool system were absent in the 5 km study reach but were sampled for reference at a nearby upstream site.

7.2 Data collection

Single samples were taken from 26 potential habitats on the River Kym study reach during August 1989, using the same sampling methods as on the River Welland (Section 5.2). A further six samples were taken as a control from a nearby upstream site where a limited riffle-pool system occurred. The resources required for replicate sampling and indicator species analysis would not be available for routine assessment or for most in-house site investigations. Replicate samples were therefore not taken (Figure 7.1).

Table 7.1 Potential habitats sampled in August 1989

Blanket weed	
Cladophora glomerata in pool	
Floating-leaved macrophytes	
Floating *Nuphar lutea* pads (deep)	Floating *Nuphar lutea* pads (shallow)
Lemna minor (locally abundant at study site)	
Submerged macrophytes	
Fontinalis antipyretica (slow run)	*Myriophyllum spicatum*
Submerged *Nuphar lutea* pads (deep)	Submerged *Nuphar lutea* pads (shallow)
Potamogeton pectinatus with *Cladophora glomerata*	*Potamogeton crispus*
Fontinalis antipyretica in shallow run *	*Fontinalis antipyretica* in riffle *
Emergent macrophytes	
Glyceria maxima (whole plant)	Shoots of *Butomus umbellatus*
Roots of *Butomus umbellatus*	Shoots of *Sparganium erectum*
Emergent macrophytes (continued)	
Roots of *Sparganium erectum*	Shoots of *Schoenoplectus lacustris*
Roots of *Schoenoplectus lacustris*	*Sagittaria sagittifolia*
Emergent *Alisma plantago-aquatica*	
Particulate substrates	
Silt bank	Sand, gravel, silt and vegetation
Clay and Stones	Gravel (shallower run)
Silt in pool	Mud
Shaded riffle (kick sample) *	Mud with wood and leaves *
Riffle based on solid clay *	Gravel riffle *
Other	
Salix sp. roots	

* sampled at upstream control site

Samples were stored in a cold room at 4 °C and live-sorted within two days of collection (usually within 12 hours), with subsampling of groups represented by more than 50-100 individuals. Further identification was carried out in most cases to species (Table 7.2) as described in Section 5.2. Taxa requiring lengthy preparation and specialist knowledge were not included in the dataset, to make the information comparable with that available to any practising aquatic biologist. The data are given as Section 12 of the Annex to this report.

Table 7.2 List of taxa from River Kym

Valvata piscinalis	*Valvata cristata*	*Potamopyrgus jenkinsi*
Bythinia tentaculata	*Lymnaea pereger*	*Lymnaea stagnalis*
Physa fontinalis	*Planorbis carinatus*	*Planorbis vortex*
Planorbis albus	*Planorbis contortus*	*Planorbis complanatus*
Planorbis crista	*Ancylus fluviatilis* *	*Acroloxus lacustris*
Sphaerium corneum	*Anodonta cygnaea*	
Caenis luctuosa	*Baetis scambus* *	*Centroptilum luteolum*
Cloeon dipterum	*Cloeon simile*	
Corixidae nymph	*Sigara dorsalis*	*Sigara falleni*
Sigara fossarum	*Notonecta maculata*	*Gerris lacustris*
Gerris nymph		
Elmis aenea larva *	*Elmis aenea* adult *	*Oulimnius tuberculatus* larva
Oulimnius tuberculatus adult	*Haliplus* larva	*Haliplus fluviatilis*
Potamonectes elegans	Dytiscidae larva	Gyrinidae larva
Gyrinus bicolor	*Anacaena bipustulata*	*Stictotarsus duodecimpustulatus*
Dugesia lugubris	*Dendrocoelum lacteum*	
Piscicola geometra	*Theromyzon tessulatum*	*Hemiclepsis marginata*
Glossiphonia heteroclita	*Glossiphonia complanata*	*Helobdella stagnalis*
Erpobdella octoculata		
Asellus aquaticus		
Sialis lutaria		
Hydropsyche angustipennis *	*Hydropsyche siltalai* *	*Athripsodes aterrimus*
Phryganaea grandis	*Tinodes waeneri* *	
S. erythrocephalum larva *		
Psychodidae		

* found only at the control site

7.3 Results

The species found in the Rivers Welland and Kym were similar in many respects, as expected from two neighbouring clay streams. The major habitat difference between the streams was the absence of riffle flow, substrate and associated macrophytes on the ponded section of the River Kym. The main difference between the macroinvertebrate communities of the two rivers was absence of a set of species on the Kym which were common on the Welland, though a small number of species were unique to the Kym (Table 7.3).

Table 7.3 Species absent from one river (Welland or ponded Kym) but present in at least five samples from the other river.

Absent from the River Kym

Simulium ornatum	*Hydropsyche contubernalis*
Simulium erythrocephalum *	*Hydropsyche pellucidula*
Simulium equinum	*Hydropsyche angustipennis* *
Simulium angustipes	*Hydropsyche siltalai* *
Ephemerella ignita	*Leuctra geniculata*
Baetis scambus *	*Theodoxus fluviatilis*
Baetis vernus	*Ancylus fluviatilis* *
Baetis rhodani	*Elmis aenea* *
	Limnius volckmari

Absent from the River Welland

Phryganea grandis	*Platycnemis pennipes*
Acroloxus lacustris	

* Present at the control site on the River Kym

7.4 Discussion

The basis for habitat conservation as a tool is the assumption that species richness follows from habitat richness, subject to limits imposed by chemical water quality. There are three possible approaches to study the effect of habitat composition on the community. Habitat availability could be manipulated experimentally – this would be costly and results long in coming. The effects of habitat enhancement work can be monitored – audit surveys are now frequently implemented on recent projects. The comparison of the Rivers Welland and Kym studied effects of long-standing habitat 'damage' on macroinvertebrate species richness.

All of the species restricted to the Welland were most abundant in habitats defined by more rapid flow and coarse substrate, although they also occurred in some habitats which were present on the Kym. Of the species which were found only on the River Kym, at least *Phryganea grandis* and *Acroloxus lacustris* are characteristic of still and slowly-flowing water. The Kym is effectively a series of long pools. For its channel size in the ponded section it has a small catchment, which must reduce the impact of flood events in this section.

The samples from the upstream, riffle-pool section contained representatives of several groups absent from the ponded section. This confirms that such species are available for colonisation of the ponded section and that their failure to do so is not an artefact of stream size or location. The species richness associated with the rifle-pool section was less than that of the River Welland study site for similar habitats. This is to be expected from the small 'real' size of the stream – it is more comparable with second- or third-order tributaries of the River Welland than with the reach discussed in Section 5.

Larvae of *Oulimnius tuberculatus* were found in many samples from the ponded sections of the River Kym and yet this species is normally characteristic of riffle areas. The distribution of the adults was much less general: they were almost entirely confined to the roots of willow trees.

The environmental conditions there must form a tolerable substitute for the riffle habitat.

With the exception of *Oulimnius*, riffle species were not found on the ponded section even though they were present at an upstream site. The River Welland study, in contrast, found many species occurring in smaller numbers away from their optimum habitat. This is a recurring source of uncertainty in the use of species distributions for habitat classification – within the set of habitats in which a species is observed there is a smaller set which must be represented to sustain a viable population. The concealed requirements could be for egg-laying sites, or needs of a specific life-stage, or even features on a wider spatial/temporal scale. Individuals can also occur in inappropriate habitats through drift (intentional or otherwise) or be recorded in error through passage on sampling equipment. Pseudospecies (categories of abundance) have been used as one measure to lessen the effect of errant individuals on habitat classification (Section 4 *et seq.*). Doubtful occurrences were not explicitly removed from the Welland or Wissey classifications because reproducible criteria are hard to devise; and because the level of independent knowledge about environmental requirements differs between taxa (e.g. Elminthidae are well-studied but information on the Psychodidae is less readily available). There are three main factors which might influence the presence of 'misleading' species in a habitat:

- Abundance of the species. If there are more individuals in the river then there is a greater chance of some moving or drifting to unsuitable habitats.

- Distribution of the main habitat. Species which have true abundance maxima scattered throughout the river are more likely to turn up elsewhere.

- Flow regime. Habitats on rivers with a stable flow regime are less likely to include species carried from other locations.

The study reaches of the River Welland and River Kym differ on these three points with respect to riffle spcies. The riffles on the River Kym were small; and distant from many of the habitats on the ponded section. On the River Welland, for the most part the riffle-pool system was strongly developed and there were ample sources for individuals to pass to other habitats. The clay catchment of the River Welland ensures that storm events at all times of the year can produce flood peaks in the river channel. The engineered channel at the Kym site protects against floods with a long return period, given the smaller catchment. Summer storm events, even though running off clay, must have a lesser impact on water velocity through the ponded section than an equivalent part of the River Welland.

Differences in habitat availability on the Welland and Kym study reaches clearly led to differences in the aquatic macroinvertebrate community. It then follows that attention to the reasons for habitat differences would be as valid as direct attention to the individual macroinvertebrate species. Furthermore, since the faunal differences followed predictably from differences in habitat availability, a habitat survey of the Kym would have been an effective surrogate for the full biological survey described above. The factors governing habitat availability are readily decided; compared with the state of the river; and acted on if possible and appropriate. Recommendations for habitat enhancement might be based in the first instance on the kind of checklist given for the River Welland in Figure 5.5 and shown (completed for the ponded Kym reach) in Figure 7.1.

Gravel ?	✓	Run – *Nuphar* ?	
Riffle ?		Pool – *Nuphar* or *Nymphaea* ?	✓
– with *Fontinalis* ?		– *Elodea* ?	
Mud – with leaf litter ?		– Blanket weed ?	✓
– without leaf litter ?	✓	Other submerged plants ?	✓
If none above, sand ...		– how many (for info) ?	4

Margins – 'reeds' ?	✓
– *Rorippa* (or similar) ?	
– *Phalaris* ?	
– *Agrostis* (or similar) ?	

Total Score: 6

Figure 7.1 Checklist for assessing habitat richness for benthic macroinvertebrates
(Developed on the River Welland, completed for the River Kym study reach)

The list identifies which most important habitats are missing – the habitat richness of the ponded stretch of the River Kym would be enhanced by reinstatement of the riffle-pool system and the encouragement of more diverse marginal vegetation.

7.5 Recommendations

The biological survey of the River Kym study reach produced a species list which was largely predictable from the habitats present. Therefore the conservation recommendations do not rely upon information from the biological survey.

7.5.1 River Kym

Riffle system

Intervention to reinstate a riffle-pool system to the ponded section would involve removal of the fixed heads or mitigation of their influence through design alterations. This might not be possible, would certainly be expensive, and is probably undesirable. The natural state of the river is a small clay stream which is reproduced at a multitude of other sites in the region. The current state is an extensive linear pool, rich in species which elsewhere are often found at sites with a greater maintenance requirement and hence more disturbance. In the context of the whole catchment, riffle systems are present on small streams, so gains would be quantitative rather than qualitative. Impounded reaches of lower water quality than the Kym present a stronger case for restoration, since they are unlikely to support the diverse fauna of the Kym.

Margins

Encouragement of marginal vegetation would be a valuable conservation measure for the ponded section. Most of the rivers in the region have been engineered to a past design which precluded extensive margins and so intervention would have considerable value in a wider context also. The best course of action would require consultation between conservation and river maintenance interests. The biologist's preferred approach might be to further deepen a part of the channel and use the load thus obtained to form shelves at water level (which is almost fixed in the ponded section). The shelves would then colonise with herbaceous marginal species rather than stout emergent plants, while the remaining channel would be less prone to growth of *Schoenoplectus lacustris* and *Sparganium erectum*. Creation of a low-maintenance channel with reduced hydraulic roughness would surely be acceptable to drainage engineers – but the details or overall feasibility of the design would be determined using their knowledge of river mechanics.

7.5.2 Functional habitat methodology

Habitat distribution

The importance of size and frequency of habitats was shown by the River Kym results. The 'linear ponds' which formed the River Kym study reach had a particular richness of species characteristic of slow flows, which would not have been fully expected from the smaller Welland pools. Riffles on the upstream Kym site were small and isolated – they did not support the whole of the Welland riffle species list. The distribution of habitats should be taken into account when surveying functional habitats and when forming consequent recommendations for conservation. There may be habitats which are present but require enhancement to assume their full value; others may assume special value if they are unusually frequent or extensive.

Use of existing biological data

The first approach to conservation assessment of a river would normally be through existing data, often in the form of species lists from biological sampling. The classification produced by TWINSPAN includes a detailed inventory of 'preferential' species at each division. Procedures should be developed for the prediction of habitat status from species lists. This would enable investigators to collate the most relevant information prior to a field survey. Specific shortfalls in species richness may be suspected, in which case the corresponding habitat issues can be investigated specifically.

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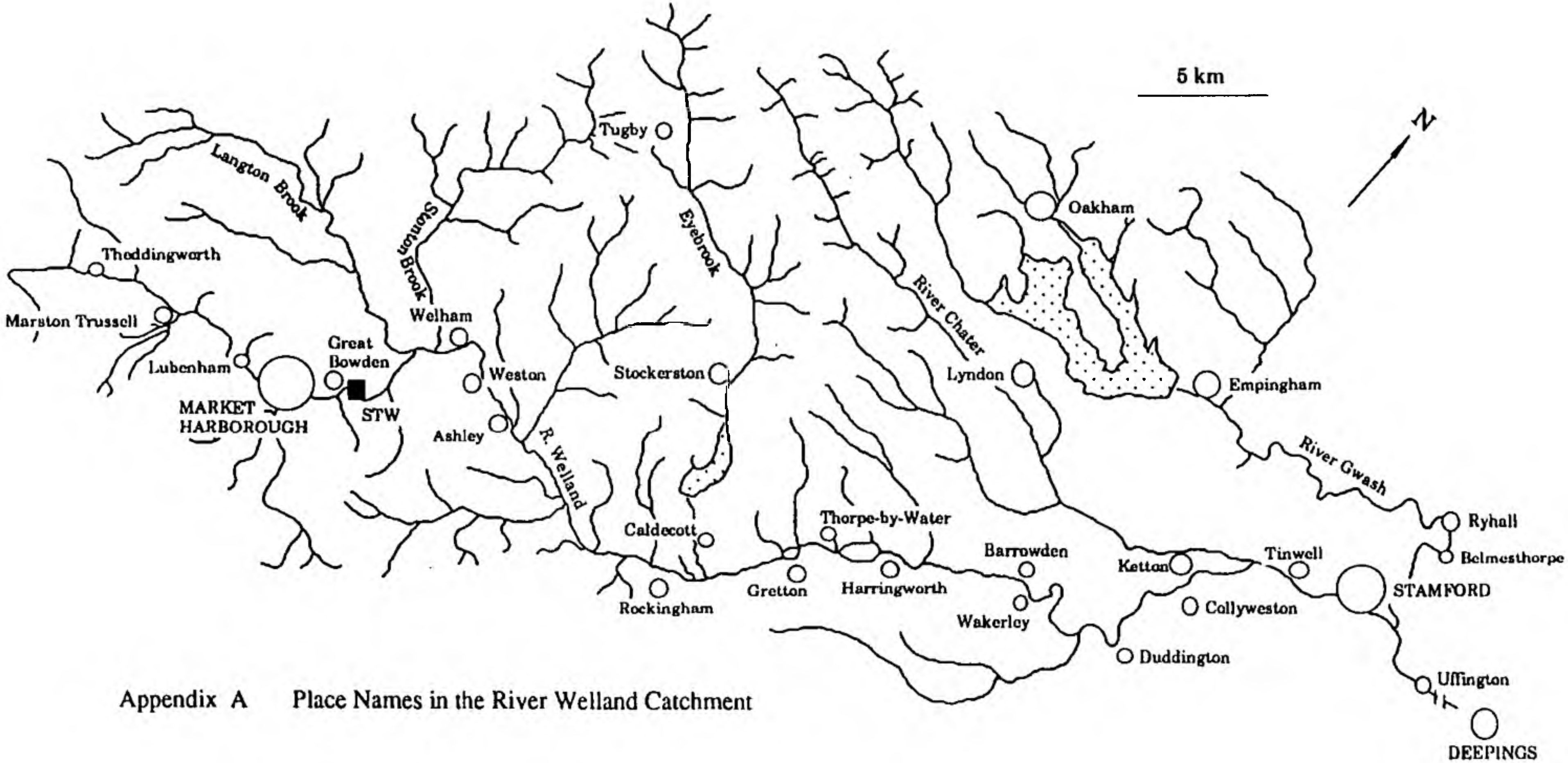


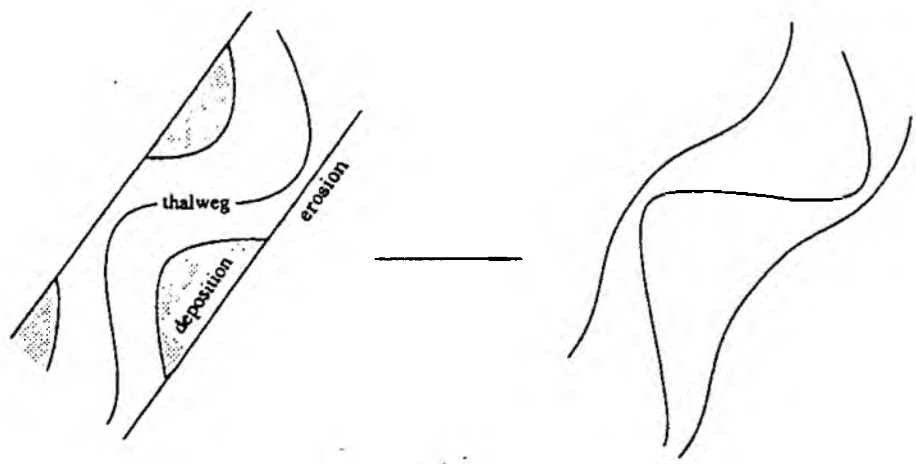
Appendix A Place Names in the River Welland Catchment

B. NOTES ON RIVER MORPHOLOGY

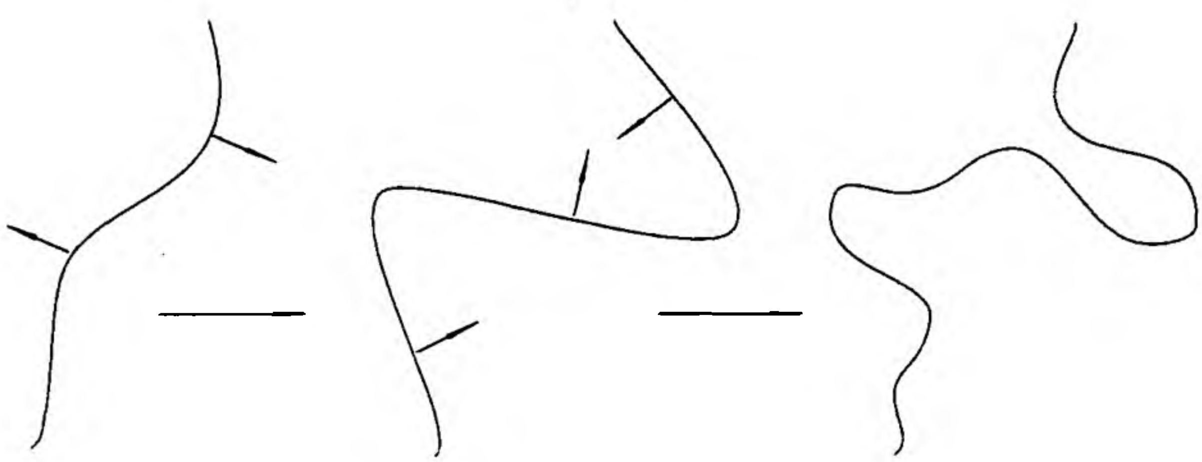
Meandering and sinuosity

River channels tend to *meander* from side to side, rather than flow downhill in a straight line. There are various hypotheses for the underlying mechanism but the observations on which they are based are unequivocal.

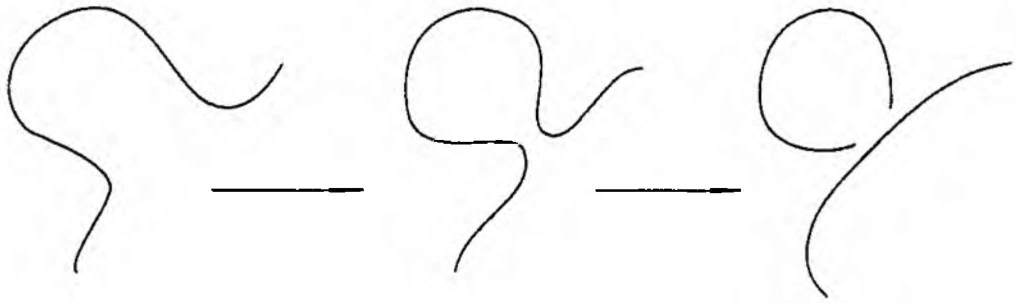
In a straight channel, the path of the main flow, or *thalweg*, swings from one side of the channel to the other. Where the thalweg swings towards the bank erosion occurs, and the eroded material is largely deposited in the areas where the thalweg swings away from the bank (*asymmetric shoals*). Over a period the process of erosion and deposition causes sinuosity of the channel itself rather than just of the thalweg. The shoals are then often called *point bars*.



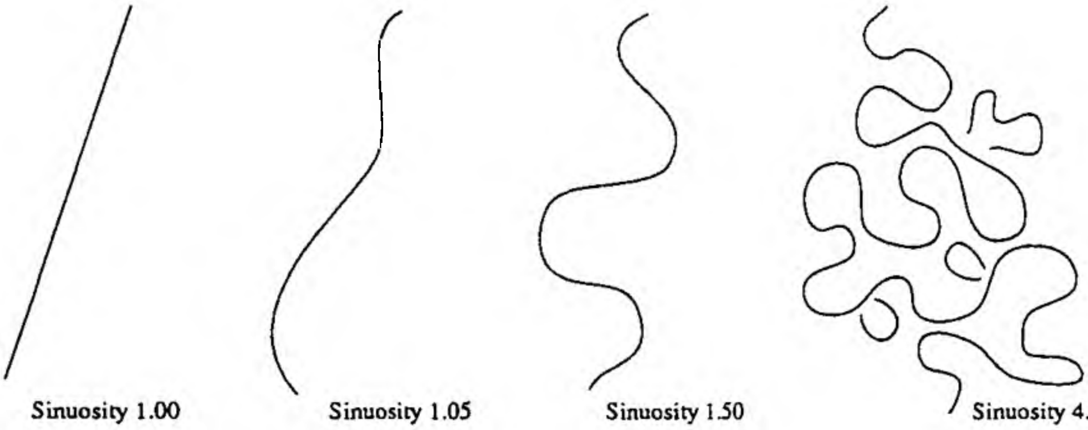
As meander arms grow, they can become long enough to contain waves of the thalweg and this gives rise to more complex meander patterns.



The process of meandering brings about an increase in channel length. Channel length is lost when highly-developed *(incised)* meanders are cut off through erosion at their neck, giving rise to *ox-bow lakes*.



In the natural state these processes of meander formation and loss reach a dynamic equilibrium, with more or less constant channel length. The degree to which a river meanders can be described by its *sinuosity*, which is the ratio of channel length to valley length. A river is usually described as meandering if it has a sinuosity of more than 1·5, but sinuosity can sometimes be more than 4.



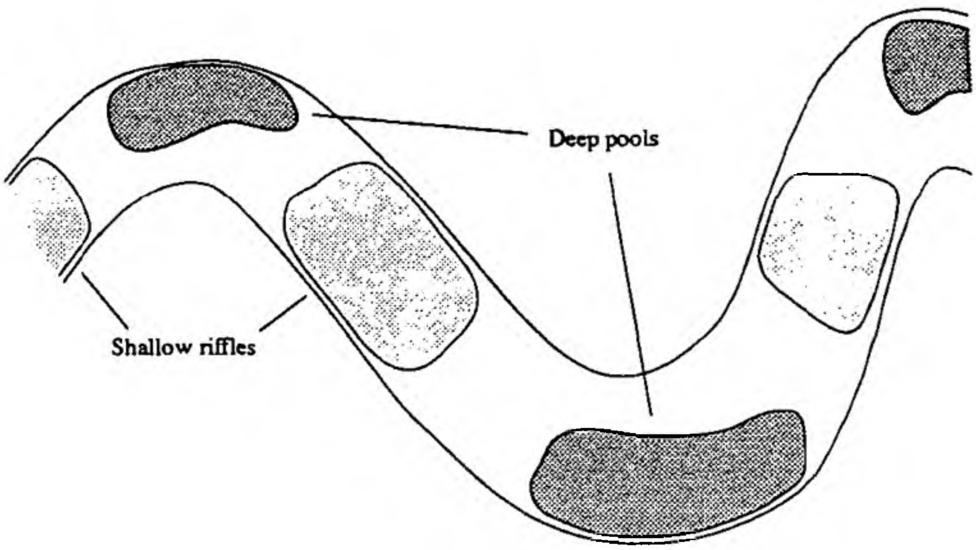
Two relationships have been found empirically:

- The width of the channel is proportional to annual mean discharge for reaches with similar geology.
- The wavelength of meanders is about 10-14 channel widths.

These two relationships can be combined to predict that meander wavelength will be proportional to the annual mean discharge.

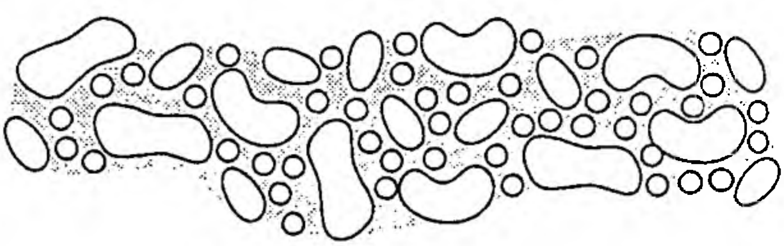
Riffles and pools

As well as a more or less predictable meandering of the channel, many rivers have a periodic fluctuation in their depth and in the particle size of the substrate. Strict geomorphological definitions allow for only two classes (*riffles* and *pools*) which are often defined as deviations above and below a regression through the long profile of the channel. The long profile is not smoothly undulating, and biologists generally recognise a third class of flow/substrate (*runs*), lying between discrete riffles and pools, which is of ecological importance.



The generation of sinuosity and riffle-pool sequences is linked. Pools generally occur at the apices of meanders and riffles at the points of inflection. Therefore, the distance between riffles tends to be 5-7 channel widths, and should be correlated with the annual mean discharge.

Riffles are not the same as the asymmetric shoals which are associated with far-bank erosion. The position of riffles changes very little, due to their position in the meander sequence, and riffles of long standing become solid (*armoured*) due to the packing of different particle sizes.



C. MACROPHYTE SPECIES LISTS FROM RIVER WELLAND SURVEYS IN 1987

1. Species occurring at least in part within the river channel

Polygonum amphibium — amphibious bistort
Polygonum hydropiper — water-pepper
Both uncommon but widespread.

Polygonum persicaria — redshank
Common and widespread. One of the first species to colonise newly-worked bank. Sometimes rooted in the channel.

Rumex hydrolapathum — water dock
Only one patch in the main channel, at Tallington, but abundant in old channels to the south of the river at that point.

Ranunculus penicillatus — river water crowfoot
Abundant in fast water from about Harringworth downstream.

Nuphar lutea
Found in slow pools in all but the highest reaches. Also occurs in some faster water, where it does not reach the surface.

Rorippa-nasturtium aquaticum — watercress
Widespread marginal, extending into channel in higher reaches and in Deepings mill-streams.

Rorippa amphibia — great yellowcress
Ubiquitous marginal, more common downstream.

Myriophyllum spicatum — spiked water milfoil
Widespread but never really abundant from about Duddington downstream. Most common around Collyweston and the Deepings.

Ceratophyllum demersum — rigid hornwort
First appears at Uffington, common locally in the Deepings and throughout the fenland section.

Callitriche stagnalis agg. — a water starwort
Frequent in slower reaches of main river. Also in faster water on River Gwash.

Oenanthe fluviatilis — a water-dropwort
Berula erecta — lesser water-parsnip
Both species only found in the River Gwash, where they were abundant in moderate and fast flows, but were not seen to flower.

Apium nodiflorum — fool's watercress
Similar distribution to watercress, extending more into ditches and other wet areas away from the main channel.

Myosotis scorpioides — water forget-me-not
Mentha aquatica — water mint
Veronica beccabunga — brooklime
Veronica catenata — pink water speedwell
Widespread marginal herbs. *Myosotis* and *V. beccabunga* are common throughout and are often found away from the main channel in wet places. *Mentha* and *V. catenata* are localised and never common.

Solanum dulcamara — woody nightshade
Ubiquitous. Sometimes in margins but usually riparian.

Petasites hybridus
Localised in shady upper reaches.

Alisma-plantago aquatica — common water-plantain
Same distribution as *Rumex hydrolapathum.*

Sagittaria sagittifolia — arrowhead
Widespread but only locally common in slower water.

Butomus umbellatus — flowering rush
Once common along the main river but not found there during the survey. Abundant in an old ox-bow lake at Ashley.

Elodea canadensis — Canadian pondweed
Ubiquitous but very variable in abundance. Most common from Welham to Gretton and in the Fenland section.

Potamogeton natans — broad-leaved pondweed
Widespread but confined to small patches in slow pools.

Potamogeton polygonifolius — bog pondweed
One patch found upstream of Tallington.

Potamogeton lucens — shining pondweed
Occasional in slower reaches from Duddington downstream and more commonly in the fenland section.

Potamogeton perfoliatus — perfoliate pondweed
Common in all but the fastest currents from Welham downstream and in the fenland section.

Potamogeton crispus — curled pondweed
Widespread but only locally common.

Potamogeton berchtoldii — small pondweed
Abundant in the Greatford Cut and occasional in the slower reaches of channels in the Deepings.

Potamogeton pectinatus — fennel pondweed
Zannichellia palustris
P. pectinatus is common throughout the mainriver and is particularly abundant between Market Harborough and Stamford. In the River Gwash it is uncommon, while the similar *Zannichellia*, which is absent from the main river, is abundant.

Juncus inflexus — hard rush
Juncus effusus — soft rush
J. inflexus is the more common, though both are found throughout the catchment as marginals and in moist soils away from the channel.

Iris pseudacorus — yellow iris
Localised and never common from Harringworth downwards.

Lemna minor — common duckweed
Found in pockets of still water throughout.

Lemna trisulca
Abundant in a cut-off pool above Tallington, and one patch on the main river at Uffington.

Sparganium erectum — branched bur-reed
Sparganium emersum — unbranched bur-reed
S. erectum is a common marginal throughout and in wet places. *S. emersum* has been recorded locally but was not seen in flower during the survey.

Typha latifolia
Widespread but rare marginal in the lower reaches and in standing water in cut-offs.

Carex acutiformis — lesser pond-sedge
Carex otrubae — false fox-sedge
Both widespread from about Welham downstream. *C. otrubae* is scarce but *C. acutiformis* occurs commonly and is also found on wet ground outside the channel.

Glyceria maxima — reed sweet-grass
Glyceria fluitans — floating sweet-grass
G. maxima is abundant throughout, usually as a marginal but extending into the channel in shallow water. It is also found in wet soil away from the channel. *G. fluitans* is locally common, especially in the Deepings.

Phalaris arundinacea — reed canary-grass
Ubiquitous and abundant. May form a monospecific fringe along the bottom of steep banks on the middle river. Not usually rooted below summer water level, and often associated with the more aquatic *Sparganium erectum*.

Phragmites australis — common reed
Found in dense marginal stands from Welham downwards, but confined to about five small sites.

2. Species usually associated with the river but not within the main channel

Cardamine pratensis — lady's smock
Frequent along the upper river.

Filipendula ulmaria — meadowsweet
Common along ditches, especially at Collyweston.

Impatiens glandulifera — Himalayan balsam

Found only around the bridges at duddington and Collyweston, where it occurs in dense stands on moist ground.

Epilobium hirsutum — great willowherb

Ubiquitous riparian plant, especially on steep banks from Welham downstream, though not usually abundant.

Conium maculatum — hemlock

Locally common at the top of the riverbank along ploughed fields.

Symphytum sp. — comfrey

Scutellaria galericulata — skullcap

Scrophularia auriculata — water figwort

Locally common on the bankside.

Plantago major — greater plantain

Occurs on disturbed ground around cattle drinks more than on adjacent land.

Dipsacus fullonum — teasel

Arctium lappa — greater burdock

Both locally common, moreso downstream.

Juncus articulatus — jointed rush

Common in the perennially wet seepages between Wakerley and Tixover.

Luzula campestris — field wood-rush

Common at one marshy site opposite Tixover Church.

Deschampsia cespitosa — tufted hair-grass

Ubiquitous but never far from the water.

Alopecurus geniculatus — marsh foxtail

Only found during the survey in damp seepages below Easton and at the edge of the old canal at Stamford.

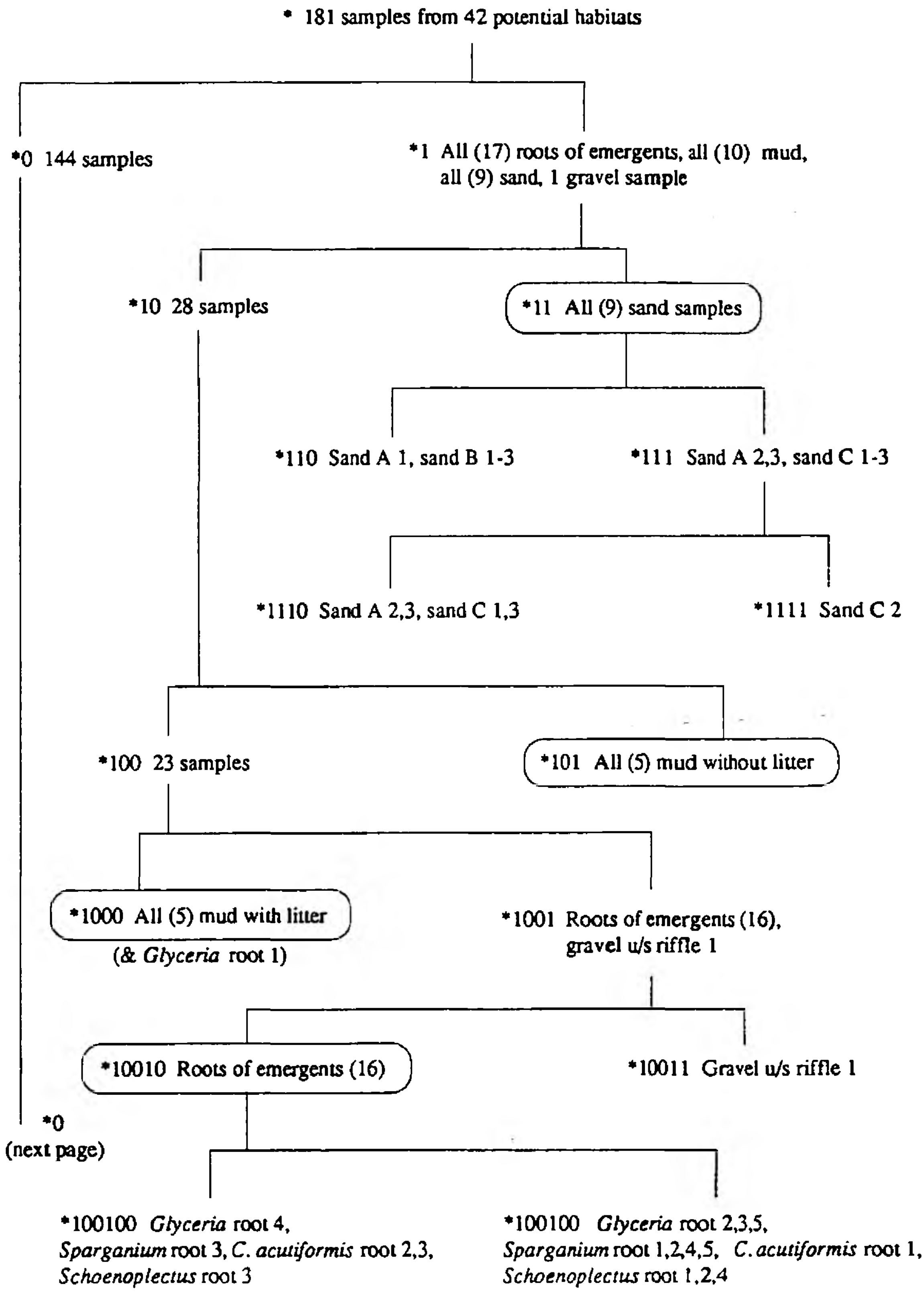
3. Species identified but which had no apparent affinity with the river

Urtica dioica
Polygonum aviculaire
Bilderdykia convolvulus
Rumex crispus
Rumex obtusifolius
Rumex acetosa
Stellaria graminea
Stellaria media
Cerastium fontanum
Silene latifolia alba
Silene dioica
Silene vulgaris
Lychnis flos-cuculi
Ranunculus acris
Ranunculus repens
Fumaria officinalis
Papaver rhoeas
Papaver somniferum
Brassica napus
Capsella bursa-pastoris
Allaria petiolata
Sanguisorba minor
Rubus fruticosus
Potentilla reptans
Geum urbanum
Vicia cracca
Vicia sepium
Melilotus officinalis
Medicago lupulina
Lotus corniculatus
Trifolium campestre
Trifolium pratense
Trifolium repens
Geranium pratense
Geranium robertianum
Geranium molle
Geranium dissectum
Malva sylvestris
Viola arvensis
Bryonia cretica
Epilobium angustifolium
Hedera helix
Anthriscus sylvestris
Torilis japanica
Heracleum sphondylicum
Convolvulus arvensis
Galium mollugo
Galium verum
Galium aparine
Ajuga reptans
Prunella vulgaris
Glechoma hederacea
Lamium album
Stachys sylvatica
Bellis perennis
Chamomila suaveolens
Achillea millefolium
Leucanthemum vulgare
Cirsium arvense
Cirsium vulgare
Cirsium acaule
Carduus acanthoides
Tragopogon pratensis
Sonchus asper
Lapsana communis
Taraxacum hamatum
Hypochaeris radicata
Leontodon hispidus
Allium sp.
Lolium perenne
Lolium multiflorum
Dactylis glomerata
Cynosurus cristatus
Bromus sterilis
Bromus ramosus
Bromus hordaceus
Elymus caninus
Elymus repens
Avena fatua
Arrhenatherum elatius
Holcus lanatus

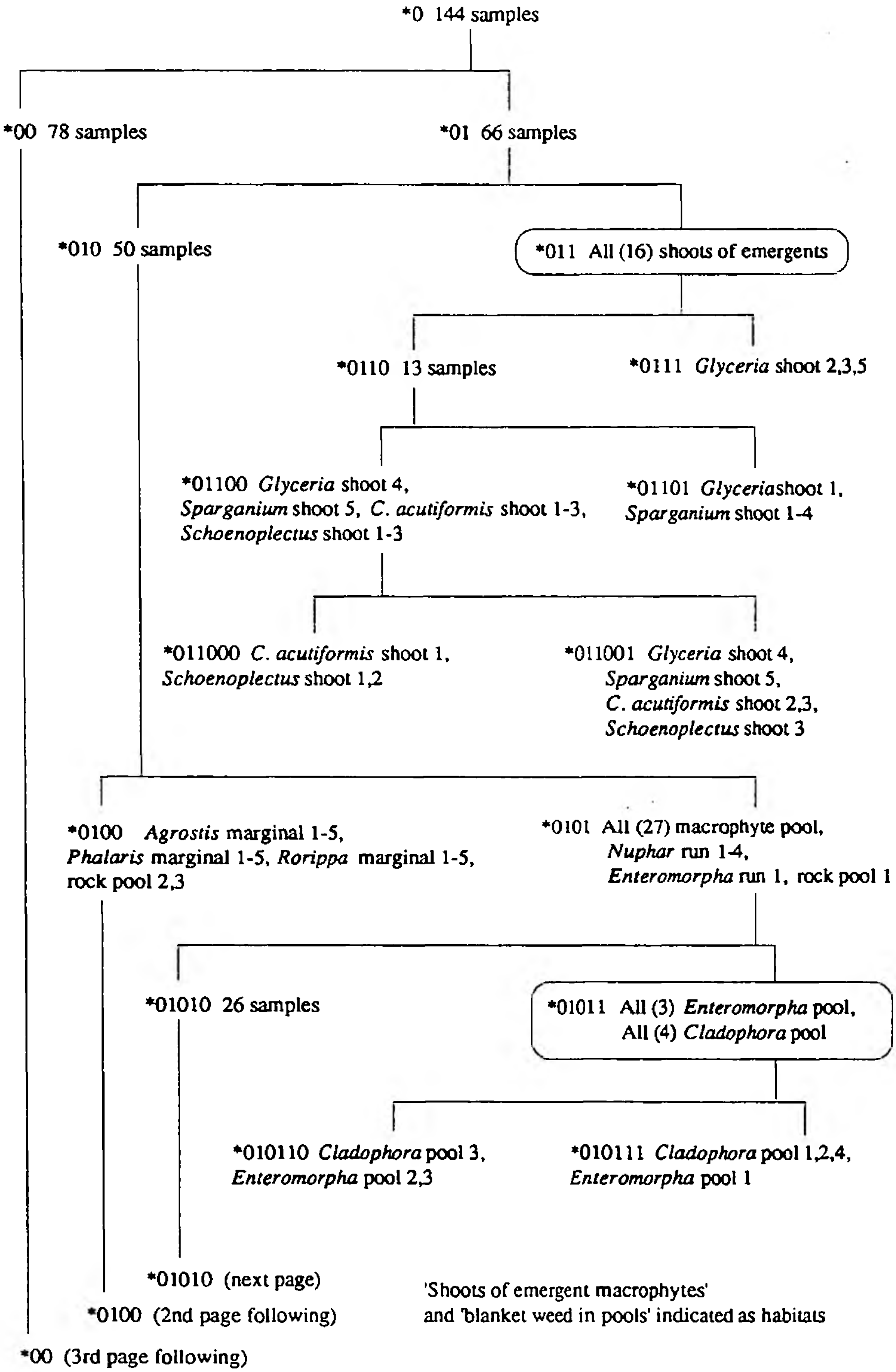
Vicia sativa	*Veronica chamaedrys*	*Phleum pratense*
Lathyrus pratensis	*Plantago lanceolata*	*Alopecurus pratensis*

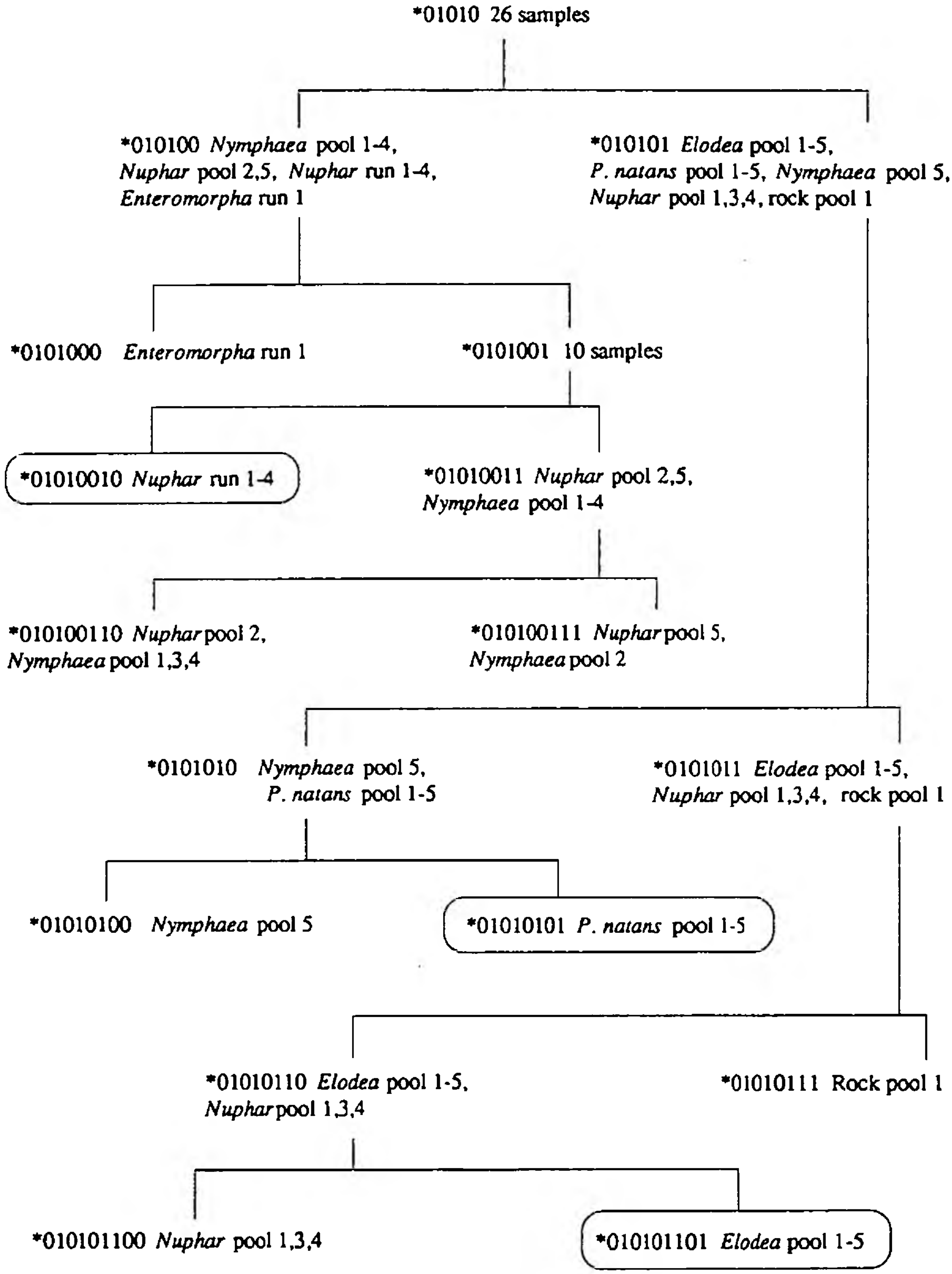
- small grasses (*Poa, Festuca* etc. were not identified during the survey)

D. TWINSPAN CLASSIFICATION OF RIVER WELLAND HABITATS

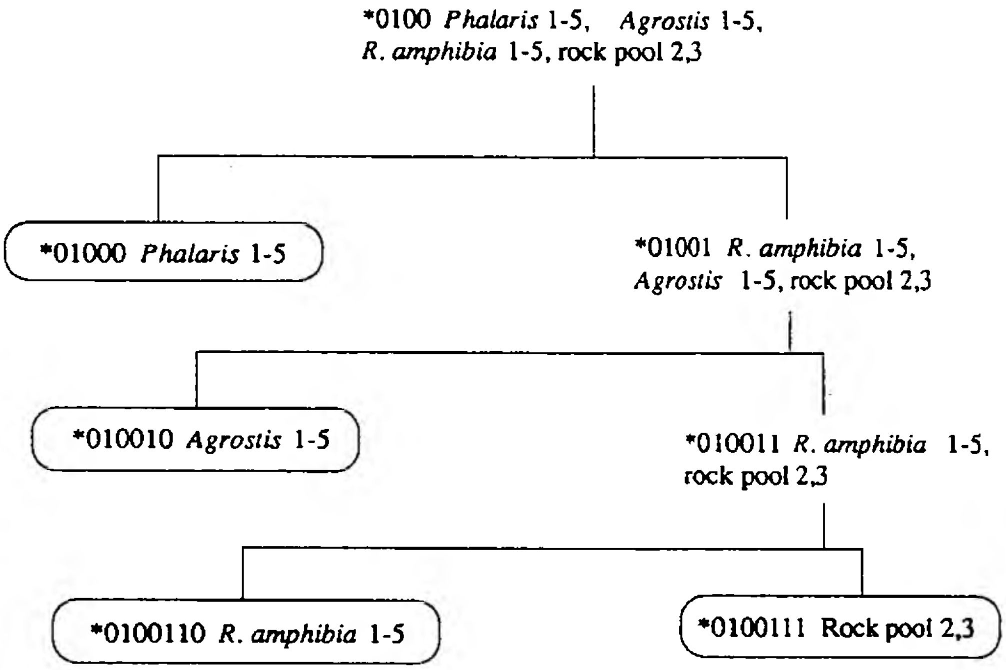


'Sand', 'mud with litter', 'mud without litter', and 'roots of emergent macrophytes' indicated as habitats

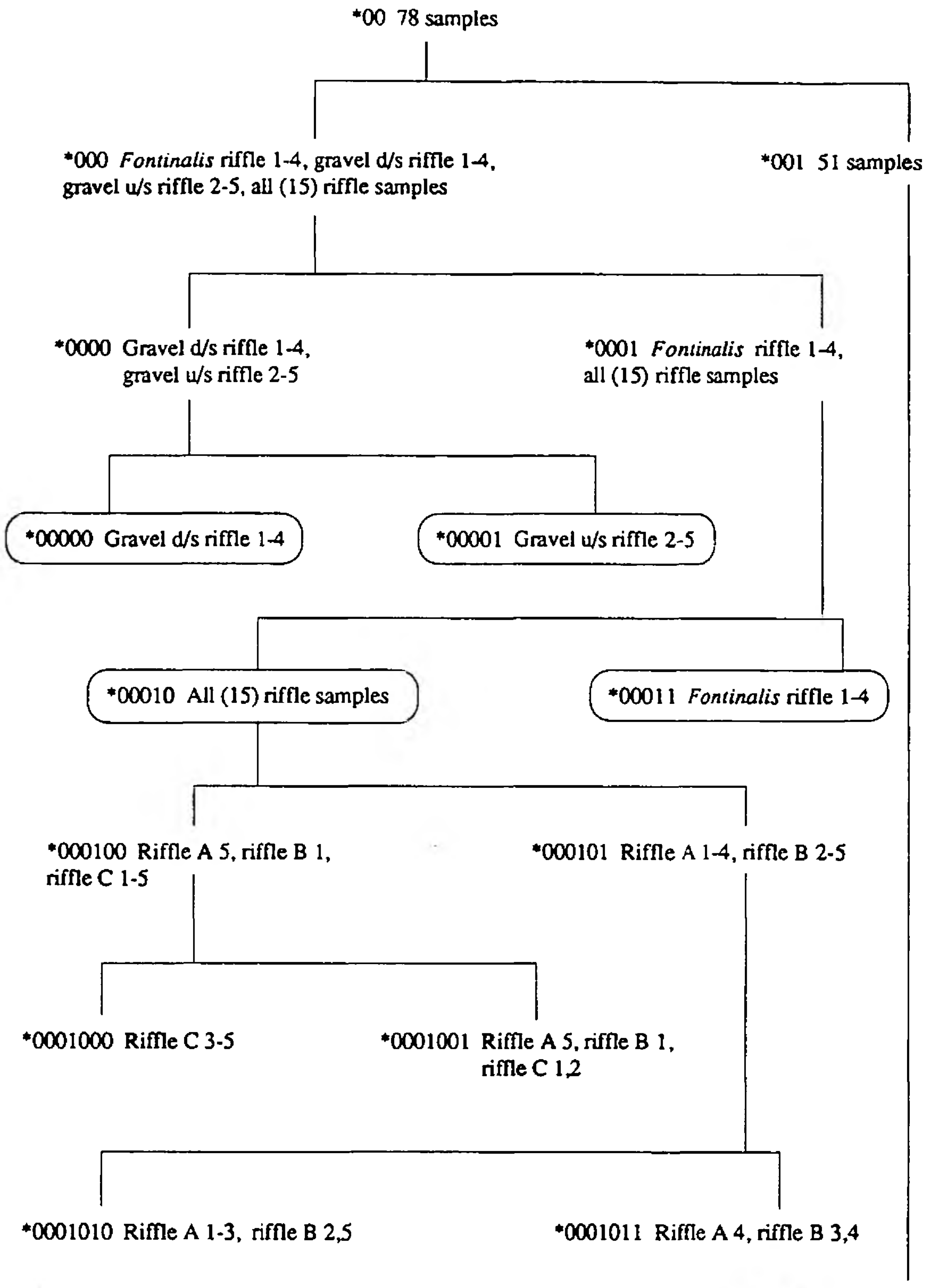

*0 144 samples
*00 78 samples
*01 66 samples
*010 50 samples
*011 All (16) shoots of emergents
*0110 13 samples
*0111 *Glyceria* shoot 2,3,5
*01100 *Glyceria* shoot 4, *Sparganium* shoot 5, *C. acutiformis* shoot 1-3, *Schoenoplectus* shoot 1-3
*01101 *Glyceria*shoot 1, *Sparganium* shoot 1-4
*011000 *C. acutiformis* shoot 1, *Schoenoplectus* shoot 1,2
*011001 *Glyceria* shoot 4, *Sparganium* shoot 5, *C. acutiformis* shoot 2,3, *Schoenoplectus* shoot 3
*0100 *Agrostis* marginal 1-5, *Phalaris* marginal 1-5, *Rorippa* marginal 1-5, rock pool 2,3
*0101 All (27) macrophyte pool, *Nuphar* run 1-4, *Enteromorpha* run 1, rock pool 1
*01010 26 samples
*01011 All (3) *Enteromorpha* pool, All (4) *Cladophora* pool
*010110 *Cladophora* pool 3, *Enteromorpha* pool 2,3
*010111 *Cladophora* pool 1,2,4, *Enteromorpha* pool 1
*01010 (next page)
*0100 (2nd page following)
*00 (3rd page following)
'Shoots of emergent macrophytes'
and 'blanket weed in pools' indicated as habitats



'*Nuphar lutea* in flowing water', '*Potamogeton natans* in pool', and '*Elodea canadensis* in pool' indicated as habitats. Unclear whether *Nymphaea alba* in pool' and '*Nuphar lutea* in pool' should be regarded as a single habitat or two separate habitats.



'Phalaris arundinacea', 'Agrostis stolonifera', 'Rorippa amphibia'(all marginal) and 'rocks in pool' indicated as habitats



*001 (next page)

'Gravel d/s riffle', 'gravel u/s riffle', '*Fontinalis* in broken water' and 'riffle substrate' indicated as habitats

*001 51 samples (all are submerged macrophytes)

*0010 23 samples

*0011 28 samples

*00100 14 samples

*00101 *P. perfoliatus* run 3-5, *Ranunculus* riffle 5, *Ranunculus* run 1-5

*001010 *P. perfoliatus* run 4,5, *Ranunculus* riffle 5, *Ranunculus* run 4,5

*001011 *P. perfoliatus* run 3, *Ranunculus* run 1-3

*001000 *P. pectinatus* run 1-4, *P. pectinatus* riffle 2,3, *Ranunculus* riffle 1-4

*001001 *Fontinalis* riffle 5, *P. pectinatus* riffle 1, *Schoenoplectus* run 1,3

*0010000 *Ranunculus* riffle 2,4

*0010001 *P. pectinatus* run 1-4, *P. pectinatus* riffle 2,3, *Ranunculus* riffle 1,3

*00100010 *P. pectinatus* run 1,2,4, *P. pectinatus* riffle 2,3, *Ranunculus* riffle 1,3

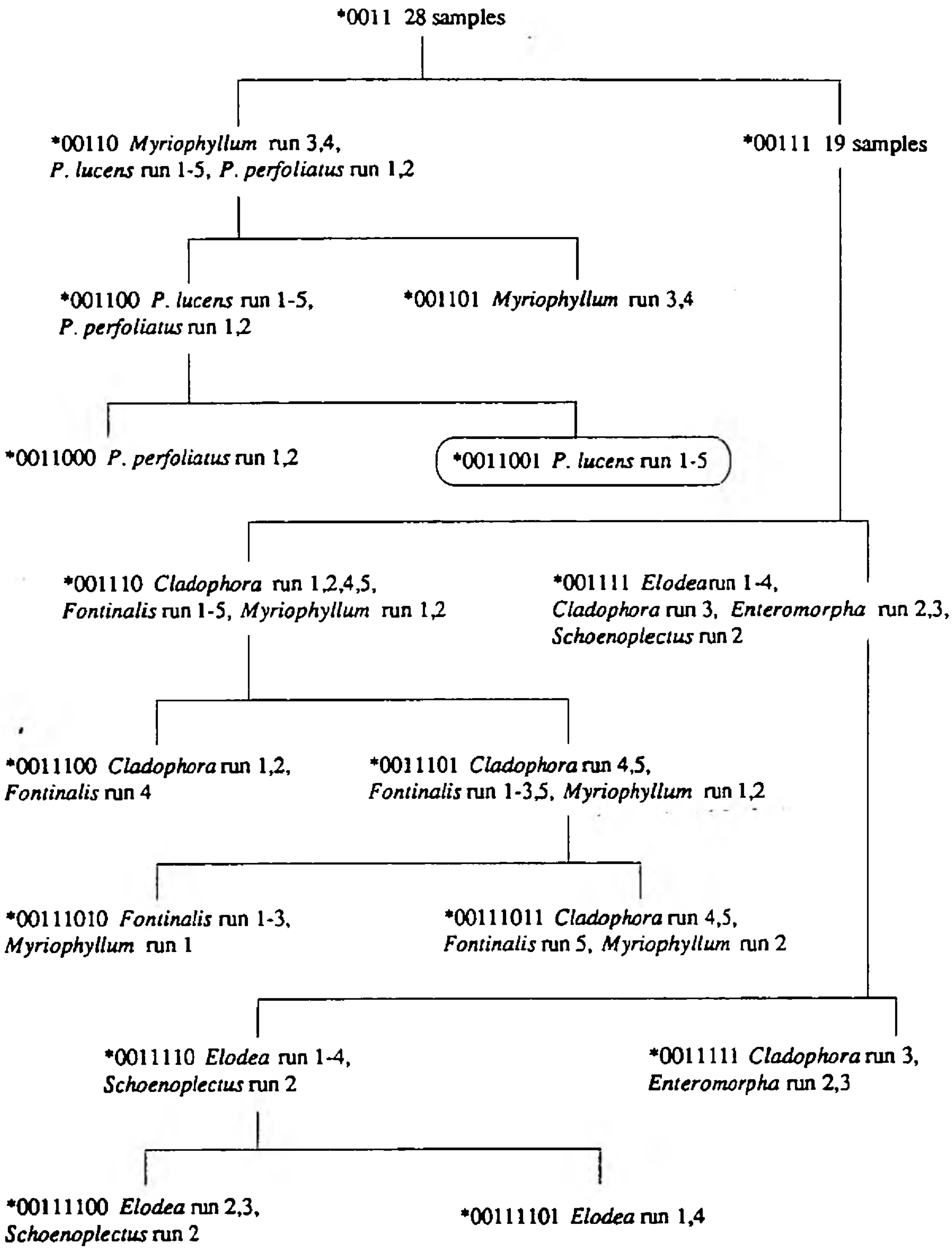
*001000101 *P. pectinatus* run 3

*001000100 *P. pectinatus* run 2, *Ranunculus* riffle 1

*001000101 *P. pectinatus* run 1,4, *P. pectinatus* riffle 2,3, *Ranunculus* riffle 3

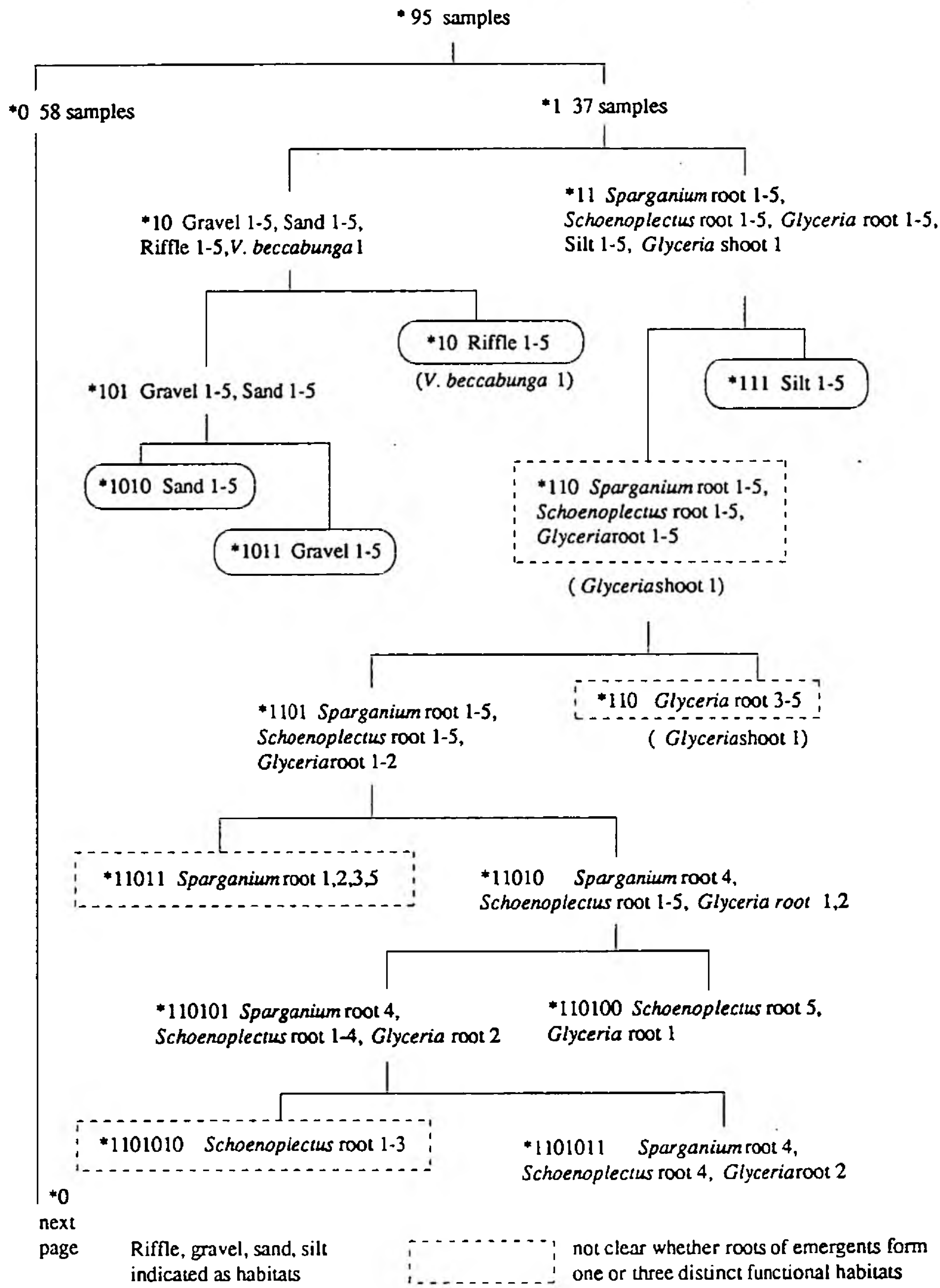
See notes on the next page

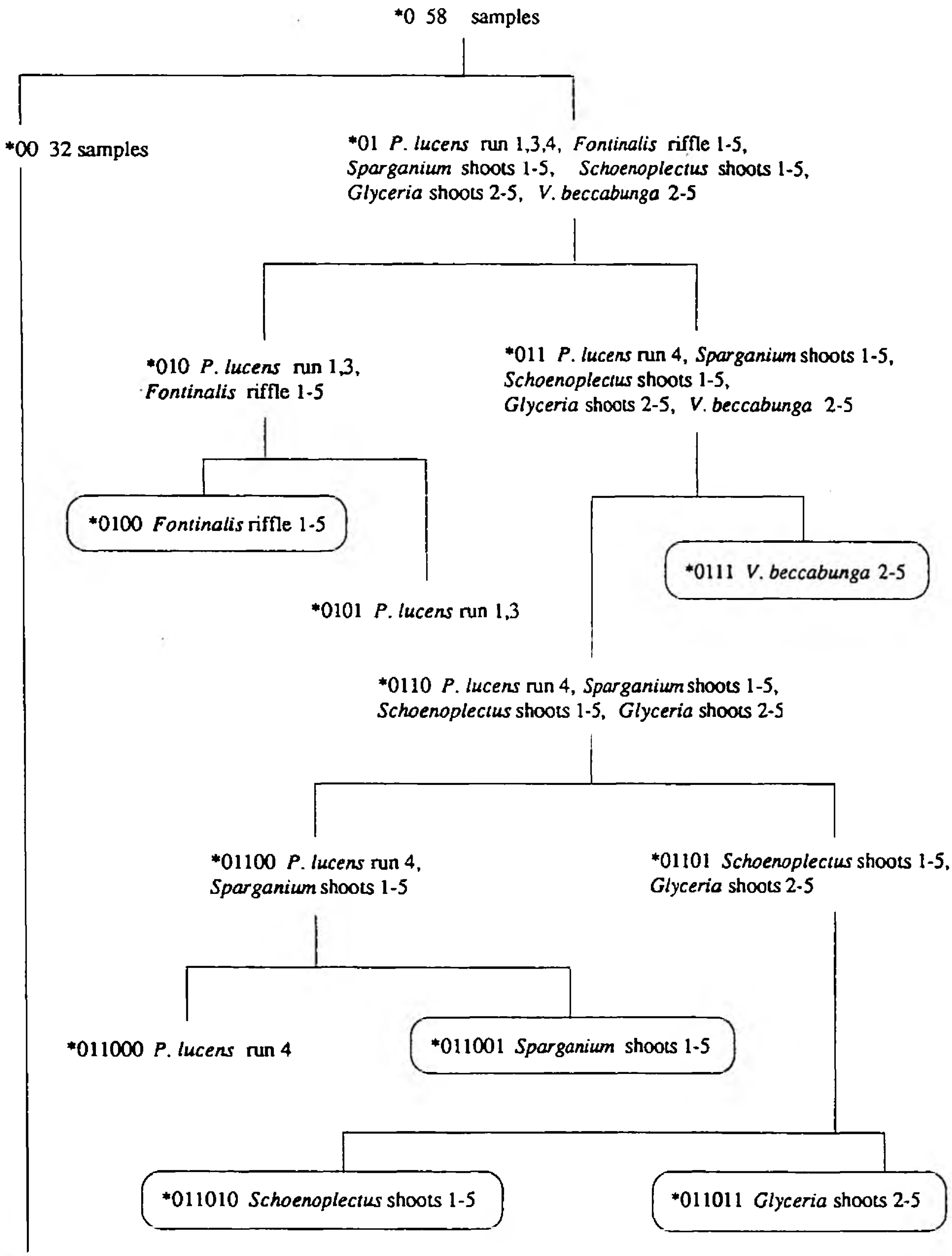
*0011 (next page)



Division of the submerged macrophyte samples in group *001 is complex. The only habitat which is suggested by isolation within the classification is '*Potamogeton lucens* in flowing water'

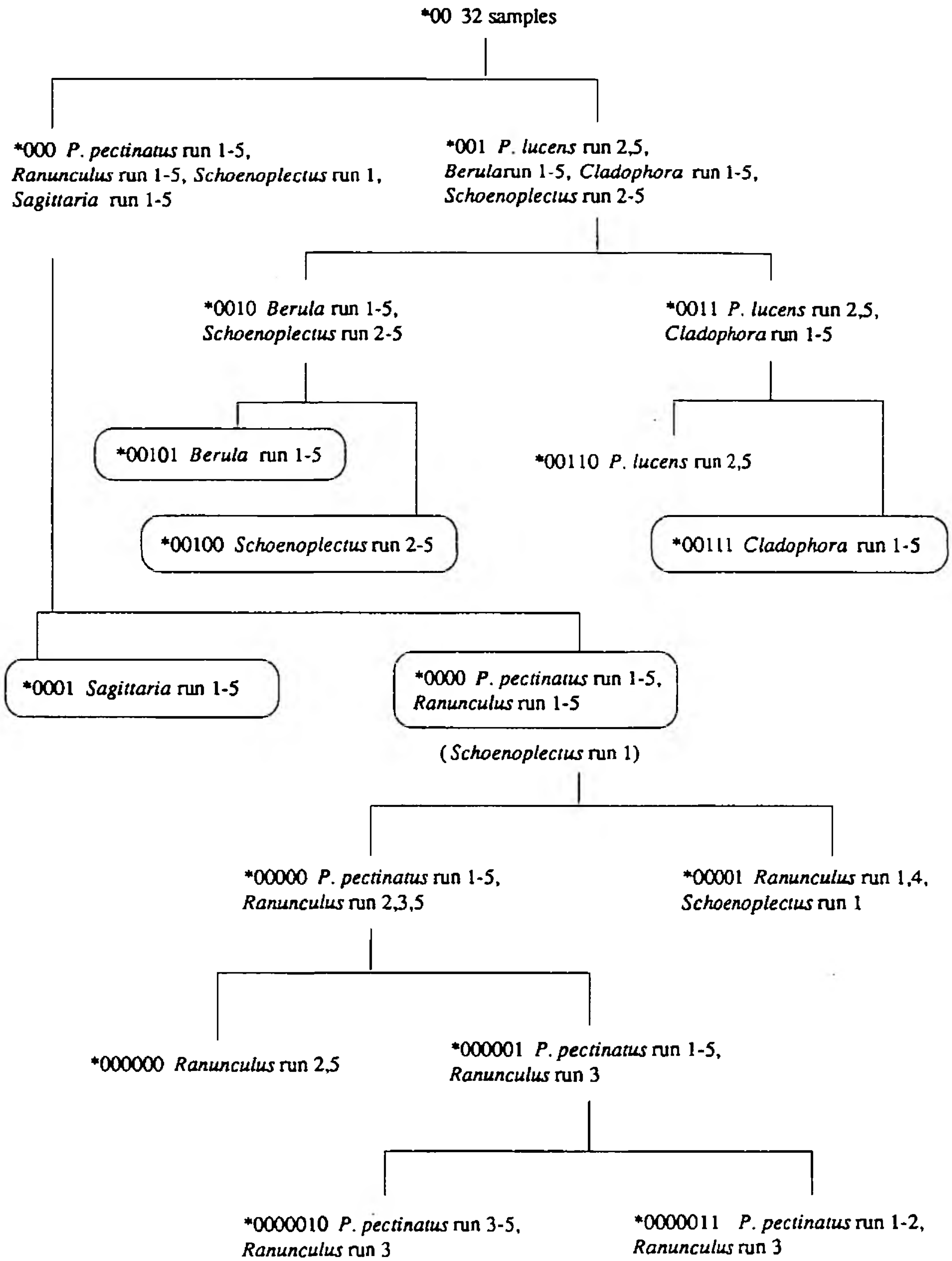
E. TWINSPAN CLASSIFICATION OF RIVER WISSEY HABITATS





*00 next page

Marginal *V. beccabunga*, *F. antipyretica* in run, shoots of *Sparganium*, *Glyceria* and *Schoenoplectus* indicated as discrete functional habitats



Berula, Cladophora, Schoenoplectus, Sagittaria and *Ranunculus / P. pectinatus* (all in run) are indicated as distinct functional habitats

NOTES