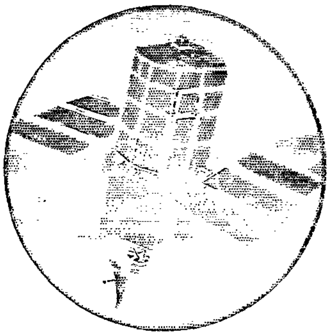
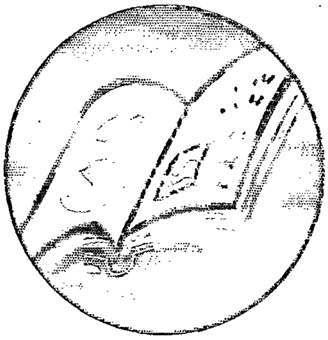
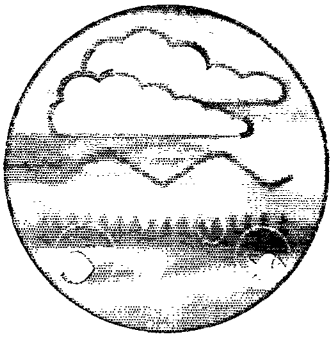
River Channel Typology: Feasiblity for Use in River Management







Research and Development
Technical Report
W87

ENVIRONMENT AGENCY

River Channel Typology: Feasibility for Use in River Management

Technical Report W87

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Statement of use
This report examines the feasibility of developing a river channel classification within the framework for river management in the Environment Agency. The Channel typology relates morphological characteristics to channel processes and will assist understanding of the factors affecting the stability of natural river channels. This first phase of work is based on river channels in Thames Region and without further development the classification currently has limited applicability.

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EXECUTIVE SUMMARY

Substantial progress has been made towards a geomorphological classification of semi-natural rivers from the "dimension" variables. The classification is useful in its own right as a statistically-justified delineation of rivers on the basis of substrate type and it has the potential further to classify channels as sub-groups of substrate types on the basis of geomorphological features. A classification based on substrate type makes it relatively easy to conceptualise for the casual user. It also demonstrates that the TWINSPAN technique has applications for deriving classes from this type of mixed data - subject always to constraints imposed by the quality and appropriateness of the datasets themselves.

The techniques used to relate driving variables to the dependent variables demonstrate that specific power is the single most important variable available to explain reach geomorphology and substrate composition. The relationship between the dependent and driving variables revealed by redundancy analysis suggest that changes in specific power (which could be effected by river engineering) have the potential to transform a reach to an adjacent class and therefore, theoretically to alter its geomorphological features. However, the ability to predict dependent variables or class membership from driving variables is extremely limited and any transformation of a river from one class to another will be constrained by the dominant effect of channel substrate size on class.

It has been shown that it is possible to conduct a provisional channel stability analysis using RHS field data and a set of rules-based allocation queries. This procedure is limited and does not possess the important spatial associations generally required for geomorphological assessment. Nevertheless, at broad level, four stability groupings were identified that should be tested for statistical significance following the inclusion of the 1995 RHS database. A test for the predictive ability of stream power showed that although each group was statistically significant, there was not the expected association between unstable sites and high stream powers. This is considered to be an artifact of the data distribution and the errors inherent in the estimation of stream power. Despite these limitations, it is clear that the majority of rivers sampled are of relatively high energy, and exhibit some degree of instability in their bed and or banks. Those channels that have unstable characteristics and low stream powers are dominated by fine sediment substrates.

Overall, progress in the refinement of an operational river channel typology appears likely to be best achieved by focusing on:

- **Enhanced data,** particularly the prospect of using RHS 1995 data collected on the improved geomorphological specification.

- **Enhanced information handling,** perhaps by exploiting the advantages of replication by maintaining the TWINSPAN analysis of 1995 data (and possibly combined 1994/1995 data), but supplementing this with other visualisation or analytical techniques. In addition, a core refinement would be a focus on the introduction of simple (probably rule-based) indicators of channel stability.

- **A management focus** for the project output is essential. This could take the form of procedures through which to incorporate River Channel Typology into the standard practices of the Agency. It would also be necessary to provide an input to any drafting of guidelines on new approaches to river management, and to prepare for the design of a sustained training programme to ensure wide and informed uptake of the techniques devised.

KEYWORDS

Geomorphology; River Classification;

GLOSSARY & ACRONYMS

Channel classification	the division of the channels into types based on selected criteria
Channel sensitivity	the propensity of the channel to change in response to imposed actions
Channel typology	classification structure describing river channel attributes
Cluster analysis	an agglomerative technique which identifies groupings within parameter sets
DCA	Detrended Correspondence Analysis - an ordination technique
DECORANA	a Detrended Correspondence Analysis
Discriminant analysis	a divisive classification technique that divides on the basis of parameter groupings
Fluvial Audit	A geomorphological survey technique developed for the Agency which seeks to identify potentially destabilising phenomena and their cause. This national framework provides local survey and interpretation of geomorphological status and dynamics..
Geomorphological drivers	principal physical attributes of the river and catchment system which control system behaviour and can therefore be used to discriminate or allocate channel classes
IFE	Institute of Freshwater Ecology
IOH	Institute of Hydrology
RCS	River Corridor Survey - a mapping based inventory of river channel habitat features
RCT	River Channel Typology
Redundancy analysis	a technique for relating many independent variables to many dependent variables
RHS	River Habitat Survey (see appendix 1 for parameter acronyms)
River inventory	database of river information and photographs
Semi-natural sites	river reaches with negligible engineering modifications or evidence of channel management
SERCON	System for Evaluating of Rivers for Conservation

Sinuosity	the degree of direction change within a channel planform, channel length divided by down valley length
Stability index	index based on the summation of factors indicating channel stability (see Appendix 2 for criteria)
Stream Power	measure of the ability of a river to do work, a function of discharge and energy slope
TWINSPAN	Two Way Indicator Species Analysis - a principal component analysis

1. INTRODUCTION

1.1 River Channel Typology and the Agency

Geomorphology is a fundamental component of the river system, and is therefore basic to the operations of many sectors of the Agency. Since river channels display almost infinite variety, it is desirable to develop a simple typology which would provide both an introductory channel description for reporting purposes and a prediction of likely channel future behaviour, with or without management intervention. In order to be cost effective, such a typology has to be designed as far as is possible around existing datasets (and thus existing scales of approach) - notably the substantial and growing data archive produced for the River Habitat Survey. The River Channel Typology R & D Project has thus been devised within the classic dilemma of applied science: the need to maximise scientific rigour while at the same time ensuring acceptable cost and widespread ease of use (including by non-specialists).

River Channel Typology (RCT) should be a routine and significant component in Agency decision-making and operations, and it will therefore need to play a distinctive and inherently justified role alongside other classificatory approaches including River Habitat Survey (RHS), River Corridor Survey (RCS) and large-scale conservation evaluation (SERCON). The effective coexistence of such evaluative and operations guidance systems within the Agency represents a strength rather than a weakness, provided that each component is applied at the appropriate stage and in appropriate circumstances without creating overlapping survey requirements. The river channel information needs of the Agency are many and varied, and it is inconceivable that they could or should be met by a single descriptive, interpretative and predictive protocol. But equally, it would in practical terms be unacceptable to introduce conflicting or overlapping classificatory systems within a single organisation, and the RCT has thus been devised specifically to offer the benefits of geomorphology's powerful indicative and predictive capability without overlapping or confusing the similarly important roles of other established systems. The basis for, and rationale of, this coexistence of distinct approaches is discussed below.

River Channel Typology is in effect a device for instilling basic geomorphological inference into routine Agency investigations and operations, and as such its role and context are both determined by the nature of geomorphology in relation to other sciences of the river environment. Channel geomorphology (which incorporates materials, forms and processes) is a significant component of habitat, and thus at one level represents a standard input to ecological conservation facilitating systems such as RHS and to ecosystem management for fisheries enhancement. At the same time, however, it is important to note that geomorphology is a constituent part of the environment in its own right. On that basis, RCT may have independent significance as an indicator for geomorphological conservation and landscape enhancement quite apart from its inter-relationship with ecology. The symbiosis of geomorphology and ecology in such contexts is already catered for in the geomorphological inputs to RHS, and geomorphology could also potentially be added to an extended SERCON approach. Similarly, RCS currently includes descriptive elements which could be regarded as geomorphological, but with its rather different purposes it has relatively rarely been used for geomorphological inference or prediction. Manifestly, there are many contexts in which geomorphology and ecology do relate so closely that they can appropriately be handled within a common survey, analytical and decision-support approach - but this is neither the whole story, nor necessarily the most important part of the story.

It is clear, nevertheless, that in conservation (and associated habitat quality) terms, RHS carries the core role of integrating geomorphology with ecology. As will become apparent later in this report, both RHS and RCT recognise channel substrate to be a potent overall diagnostic of geomorphological characteristics, with strong spatial and attribute inter-correlations which reflect the underlying control of river power. In part, this convergence may owe something to the fact that both classifications have been generated from the same data set, but the common outcome from two separate analyses is an encouraging sign that the distinctively different purposes of RHS and RCT can be served by a single approach to channel typology.

At first sight, this could be taken to imply that the RCT classes should be incorporated within RHS, and for basic reporting or classificatory purposes there may be some merit in this suggestion. However, a complete fusion of the two systems is neither a necessary nor a desired conclusion. In the role that is envisaged (below) for the RCT, the RHS national database serves a valuable purpose in providing an initial basis for identifying the primary channel characteristics which can best be used to designate channel classes and define the boundaries between them. Operationally, however, it is expected that the use of RCT in circumstances such as Catchment Management Planning or the predesign scoping phase of a Flood Defence Project will utilise data collected outside the RHS framework. It is important, therefore, that the implementation of the RCT (as opposed to its initial designation) must be free to benefit from being able to adjust to this broader information-gathering and inferential basis. Although both RCT and RHS are likely to serve a broad range of purposes, there are some distinctions inherent in their titles - the River Habitat Survey focuses specifically on habitat, environmental quality and conservation, while the River Channel Typology is a generic device which has equal relevance to almost all sectors of Agency activity.

There can be little doubt that in scientific principle, geomorphological purposes are best served by data collected by surveyors with significant geomorphological understanding. As in every other scientific discipline, trained practitioners are best able to interpret guidelines, achieve consistency, perceive subtle variations and be able to supplement routine observation. In practice, however, resource limitation implies that such a target may well often be difficult to sustain, and it is expected that in the short term much data collection will continue to be by non-specialists. Nevertheless, since the RHS data will remain the primary national reference archive of channel descriptors, it is important to the Agency that the geomorphological observations within the RHS surveys should continue to evolve so as to maximise their ability to serve the dual function - and these data needs are addressed later in the report. Continued geomorphological enhancement of data collection would be particularly significant if RCT operationally was to be implemented (at least for conservation purposes) as a component of, or supplement to, an evaluative process driven by RHS. However, the appropriateness of regarding RHS and RCT as symbiotic is ultimately dependent on further consideration of the purpose, nature and implementation of the two systems.

The clear parallels between RHS and RCT thus far identified are rooted in a common concern with conservation, and thus with the overall evaluation and classification of environmental quality. However, it has already been stressed that the purpose of RCT is in no way limited to conservation. Given the hydraulic significance of geomorphology, the task of providing indicators of channel behaviour which can underpin decisions and operations based on the function of the channel in conducting water and sediment flow is of equal or greater importance. Channel forms and materials interact with the processes of water and sediment flow in such a way that modification of either component has significant impacts on the other. By recognising this association, the Agency has in recent years pioneered the development of river management and "soft" engineering principles which enhance the land drainage effectiveness of the channel while maintaining or improving its overall environment, to the ultimate benefit of landscape and conservation as well as flood defence. RCT should be seen primarily as a technique for supporting such enlightened river maintenance, engineering or restoration. Its close links with RHS thus become welcome bonuses rather than the main design requirement, and in this context the two systems stand alongside one another rather than being fused. The need for compatibility and the efficiency gains of close co-operation are undiminished, but the drive for complete integration is much reduced.

Inherent in this distinction of purpose is an important contrast of nature between RHS and RCT. The conservation management purpose of RHS is predicated on the need to supply indicators of conservation status which can underpin investment prioritisation and act as a basis for performance monitoring. The habitat quality concepts involved permit channels with enhancement capability to be identified, and offer valuable guidance as to the type of enhancement that might be viable. The same indices highlight areas of particular quality which should be protected from adverse impacts from management tactics or development projects. A similar range of functions can be specified for RCT, reinforcing the comparability and interaction between the systems. However, in the case of RCT the core function is actually quite different - it is to predict channel dynamism and thus serve as an indicator of potential morphological and sedimentary instability and vulnerability, aspects which are specifically addressed in the Report below. Geomorphology is dominated by in-channel and down-channel links which transmit physical impacts, and which therefore must be regulated or protected as part of the river management process. Thus it is the task of RCT to characterise channels in such a way that simple observable diagnostics may be used to infer past process dynamism and predict future process dynamism. In this aspect of its function, RCT will usually be employed quite separately from RHS.

Although it was not the remit of Phase I of the RCT Project to create an implementation infrastructure, it is highly instructive to give flesh to the above discussion of the relationships between RCT, RHS and RCS by considering the possible RCT implementation contexts. Without doubt, an important and routine function of the data (and perhaps derived map) outputs of both RHS and RCT will be to provide an initial indication of ecological and geomorphological status in response to queries at the sub-catchment scale. In this reactive mode, much of the information communicated will be of attributes (including overall classifications) already assigned to rivers and stored in the archive, and in this respect there is much to be said for instituting a single query structure incorporating RCT within RHS so that all pertinent data are yielded by a single extraction. To be effective, the combined information system will need to be actively managed, both to ensure that information is updated and to reap the associated benefits of developing an ability to monitor change. In the fullness of time, update may be effected by a repeat national survey. In the meantime, there is much to be gained from ensuring that ad hoc observations undertaken in support of individual projects or planning exercises should be fed back to the RHS database. This presupposes that the RHS survey procedure (enhanced periodically as appropriate) should become the routine standard for this scale of observation.

In the case of RCT, particularly where channel dynamism is the main focus, an equally important context for implementation is likely to be systematic queries driven by Agency procedures such as Catchment Management Planning and river restoration. In both these contexts, the national data archive would offer an initial indication of likely status and dynamism, as well as providing the best available estimate of national (or regional) statistical norms for any particular attribute within a given channel class. RCT would be expected to become a standard initial query mechanism for these purposes, but would not be geared in itself to providing local (reach and sub-reach) indicators, for which purpose the existing procedure of Fluvial Audit would be the preferred approach (Fluvial Audit is a national procedure adopted by the Agency specifically for Flood Defence purposes, which provides a detailed local-scale survey and interpretation of geomorphological status and dynamics: its role is in some senses similar to that of River Corridor Survey providing sub-reach detail in the context of a broader RHS query). Similarly, with major river engineering projects RCT would provide review data to place the proposals in context, but Fluvial Audit would be necessary to provide a design and impact evaluation input. The conceptual and practical links between geomorphology and river engineering in the Agency have become well-established and effective during the 1990s, and this move is to be applauded. The various components of the Agency's emerging set of national procedures thus fit neatly together, and the selection of the appropriate approach for a particular purpose could be assisted by a simple procedural guideline until familiarity is acquired by the "intelligent client" co-ordinating or commissioning the work.

While it may be possible (though not ideal) to envisage simple geomorphological data for incorporation in RHS and RCT being gathered in the short term by non-geomorphologists, this flexibility is clearly not available with Fluvial Audit. Since the role of reach and sub-reach data is to provide a definitive indication of design inputs and impact predictors, observation cannot be delegated to non-specialists without threatening the quality assurance of the output recommendations or decisions. Through such a set of implementation contexts and approaches, RCT should become accepted as a powerful geomorphological technique in its own right, while at the same time fitting effectively into the broader conservation strategy of the RHS procedure.

1.2 The development of a River Channel Typology

The first focus of the project has been on a series of attributes of flow, sediment flux, channel perimeter and context within the catchment which would ideally be used to typify meaningful channel classes. A key scientific input was the designation of what are regarded as the primary drivers of the fluvial system in a variety of domains (location; condition; energy; resistance; pattern) and at a range of scales (catchment; sector; reach; section). For this, ideal set of factors, thresholds or "partings" have been recognised wherever possible, so as to identify states of the variables that are diagnostic of the condition of the river channel.

In addition, it has been recognised that channel dynamism is of crucial management importance. It describes changes which the channel has undergone, those which it is currently experiencing and those which it could exhibit in the future - again, with or without management intervention. In effect, this represents the degree of channel sensitivity: how likely it is to undergo change and alter its class within the typology. This change may be detrimental (e.g. environmental impact of works) or beneficial (e.g. river restoration or enhancement). It is, therefore, possible to consider moving towards the notion of developing management guidelines on a rule base which works from the typology. For such guidelines it is considered essential to have dynamic indices as driver variables (e.g. stream power) which can be altered by management actions.

However, although the typology is science-driven in principle, it is distinctly data reliant in practice. The ideal list of input variables has had to be replaced by a partial list of available data, with many proxy variables where the required attribute or driver is unavailable. Some supplementation of data was undertaken, but the potential for initial data collection within the project timescale and budget was limited. In essence, the typology is consequently heavily constrained to a sample of channels and channel attributes selected for the purpose of the River Habitat Survey and based upon its 1994 field survey protocols. The 1995 protocol are significantly different in geomorphological terms, but the 1994 data list is substantially less than ideal therefore, it has been necessary to concentrate on devising a robust concept and methodology, to be prototyped on 1994 data, with the assumption that the Agency may chose to refine the operational typology on the basis of the RHS95 data or on a custom dataset acquired specifically for geomorphological purposes.

Much of the first half of the project was devoted to assembling and standardising a coherent dataset, and to identifying that subset of the overall RHS94 archive that could be regarded as semi-natural (467 sites were so designated). The strong overrepresentation of sites in the North and West of England and Wales within this subsample is viewed as problematic given the desired national scope of the typology. The relative paucity of process-related and dynamic information is a further challenge derived from the form of the available data. Much of the dataset was not even interval or ordinal, but categorical or present/absent. This poses serious problems for sophisticated statistical processing, and renders the derivation of hybrid variables so difficult that some become virtually meaningless.

The original concept of the data analysis had been to use clustering methods to group rivers with similar driving variable characteristics, and then to use discriminant analysis to allocate rivers to classes using driving variables. Using discriminant analysis one might be able to back-predict class with a high success rate but it would be difficult to interpret the "driver-classes" generated without being able to relate them to a pre-existing geomorphological classification of river channels - a classification of the dependent/dimension variables. Therefore, the method adopted was fully to develop a classification of the channel morphological variables which would then be used for comparison against a classification produced purely from the "drivers". For example, redundancy analysis could be used to test how much of the variance in the dependent variables is accounted for by the driving variables; and discriminant analysis could be used to test how far the driving variables predict class membership derived from dependent variables.

In the first instance a classification derived from TWINSPAN produced an initial dendrogram of channel types, and the clustering was dominated largely by channel substrate type, with a large degree of association being apparent between substrate classes, channel gradient, and the presence of rapids and cascades which tended to order the groups from right to left. Groups 1-8 have progressively finer substrate, beginning with boulder and bedrock channels in Group 1 and ending with clay in group 8. In fact, it is quite remarkable how the classification orders sand (group 6), silt (group 7) and clay (group 8) in order of their respective grain size. Substrate is important in terms of biological habitat and so there may be some useful relationship between a physical classification of this type and biotic/environmental habitat value.

However, after generating the first classification it was decided that some of the variables were unsuitable to contribute to the classification. During several subsequent TWINSPAN classifications a number of modifications were made, and a refined dendrogram is presented. This is believed to be more robust because of the removal of confounding variables such as the "artificial" substrate, bankfull dimensions and gradient, and the replacement of the categorical measure of sinuosity. Distributions of the variables were examined to decide if transformations were necessary to run in TWINSPAN. The riffle index and sinuosity were transformed into classes, and it then became straightforward to manipulate the remaining variables with the TWINSPAN cut-offs to produce greater resolution. A stability index was produced by GeoData which was to be added to the dependent variables. This, it was hoped, would contribute a measure of erodibility or resistance to stream power. However, it proved difficult to classify a large number of sites or to develop a scale of stability that could be interpreted easily. A scale was devised relating to the stability of bank and channel substrate. However, the vast majority of sites fell into only two categories because the information available in the 1994 RHS survey was not suitable to derive a stability index.

The refined dendrogram was easier to interpret because, for example, riffle-pool frequency has been controlled for width. It can be compared with the initial classification in a cross-tabulation of class. This shows that the classifications are similar, as most reassignments of class occur close to the 'diagonal', top left to bottom right, i.e. any reclassification is to adjacent groups.

Substrate size/category is clearly a persistently dominant feature in the classifications. This is useful because there is a de facto classification of rivers based on predominant channel material. Rivers are often described by fluvial geomorphologists as, for example, boulder, cobble, gravel or sand-bedded, alluvial or clay channels as the first, most basic, level of description. While there is great variety within these simplistic classes, this serves to locate the river within a broad range of geomorphological types. The classification developed here refines and adds scientific rigour to this common description by determining "partings" between classes and by integrating important geomorphological variables with substrate types. It is apparent that most of the classes have distinctive geomorphological characteristics, as well as substrate category, but detailed prediction of these characteristics may be elusive.

The summary of river channel class characteristics below includes descriptions of classes in relation to driving variables, although these were not used to generate the classification.

- **Classes 1 & 2** are dominated by a combination of boulders, cobbles and bedrock. The main distinguishing features between classes 1 and 2 are that the riffle index for class 1 channels is relatively low, there are fewer side bars and fewer eroding cliffs.
- **Class 3** is dominated by bedrock and boulder channels with some gravel/pebbles. Proportion of bedrock is high, and channel sinuosity is the lowest of all. Rapids and cascades are usually present.
- **Class 4** rivers are dominated by cobble-bedded channels, usually with gravel/pebbles. They have a relatively high number of side bars, and cascades are almost completely absent. Channel sinuosity is high as is the riffle index, and bankfull width is the largest of all classes. This is a powerful class of rivers with marked erosional activity.

- **Class 5** rivers are dominated by a combination of cobbles and gravel/pebble, nearly always with some bedrock. They have a relatively high number of point bars and relatively low channel sinuosity.
- **Class 6** rivers are dominated by a combination of cobble and gravel/pebble beds and nearly always have boulders. They are far up the river network, and there are no channels greater than 3rd order. These are the smallest width channels, and have the highest gradient. Their apparent stability may result from coarse substrate and the resistance provided by boulders in the bed.
- **Classes 7 & 8** are almost exclusively gravel/pebble bedded rivers. Class 7 rivers have a marked tendency to have steeper channel gradients than class 8. Rapids occur but are uncommon in both classes. Bankfull widths appear to be slightly greater in class 7, which also has much higher riffle indices than class 8, more point bars, more side bars and more eroding cliffs.
- **Class 9** rivers are dominated by gravel/pebble substrate with some cobbles. In geomorphological terms, this class is very similar to class 8, though side bars are more common in class 9 and the rivers are slightly larger
- **Class 10** is also dominated by gravel/pebble bedded rivers in combination with significant amounts of silt. Class 10 is distinguished from classes 8 and 9 by a greater prevalence of mid-channel bars and point bars.
- **Class 11** rivers are dominated by gravel/pebble beds in combination with sand. This group is also characterised by a very infrequent occurrence of side bars.
- **Class 12** is a group of sand-bedded rivers with some gravel/pebble substrate. The flow regime is dominated by glides with very infrequent slacks. Mid-channel bars and eroding cliffs occur with greater than average frequency. Side bars are also relatively frequent, and median channel sinuosity is higher. Riffle index and reach altitude are low.
- **Class 13** is a relatively large group of silt-dominated rivers. Riffle index is joint lowest with class 12. Sinuosity is relatively high, as one would expect in lowland channels. Side bars, point bars, mid-channel bars and eroding cliffs are rare, suggesting relatively stable fluvial systems with little deposition and little erosion. Gradient is low and so specific power is also low.

Assessing the success or validity of the classification produced is a largely subjective process. To some extent it has been possible to find statistically significant differences between variables by class which gives an element of objective validity to the classes but in many cases this is not possible. A further technique that gives some idea of the separation of classes is ordination. Other methods of clustering were also investigated to compare with TWINSPAN using a minimum variance clustering of a matrix of Gower's similarity co-efficient calculated between all sites. The result was markedly less visually successful than the classes produced by TWINSPAN, but there is a large degree of similarity between the classifications generated by minimum variance clustering and TWINSPAN.

A final analytical aim was to use numerical techniques to quantify the relationship between the driving variables and the dependent variables or channel features. There were two aspects to this (i) to see how far it was possible to predict TWINSPAN-derived dependent variable class from the drivers and (ii) how much of the total variance in the dependent variable set could be explained by the drivers and which of the drivers were most important in accounting for variance. Discriminant function analysis was used to try to predict dependent class from driving variables. The correct prediction rate was low - only about 17% of sites could be correctly allocated to class by the driving variables. Specific Power was the most important predictive variable among the drivers. The redundancy analysis showed that about 8.5% of the variance in the dependent variables can be accounted for by the driving variables. Specific power is by far the most important single variable, explaining about 6.2% of the total variance. This may seem a very weak relationship but such results are common with environmental data where there is a lot of "noise" and where the dataset is an eclectic collection of variables.

It is not completely satisfactory to restrict channel substrate to being either an independent or a dependent variable. Substrate size and roughness play a part in determining a river's flow, transport and erosive potential. However, it is sometimes difficult to disentangle channel "features" from substrate type. The conceptual model was thus altered by accepting substrate type as one of the driving variables rather than a dependent variable. In a redundancy analysis this marginally improved the explanatory power of the driving variables with respect to the dependent variables. However, since transferring the substrate types from dependent to independent variables did not significantly improve the model, this approach was not pursued. Instead, sites were stratified into three broad bands of dominant substrate type, in order to control the effect of substrate type in determining features. A separate redundancy analysis was carried out for each stratum between the dependent variables and the drivers. The result of this was that the driving variables accounted for only 5 - 7% of the total variance within each stratum.

In summary, substantial progress has been made towards a geomorphological classification of semi-natural rivers from the "dimension" variables. The classification is useful in its own right as a statistically-justified delineation of rivers on the basis of substrate type and it has the potential further to classify channels as sub-groups of substrate types on the basis of geomorphological features. The fact that it is based on substrate type makes it relatively easy to conceptualise for the casual user. It also demonstrates that the TWINSPAN technique has applications for deriving classes from this type of mixed data - subject always to constraints imposed by the quality and appropriateness of the datasets themselves.

The techniques used to relate driving variables to the dependent variables demonstrate that specific power is the single most important variable available to explain reach geomorphology and substrate composition. The relationship between the dependent and driving variables revealed by redundancy analysis suggest that changes in specific power (which could be effected by river engineering) have the potential to transform a reach to an adjacent class and therefore, theoretically to alter its geomorphological features. However, the ability to predict dependent variables or class membership from driving variables is extremely limited and any transformation of a river from one class to another will be constrained by the dominant effect of channel substrate size on class.

Finally, it has been shown that it is possible to conduct a provisional channel stability analysis using RHS field data and a set of rules-based allocation queries. This procedure is limited and does not possess the important spatial associations generally required for geomorphological assessment. Nevertheless, at broad level, four stability groupings were identified that should be tested for statistical significance following the inclusion of the 1995 RHS database. A test for the predictive ability of stream power showed that although each group was statistically significant, there was not the expected association between unstable sites and high stream powers. This is considered to be an artifact of the data distribution and the errors inherent in the estimation of stream power. Despite these limitations, it is clear that the majority of rivers sampled are of relatively high energy, and exhibit some degree of instability in their bed and or banks. Those channels that have unstable characteristics and low stream powers are dominated by fine sediment substrates.

Overall, progress in the refinement of an operational river channel typology appears likely to be best achieved by focusing on:

- **Enhanced data,** particularly the prospect of using RHS 1995 data collected on the improved geomorphological specification.
- **Enhanced information handling,** perhaps by exploiting the advantages of replication by maintaining the TWINSPAN analysis of 1995 data (and possibly combined 1994/1995 data), but supplementing this with other visualisation or analytical techniques. In addition, a core refinement would be a focus on the introduction of simple (probably rule-based) indicators of channel stability.
- **A management focus** for the project output is essential. This could take the form of procedures through which to incorporate River Channel Typology into the standard practices of the AGENCY. It would also be necessary to provide an input to any drafting of guidelines on new approaches to river management, and to prepare for the design of a sustained training programme to ensure wide and informed uptake of the techniques devised.

2. A BACKGROUND TO CHANNEL CLASSIFICATION

River channels exhibit almost infinite variety in their detail, but tend to conform to a relatively small series of broad classes in terms of their dominant characteristics and behaviour. In practice, the simplification that channel classifications offer to river scientists (for the purpose of improved understanding), river managers (for better decision making) and river engineers (to guide action) is of considerable value. Although the quest for a river channel geomorphological typology, which is one approach to classification (see Section 3), may be driven in the short term by the needs of specified application areas (notably River Habitat Survey), a river channel typology will also serve a much broader remit in the long term through application possibilities such as:

- **Survey/Review of Strategic Status** (National/Regional) *(Objective)*
    - Standard periodic reporting function
    - Summary or context for Local Environment Agency Planning
    - Response to queries (particularly in a planning context)
    - Input to large scale Environmental Assessment
- **A Context for Prioritisation** *(Judgmental)*
    - Basis for prioritising future/supplementary survey effort (identify gaps)
    - Basis for prioritising resource allocation (identify investment needs)
    - Basis for prioritising conservation/protection/enhancement/restoration
- **Specification of Action** *(Judgmental)*
    - Best Practice Guidelines
    - Work specification
    - Framework for consultation
- **Framework for Setting Performance Targets** *(Objective and Judgmental)*
- **Framework for Performance Monitoring** *(Objective)*
    - Monitoring change
    - Monitoring impact of actions and works
    - Post-Project Appraisal

By addressing such functions as these, River Channel Typology (RCT) is potentially helpful to the Agency in assisting it to:

- Meet statutory requirements
- Achieve and demonstrate public accountability
- Provide operational support to Agency functional sectors

There have been many previous attempts to design an effective river channel classification for either scientific or management purposes, but the present project differs from these in a number of respects. Most previous studies (except, perhaps, those from New Zealand) have been *regional* in scale, and (with the exception of Rosgen, 1994) were specifically *single purpose* because of the needs of their commissioning agency. Even the "scientific/educational" classifications have generally been essentially hydro-geomorphological, and few studies have set out to be generic for a range of applications. The majority of earlier attempts were *static characterizations* of morphology or habitat, though studies at Southampton and by Rosgen (1994) included evolution and adjustment. In fact, "change" needs to be handled both as an attribute that is input to the classification, and as an indicator of propensity to future change (prediction), as is discussed in Section 3 below. Most previous studies have been conducted on *natural or semi-natural channels*, free of the lengthy and extensive modification experienced by UK streams (Sections 3 and 4). In most cases, they have been dominated by the *available data*, not by a deterministic framework, and little previous work has received *practical usage* and refinement.

The present R & D project is distinctive in being data-reliant and by design essentially deterministic and generic (science-driven), rather than being derived independently from a specific data set. It is applicable at a range of scales and to a variety of Agency operational sectors, but could be rendered purpose-specific by the use of a "functional template" concept. Despite the very real challenges involved, the typology aims to be dynamic - allowing for rate-of-change as an input attribute, and for propensity for future change within a management-relevant timescale as a predictive output. The approach is analytical of the artificial influences which may dominate British rivers and their associated data sets, and is evaluative and contextual rather than just descriptive. Above all, the typology seeks to be practical, therefore being mindful of scale-dependency, tuned to specific user requirements, and sensitive to data availability and cost. The RCT project has thus produced:

- A **channel typology** (Section 10) in the form of proposed classification structures (templates incorporating user-specific rule bases and/or suggested class boundary values); procedures for allocating rivers to the appropriate class; and physical descriptions and explanations of the major classes proposed.

- An associated **river inventory** (Appendices) in the form of a growing database of river information and photographs for sites across the country, assembled partly in association with the River Habitat Survey (RHS) Project. The database has several roles, including validating class-defining rules and boundary values that have been derived in part from the data and in part from underlying scientific reasoning. The typology will also be a context for assessing the representativeness or rarity of a given river which is tested against the database (a means of assigning value, or assessing priority, will be required and summary tables and distribution maps will be produced to indicate the overall England and Wales pattern). Finally, the database will indicate what might be the characteristics of a given modified channel were it to return to being natural, thereby indicating the loss of conservation value that the channel has experienced, and providing an indicator of river restoration target and feasibility.

3. AN APPROACH TO TYPOLOGY

Typologies are customised versions of the real world, and thus require informed and meticulous design if they are to be both useful and reliable. Such design commences with a *rationale* or philosophy which reflects the underlying assumptions to which the classification will conform. In the present case, the rationale focuses on the suggestion that the state and behaviour of a river channel can be characterised by a limited number of highly significant descriptive observations which serve as diagnostic indicators from which robust management guidelines can be derived. In order to implement such an approach, it is necessary to devise a *methodology* which permits the principles to be put into operation effectively and cost-efficiently. The methodology designates a series of steps that must be taken to construct the classification and put it to work, and identifies the information that will be needed. It follows that actual implementation requires a set of *techniques* which must be applied rigorously to the *data* that are available or can be acquired. As can be seen from the diagram above, these four key steps have been allocated between the three Principal Investigators, and the Research Assistants at Southampton and Newcastle.

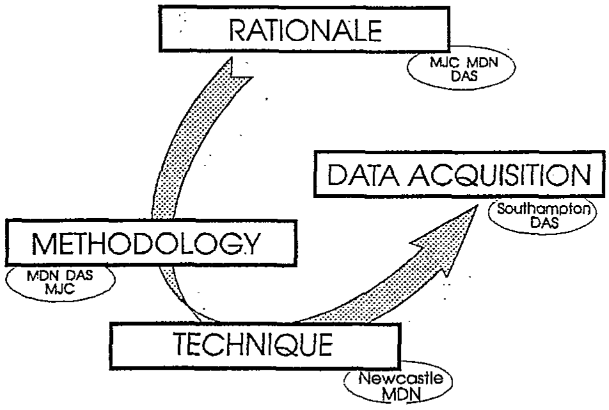


Figure 3.1 Project components and PI's

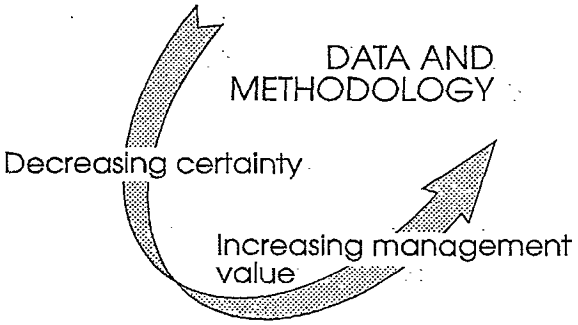


Figure 3.2 Data & methodology

Classifications using diagnostic variables derived from surrogate data are inevitably subject to imprecision and uncertainty. This is an inevitable compromise that has to be adopted if a cost-effective operational procedure is to be developed for national implementation by the Agency. Since all the data used to derive, test and implement the classification are by definition samples of a highly variable parent population of British rivers, it is difficult to place strict error limits on the process. It is, however, reasonable to assume that in moving from rationale, through methodology to specific techniques applied to real-world data, we are moving towards increasing value for management applications only at the price of decreasing certainty in the inferences drawn from the data.

It is suggested that this inherent error of classification is manageable provided that it is acknowledged. This implies that there will be some ambiguity of allocation towards class boundaries (the rules will allocate the river unambiguously into the preferred class, but it may display some characteristics similar to those of rivers in an adjacent class). In addition, the management guidelines inferred from the class into which the river is allocated may in some cases embody an element of caution based upon this difficulty of allocation at the boundaries. It should be stressed, however, that the rigour and implementation objectivity of the classification and guideline procedures here proposed renders them less error-prone than any of the available cost-realistic alternatives, particularly those which rely exclusively on experiential intuition based on subjective observation.

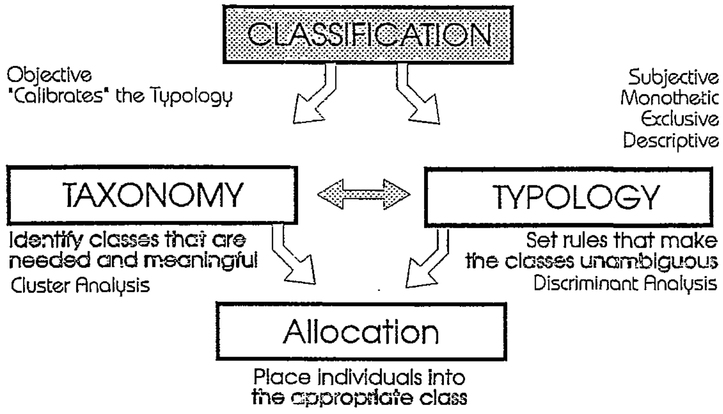


Figure 3.3 Classification relationships

In practice, classification involves two separable activities, taxonomy and typology. Each has its own contribution to make to the classification of river channels, but it is on typology that the RCT project concentrates. This focus recognizes that typology is potentially the more robust, defensible and flexible of the two processes once the scientific underpinning has been established and refined. As a generalisation it can be seen that taxonomy is essentially driven by the data, whereas typology is dominated by the underlying science. *Taxonomy* starts with the observational data sets and uses an approach such as cluster analysis to determine the groupings (classes) that are most clearly distinguished and thus most likely to be meaningful.

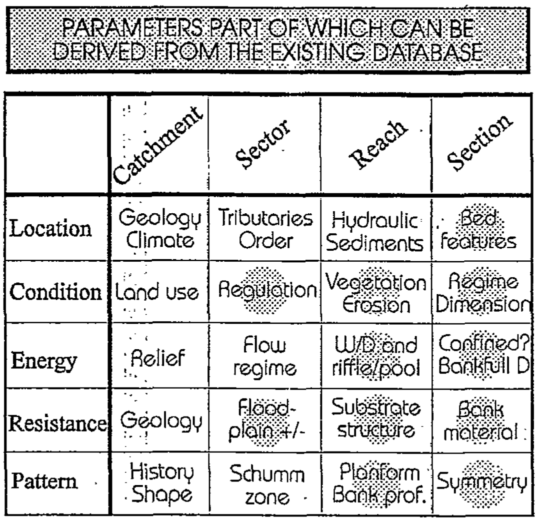
This is a quasi-objective independent check that can be used to refine, calibrate or validate a typology. The associated approach is *typology*, which seeks to define a set of rules which will allow individual cases to be allocated unambiguously to the appropriate class. A technique such as discriminant analysis will be used to yield classes, and the aim will be to exclude definitions by which an individual could equally well be allocated to more than one class. Clearly, there is an iterative interaction between taxonomy and typology such that the resulting classification will be in part a product of the data set used to devise and test it. Any bias in the data will influence the rigour of the classification. It follows that the progressive increase in size of the River Habitat Survey (RHS) data archive on which the channel typology is partly based will be expected to lead to progressive refinement of the typology. The process of *allocation* is a separate and subsequent stage in the procedure. Once classes have been determined by taxonomy and/or defined by typology, each newly observed river channel needs to be assigned (as objectively as possible) to the appropriate class. The present RCT project is concerned with the process of erecting and evaluating the classification; in the roll-out phase operational allocation will become the dominant activity.

An effective geomorphological typology will be controlled by the driving variables that influence channel attributes and behaviour. It is apparent that both the number of drivers, and their designation, will be scale-dependent. A primary aim of the River Channel Typology (RCT) project is thus to derive the pertinent drivers at each scale, and to impose a hierarchical structure upon them. In the case of existing classifications used by British river managers, the starting point may be:

Table 3.1 Drivers for standard surveys

Survey	Drivers
SERCON **River Habitat Survey (RHS)** **River Corridor Survey (RCS)**	Geology Gradient Width/Depth : Bankfull flow

Table 3.2 Parameters part of which can be derived from the existing database.

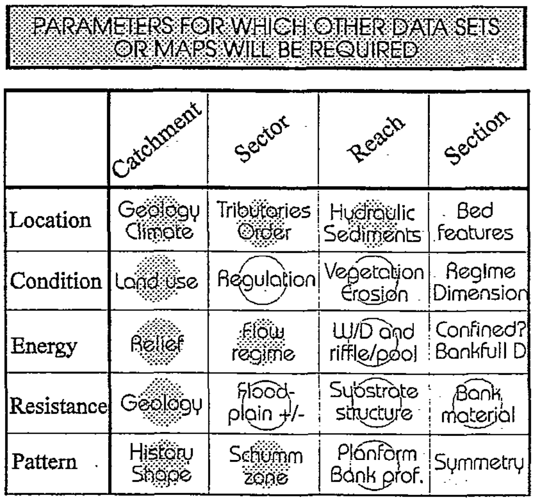


PARAMETERS PART OF WHICH CAN BE DERIVED FROM THE EXISTING DATABASE

	Catchment	Sector	Reach	Section
Location	Geology Climate	Tributaries Order	Hydraulic Sediments	Bed features
Condition	Land use	Regulation	Vegetation Erosion	Regime Dimension
Energy	Relief	Flow regime	W/D and riffle/pool	Confined? Bankfull D
Resistance	Geology	Flood- plain +/-	Substrate structure	Bank material
Pattern	History Shape	Schumm zone	Planform Bank prof.	Symmetry

For the purposes of designing a river channel typology, the first estimate of the pertinent driving variable is depicted in **Table 3.2** (opposite), along with an indication of those data that are available in the existing RHS database. The columns represent a notional scale depiction, ranging from catchment, through sector and reach to the individual cross section. (An indication of dimensions and of associated terminology is given in **Table 3.4**.) The rows on the diagram represent five primary categories of driving variable which influence the river channel - location, condition, energy, resistance and pattern. It is suggested that these drivers, acting at the range of depicted scales, dominate the characteristics of river channels, and will therefore dominate the designation of a river channel typology.

Table 3.3 Parameters for which other datasets or maps will be required.



PARAMETERS FOR WHICH OTHER DATA SETS OR MAPS WILL BE REQUIRED

	Catchment	Sector	Reach	Section
Location	Geology Climate	Tributaries Order	Hydraulic Sediments	Bed features
Condition	Land use	Regulation	Vegetation Erosion	Regime Dimension
Energy	Relief	Flow regime	W/D and riffle/pool	Confined? Bankfull D
Resistance	Geology	Flood- plain +/-	Substrate structure	Bank material
Pattern	History Shape	Schumm zone	Planform Bank prof.	Symmetry

The implication of Table 3.2 above (data availability) is that many of the diagnostic data sets that are required for the channel typology are not available in the RHS database, or are available in a form or at a resolution that is not well suited to typology. It follows that a substantial data acquisition exercise is necessary **(Table 3.3)**, both to refine and supplement the existing archive. Data categories highlighted with a shaded circle may require substantial replacement, while those highlighted with an open circle require enhancement.

For River Channel Typology, a further problem with the approach focused on the RHS data set lies in the fact that this sample may underestimate the significance of the split between "natural" and disturbed channels (Section 7.4). Since channelisation is so important and so widespread in England and Wales, it was advisable for RCT to develop an initial typology from the 476 semi-natural sites of the RHS data set, to be supplemented at some later stage by treating the 1100 managed sites as new cases to be allocated to whichever semi-natural class is most appropriate. Alternatively, "degrees of naturalness" could subsequently be assigned to the RHS sites on grounds of geomorphological assumptions applied to the spot check data. Sites

Sites that were disrupted only in ways not likely to affect geomorphological response could then be incorporated into the data used to define the typology.

As stressed above that typologies and their diagnostic driving variables are scale dependent, and a distinction has been suggested between the catchment, sector, reach and section scale. This distinction has counterparts in other classifications, as defined in **Table 3.4** below:

Table 3.4 RCT Scale terms and equivalent terms from other systems.

Scale term	Equivalent terms	Downstream Dimension	Frequency per basin	Definition
Catchment	Watershed		1	**Defined on the basis of topography.** The topographic drainage basin feeding water to a single outlet.
Sector	Sub-catchment SERCON ECS	10s or 100s of km	3 - 4	**Defined on the basis of hydrology.** A segment of river between significant tributary junctions such that the controls of hydrological regime are essentially undifferentiated within the sector.
Reach	Length	50 m - 1 km	10s - 100s	**Defined on the basis of hydraulics.** Sub-portion of a river sector over which an undifferentiated hydraulic control is exercised. In practice, often designated on the basis of morphology as a surrogate for hydraulics.
Section	Transect Swathe RHS Spot Check	1m - 5m	sampling-dependent	**Defined on the basis of sampling strategy and the local distribution of river features.** Often arbitrary location and/or spacing.

The outcome of the above derivation of likely indicators at specified scales is that it becomes possible to focus in on the actual attributes which might be regarded as appropriate as a basis for a river channel typology. These are presented in a preliminary list (Table 3.5) below.

Table 3.5 Geomorphological drivers and indices.

Geomorphological Drivers	Indices	Available in RHS?
Floods (frequency and magnitude)	Q_{bf} Q_n Ω	Not directly, but possible
Sediment Supply (type and source). Sites should be classified as sediment starved, net sediment receivers or equilibrium.	Categorical size D_{50} etc Fresh/loose/compact Bars/bank erosion Context u/s	RHS Not available RHS (qual) RHS In some cases
Perimeter (type/condition)	% silt/clay (Schumm & W/D) Vegetation Eroding/stable/depositing Roughness	Not available RHS RHS photo RHS photo
Context Relationship to other (RHS?) sites u/s and d/s History (planform)	Location NGR lat/long Network (order) Catchment (sub?) Planform instability Vertical instability	RHS &/or conversion Maps? Maps Photos/maps RHS photos

4. A PROCEDURE FOR DEVELOPING A CHANNEL TYPOLOGY

Section 2 above has indicated the broad rationale for developing a channel typology from a set of proposed attributes acquired at a set of suggested scales. An appropriate methodology for implementing such a typology must cope with the distinct differences of status (availability and reliability) of the different variables; and must work from basic but robust designations towards more powerful but more problematic procedures. Within the typology procedure itself, it is necessary to define the parameters on the basis of which the classes are to be designated. For the RCT project, it is suggested that three headings of particular and distinctive significance are channel attributes, channel sensitivity (propensity for change) and channel dynamism (the rate and nature of the change that is actually taking place. Channel attributes are essentially descriptive parameters derived from the RHS archive or from one of the supplementary data acquisition exercises. They permit reasonably robust prediction of channel sensitivity. Channel dynamism, on the other hand, can only be inferred indirectly from the sensitivity, or directly from descriptive attributes. Dynamism is of great management value as an indicator of changes which could be induced, or which should be avoided, but it has to be built from the typology using some form of rule base or expert system.

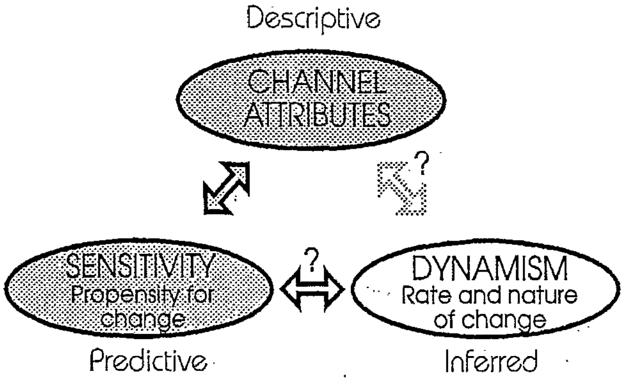


Figure 4.1 Parameters for classification

Each of the three primary categories can be amplified as an operational matrix, which indicates the likely form of the data and permits definition of appropriate techniques.

The channel attribute matrix (Table 4.1 and Appendices) describes each individual channel that is to be classified, and also offers a basis for defining the thresholds/partings for each variable that might be of significance for setting typological rules.

Table 4.1 Channel attribute matrix

CHANNEL ATTRIBUTE MATRIX What the channel is like		
PHYSICAL ATTRIBUTES	**MORPHOLOGICAL ATTRIBUTES**	**PROCESS ATTRIBUTES**

This was the starting point for the typology, and was applied at Newcastle RA on the basis of data derived from RHS or supplied from Southampton (Section 9 and Figure 9.1).

Table 4.2 Channel sensitivity matrix

Propensity for change : proximity to a critical threshold What the channel might do - what has been done to it	
EVOLUTION - reversible?	**MUTATION - irreversible?**

A channel sensitivity matrix such as Table 4.2 would have the ability to define propensity for change, and also specifies likely management ability either to move a channel away from a threshold or to move it over the threshold, depending on circumstances. Such a flexible approach caters for river classes that can easily migrate into one another, and acknowledges that some drivers tend to push rivers across proximate thresholds. This matrix embodies elements of subjectivity, though its logic is science-driven. Sensitivity has to be predicted, since it is not an observed or measured attribute. Ideally, it should be derived from the same classificatory technique that creates classes from the channel attribute matrix. Indeed, the channel attribute categories could, in principle, be subdivided into inherently stable and unstable sub-units at this stage. Interpretative indicators of geomorphological stability can be derived from the available data provided that this process is based on assumptions (further considered later) such as:

- Correct identification of geomorphological features by field surveyors
- Consistent identification of features across all RHS groups
- Data scaled in relation to channel width (e.g. pool-riffle spacing: number of point bars per unit length)

The broad aim of this procedure is to develop criteria for discriminating between those channels that exhibit stable geomorphological properties (e.g. stable perimeters; vegetated deposits) and those which are dynamic (e.g. eroding perimeters; numerous sediment storage units) - further discussed in Sections 9.4 and 12.2. An early interpretation was made of the stability categories so that type and direction of river channel change could be inferred (Table 4.3), and this is refined in Section 12 below.

Table 4.3 Interpretations of stability categories

Category	Bank Material	Substrate	Bank Feature	Channel Features
Stable or Equilibrium Channels	Bedrock * Boulder/Cobble * Sticky Clay * Peat *	Bedrock * Boulder * Cobble * Clay * Liverworts/ Mosses * Consolidated (SWEEP)	Semi-continuous trees (E) Continuous trees (E)	VPB (>3) VSB (>3) VMCB (>3) Mature island * Exposed bedrock/ Boulder * Ave No of pools and riffles (C)
Unstable or Dynamic Channels	Gravel/pebble/ sand * Earth * Bare *	Gravel/pebble * Sand * Silt/mud * Unconsolidated (SWEEP)	Eroding earth cliff * Vertical/ undercut (SWEEP) (E) Vertical+toe (SWEEP) (E)	UVPB (>3) UVSB (>3) UVMCB (>3) > Ave No of pools and riffles (C) < Ave No of pools and riffles (C)
* is SPOT values >= 5 (E) is SWEEP values where abundance >33%				
(C) is a value calculated according to the following: Divide 500m reach by bankfull width = X Divide X by 3 = Y Divide X by 10 = Z Ave No of pools and riffles occurs where >= Y <= Z > Ave No pools and riffles occurs where > Z < Ave No pools and riffles occurs where <Y				

Table 4.4 Channel dynamism matrix

What the channel is doing	
OSCILLATORY CHANGE	**PROGRESSIVE CHANGE**
Instability	Planform migration
Cut and fill	Bedform migration
etc.	etc.

The characteristics inherent in channel dynamism are critically important both in terms of understanding and as a basis for management - where they can form the basis for management guidelines. There are, however, many problems. Ideally, trend should be distinguished from noise, and reversible change has to be distinguished from the irreversible, but in practice this is unlikely to be achieved. A first identification of management-relevant indicators appears in Table 4.5, and is refined in Section 12.2.

Table 4.5 Management-relevant indicators

Indicator attributes	Provisional management interpretation
Stable banks + Unstable substrate + Unstable features	Sediment entering reach: monitor features and banks
Unstable banks + Stable bed + Stable features	Incision/sediment starvation (monitor structures for exposure of footings)
Stable banks + Stable bed + Unstable features	Sediment throughput, or beginning of change (monitor)
Unstable banks + Unstable bed + Unstable features	Aggradation - dynamic geomorphology (avoid intervention - conserve)
Stable banks + stable bed + stable features	Stable channel currently in equilibrium

The above procedures provide a provisional route towards typology definition, but their implementation demands careful synthesis of a variety of techniques. Given the availability of input variables, however selected and defined, the typology is built by seeking pattern in the data using a variety of exploratory techniques, of which the following would ideally be important (see also Figure 9.1):

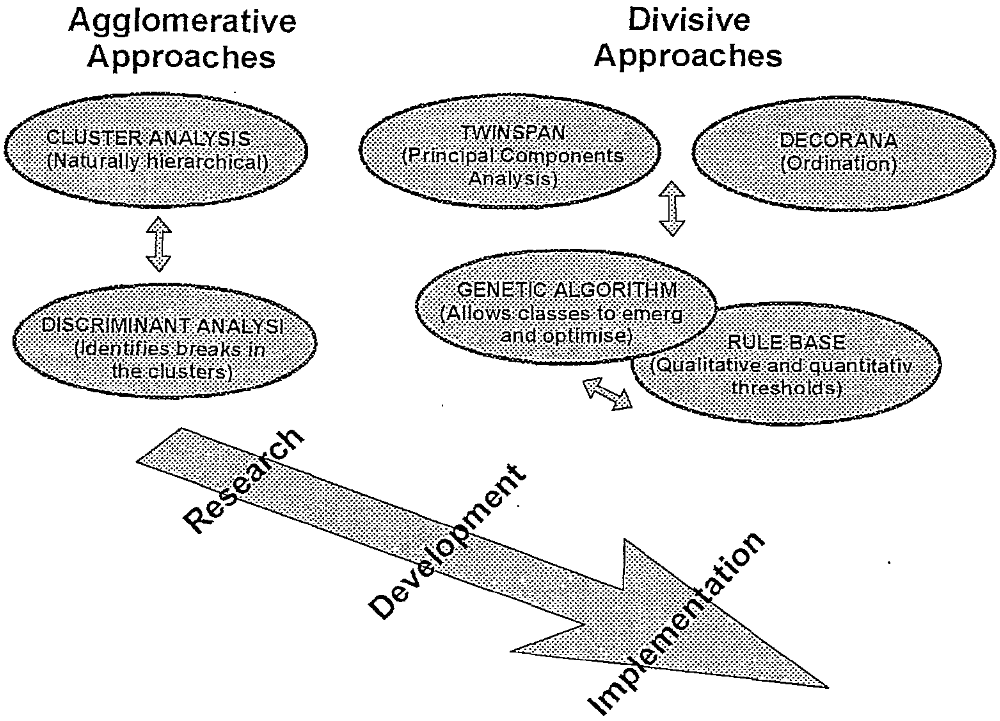


Figure 4.2 Available exploratory techniques

5. DATA FOR RIVER CHANNEL TYPOLOGY

This section introduces the requirements and types of data that have been necessary in order to provide a robust database from which to develop the River Channel Typology (see also Section 7). Given the nature of a geomorphological typology, specific data requirements arise largely from the selection of candidate "drivers" for the system. At an early stage, a list of "drivers" was discussed and agreed which recognized the scaling power inherent in attributes such as catchment area, and the allocative power of composite variables such as stream power which combines bankfull discharge, reach slope and bankfull width. In addition to the "drivers", an inventory of site attributes was required that captured the morphological diversity of natural or semi-natural streams and which would provide unequivocal boundaries between stream types. Data such as sinuosity and morphological assemblages (e.g. pools, riffles, bars etc.) were considered basic to the geomorphological allocation of river reaches within the RCT, as well as being part of the overall methodology of reach allocation into descriptive, predictive and inferred groupings: see Table 5.1 below:

Table 5.1 Drivers, descriptive and predictive attributes

Drivers	Descriptive	Predictive
Catchment Area	Substrate type	Stream Power
Bankfull Discharge	Bank Material	Reach Stability
Reach Slope	Channel Features (pools, bars etc.)	Channel pattern
Geology	Bank Features (Eroding, trees etc.)	Upland / Piedmont / Lowland
Pattern (Sinuosity)	Scaling variables (Width, Depth, etc.)	Soft Rock / Hard Rock
Location (Grid Reference/ Stream Order)	Modifications to Channel	
Bed/Bank Material	Valley Form	

5.1 River Habitat Survey Data

The database of immediate value is that developed from the River Habitat Survey (RHS) of 1500 sites within England & Wales (see Section 6). This nominally collects many of the attributes necessary for the RCT both from field and map sources. Much of the descriptive data exists within RHS concerning channel features, substrate type as well as scaling data such as Width, Depth etc. The data are clearly split into three broad categories:

Context Data:	Much is derived from maps and deals with the valley and area within which the RHS reach lies.
Sweep Data:	Site specific data that includes the scaling variables and channel features
Spot Data:	Site specific counts of bed/bank materials and some channel features

The data base also includes site photographs, taken in summer, and comprising two views; a cross-section and a reach view. These may be used to supplement or cross-check the RHS datasheets where queries occur. This dataset is currently held at Southampton.

The RHS dataset was mounted on the ORACLE Database at Southampton and on Paradox at Newcastle. Data manipulation and the creation of calculated variables such as bankfull discharge are carried out within the Oracle environment. New datasets such as Catchment Area are appended to the ORACLE database as they evolve.

5.2 Additional Data:

Although detailed, not all the information required by the RCT is available from the RHS database. Of these, the main data needs were:

Bankfull Discharge	Derived from Wharton (1992) and RHS scaled data
Catchment Area:	Derived from 1:25000 maps (1:50000 > 200km^2)
Reach Slope:	Derived from 1:25000 maps
Reach Sinuosity	Derived from 1:25000 maps
Stream Order	Derived from 1:625,000 maps
Modifications	Derived from 1:250,000 maps of Channelised Rivers (Brookes, 1983)

Values for bankfull discharge (assumed to be equal to $Q_{1.5}$ flood) were calculated from RHS derived values of bankfull width and depth, and then processed through Wharton's (1992) equations for $Q_{bankfull}$. Wharton's equations were verified against IOH gauging station values of bankfull discharge and are based on a dataset of 75 natural stream types from upland and lowland regions of the UK. Although high correlation coefficients were obtained for these equations, there was significant variance between observed and predicted values that particularly affected lowland sites for which the database was more limited. Nevertheless, the approximations have all been generated using the same assumptions which effectively means site differentiation on the basis of bankfull width and depth values. The discharge values are to be used to generate stream power by incorporating the map generated slope terms. Wharton in her Ph.D. thesis suggested that this approach was worthy of further analysis as it appeared to discriminate regional river types within upland and lowland catchments. The stream power value is driver variable of RCT and can also be used diagnostically for the prediction of channel stability.

The additional datasets were appended to the RHS database daily at Southampton and emailed to Newcastle through the Internet. Mapping of key variables and emerging channel typologies used MapInfo GIS for presentation purposes.

5.3 Data Quality

The quality of data was a main concern of the RCT. Early on it became clear that there were different weightings on the data quality required for RCT compared with that needed for the RHS. This included such attributes as slope (RHS from 1:50000 maps, RCT 1:25,000 maps as for Flood Studies) and sinuosity (derived from 1:25000 Maps over a reach length scaled to meander wavelength for RCT). Correspondingly, this necessitated the derivation of additional datasets (see Section 5.2 above).

In RCT terms there was a concern over the sample structure of RHS sites. RHS analysis concludes that out of a total of 1500 sites, 448 are semi-natural based on the complete lack of modification noted by the RHS surveyors. Early on, these sites were further refined using the database and 1:500000 maps of channelisation in England & Wales produced by Andrew Brookes (NRA Thames Region). For the present analysis, 476 sites formed the RCT sample (Section 7.4), though there was a possibility of extending this number using an additional 70 sites for which geomorphological data was known to exist within Thames Region NRA. Further extension of the sample size could be possible by relaxing the "no modifications" filter to accept that minimal modifications to channel bed and banks do not significantly modify geomorphological processes.

As a further check on representativeness, sample analysis was also conducted on the RHS sites to determine what sub-sample of the river population has been collected in the 1994 survey. This was carried out by comparing the frequency values for stream orders collected from 1:625000 maps with the distribution of stream orders within upland and lowland sites in the RHS data set. This initial survey suggests that the RHS sites are biased towards smaller streams and therefore that the larger channels are not being represented. Subsequent RHS data collection should seek to redress this imbalance.

A programme of data assessment was implemented at both Newcastle and Southampton Universities, with the aim of establishing the quality and information content of the geomorphological attributes recorded by the RHS 1994 survey protocol. There was some evidence of data discrepancies in terms of identifying values of width and depth, but the primary concern was in the correct identification of geomorphological features by non-specialist surveyors. Opportunities to cross-reference data with photographs will help to reduce some of the uncertainty regarding the identification of features or missing data where features have not been allocated or where substrates were not visible. Discussions with the field operators have also helped to clarify some points.

6. THE GEOMORPHOLOGICAL SIGNIFICANCE AND UTILITY OF RHS94 DATA

The RCT project depends very significantly upon data gathered by RHS surveyors under the protocols developed by Agency for the first surveys in 1994 (NRA, 1994). Whilst some of the present research team were informally involved with the development of the 1994 survey features and categories and whilst one of the outputs of the 1994 survey was described as 'a river typing method based on geomorphological principles' (page 20), this R&D project has essentially developed after many important decisions were made about the 1994 survey. We have had the opportunity to explore and refine the typology which was developed by NRA (it is indeed, based on elementary geomorphological principles) but to make further demands on the 1994 data, in a sense to test it to destruction in the light of:

a. Selection of features/variables to be observed/measured,
b. Detail (including spatial detail) recorded for these features/variables,
c. Degree of operator variance (non-geomorphologists were employed),
d. Levels of success in coverage and completion of surveys for individual reaches.

This section deals mainly with (a) and (b) but touches on (c). Remarks about missing data (d) are made elsewhere in the Report.

6.1 Geomorphological features for RHS94

One of the most immediate problems facing the geomorphological interpretation of RHS94 data has proved to be the validity of (and confusion between) ***flow-type*** data and data related to ***morphological units*** which control the flow. The field of 'habitat hydraulics' is very recent and, at the time of preparing guidance for RHS94, had not yielded either a fully embracing typology of recordable features (flow, morphology) or linkages between these two elements. The situation has been remedied by geomorphologists for the 1995 and subsequent surveys.

Meanwhile, the Predominant Flow Type (section F) has been recorded in RHS94 as a reduced and confused set of attributes; observers have confirmed that, for example, 'approximately laminar' (a flow type rare in nature) was used as a 'catch-all' for many flow types which we would now take to indicate the influence of several significantly different morphological units (jointly, with flow, leading to different biotopes- Padmore *et al.*, in press). Section F data, potentially very helpful to a broad geomorphological picture, are in fact largely unusable. For this reason it is also regrettable that Section X (a field typing based on ***geomorphological channel patterns***) was not completed by many surveyors; furthermore, ***channel photographs*** were not taken with geomorphological interpretation in mind (see below).

Within the 'spot-check' sections of the RHS94 form there is a wealth of information about ***materials, flows, features and modifications***. All four are highly relevant to geomorphological interpretation (but see below for spatial interpretation). It is possible to derive numbers for such features as stable and eroding banks, mid-channel, lateral and point bars, riffles and pools. However, ***riffles and pools*** were listed with 'predominant flow' and this is said to have confused their interpretation in the field. It has also become clear (and this may be a major change in the geomorphological interpretation of channel patterns) that riffle-pool sequences may be far less common than other sequences around 'raised' channel elements, e.g. riffle-run, riffle-glide and rapid (or cascade)-run.

A very justifiable fear over this form of data collection (i.e. spot-check scores) is that the quantities of geomorphological features are highly dependent on channel width; elsewhere in this report we illustrate the difficulty, therefore, of comparing ***numbers of features*** between channels of very different scales.

It should also be added here that the spot-check information on channel and bank materials is crucial to interpretation but is often a 'given' feature of a river, rather than a geomorphological feature; it therefore tends to enter the independent variable category and impart a major geographical 'stretch' to the variance of the data set.

RHS94 also includes a variety of important information related to the ***management of the channel and its geomorphology***, notably in the 'sweep-up' sections L (bank profiles), M (embankments), R (artificial features) and S (recent management). However, it was not envisaged at the time of setting up the survey that a large majority of the sites surveyed would be artificially influenced. The quest for a basic set of semi-natural sites and our concentration upon those means that these sections are effectively redundant in terms of geomorphological interpretations. Thus, in contrast to the Habitat Quality Index (to be developed by ecologists from RHS - and which uses 'damage' to derive the index) we may be abandoning very useful data by ignoring the less modified sites. The extensive channel maintenance costs incurred in modified channels in England and Wales (Sear and Newson, in press) suggest that the geomorphological system quickly recovers in the face of the more minor engineering schemes, even if basic channel dimensions are rendered impossible to compare with natural/semi-natural sites. RCT may yet need to extend its site base at the considerable penalty of deriving more map-based information.

The most important sections of the 'sweep-up' data are 'O' (natural channel features) and 'P' (channel dimensions). Once again, however, features are confused with flow types.

At this stage, it is worth stating the improvements brought into RHS95 by the geomorphological interest. These may be summarized as:

- The major geomorphological features: riffles, pools and point bars are isolated as a reach count in Section D of the 1995 survey.
- The spot check data contains a much broader selection of flow types, each with explicit links to physical biotopes (morphological units); surveyors have been trained to make selections amongst the options.
- Physical biotopes (morphological units), having been identified in transect via flow type, are 'swept up' at the end of the survey.

6.2 Spatial aspects of geomorphological features RHS94

An immediate major problem which presented itself to RHS as a whole was the poor representation in the sample of natural and semi-natural sites (defined in relation to river engineering intervention) and the ***concentration of these sites in the north and west of England and Wales*** (Section 7.4). The true variance of river channel forms, dimensions and features is not, therefore, established; in statistical interpretations we are likely to raise the significance of driving variables particularly suited to spanning this narrow range. In classification we may, for example, expect a wide range of representative case numbers in some classes whilst others may be relatively 'empty', forcing different levels of classification to be applied to different groups.

The second restriction on geomorphological interpretations is almost equally inevitable and arises from the reach/transect ***form of the survey as a whole***. Geomorphologists stress the interconnectivity of the sediment system in catchment channel networks (Sear and Newson, in press); RHS necessarily uses stratified random samples without reference to this system. The particular problem faced by RCT in seeking process-related information is therefore obvious. Whilst river ecologists may be prepared for poorly developed floral and faunal communities (and hence spatial imhomogeneity), geomorphologists consider linear, interconnected systems and this project needs to seek manipulations which 'reassemble' the RHS sites. At the very least, we have to consider the photographic evidence collected by RHS as a means of doing this. An alternative, described elsewhere, is the use of rule bases to impose new levels of classification upon the basic site data - to indicate, for example, forms of ***geomorphological stability or instability*** (see above).

Finally, the spatial accuracy of certain RHS measurements is not up to ***conventional geomorphological standards***; the opportunity should have been taken to measure channel gradient in the field, rather than general reach slope from 1:50,000 maps. Stream order was hastily measured from 1:625,000 maps. In both cases the minimum map standard desirable would have been 1:25,000.

7. TOWARDS A CHANNEL TYPOLOGY

The following sections of the report (Sections 7-11) are an account of the data analysis undertaken as part of the River Channel Typology research project. Particular attention has been paid to the process of selection of variables and the data transformations used in the numerical analyses. The initial task was to reassemble the RHS database from the individual datasets and then to process and extract material relevant to river geomorphology. The second stage was implementation of TWINSPAN and of the data transformation necessary to achieve meaningful results.

A series of classifications were produced through TWINSPAN as the selection and transformation of variables was refined and interpretation of the outputs improved. In the first instance, an overview of this process is given by describing the first and then the most recent classification, and by discussing their similarities and differences. Detailed statistics of the characteristics of stream classes proposed are also given together with a key to allocate new cases to classes. Results of the analysis undertaken to relate driving variables and dependent variables is also given with an account of the research approach.

7.1 Original data:

The RHS survey data were received by Newcastle University in an ASCII format. The data consisted of the database held by the RHS Project, and comprised:

- "Spot-check" data for 1521 sites (approx. 15213 spot-checks, 10 for each site)
- "Sweep" data for 1521 sites

A further set of data for the RHS survey was collected from OS maps by Institute of Freshwater Ecology, Dorset. This was obtained from IFE separately and added to the dataset received from the RHS project (Peter Fox: North-West Region).

7.2 Data audit:

The first task was to document the variables in the dates (approx. 160 in total) by cross-checking against the original RHS surveyors' schedule. No proper list of variables, variable names or coding existed. Proper documentation of these would have considerably speeded up the process. In order to assemble the pieces of the database it was also necessary to check for duplicated and missing data.

7.3 Creation of one data set:

In order to combine data from the "spot-check" and the "sweep" datasets it was necessary to sum attributes at the spot-check level in order to create data consistent with the sweep 500m reaches. Spot-check variables needed to be summed for each site to create new variables consistent with the sweep data. For example, channel substrate type was recorded as one of 8 categories in one variable by the surveyors. In order to sum this variable to attribute it to a single site, a set of 8 dummy variables was created, one for each substrate class. Then these variables were summed for each set of spot-checks to give a frequency of substrate types for each site. Frequencies were then converted into a % score for each substrate type for sites. Similar transformations were used on the remaining spot check data. These data could then be integrated with the sweep data once they had been converted to a site-basis.

In addition to this, data was received from the Institute of Freshwater Ecology (Hugh Dawson) and "stream order" data were derived at Newcastle from a 1:625,000 map. These data were also combined with the spot check and sweep data to form the master dataset. See Appendix 1 for a full summary of the dataset.

7.4 Semi-natural sites:

A decision was taken at an early stage to concentrate solely on "semi-natural" sites, i.e. river reaches with negligible engineering modifications or evidence of channel management such as dredging. A subset of sites were chosen in accordance with the methodology used by the RHS project (Peter Fox) for selection of semi-natural sites, giving a total of 484 sites out of a total of 1521. The criteria used to select sites were as follows:

- recorded as semi-natural by the surveyor
- no channel modifications
- only 1 bank modification spot check per bank
- no dams, culverts, weirs or bridges
- no navigation

In addition to this, a further 7 sites were excluded from the subset as they were judged from photographs to have been modified and one excluded because of unreliable data, giving a total of 476 sites. These data form the basis of all the analyses described below. The original rationale for this was in order to be consistent with the NRA/IFE typology of "river habitats" which developed a predictive model of river habitat from the RHS dataset, using semi-natural sites only. This gave a range of predicted habitat types depending on a number of physical variables: altitude, slope, solid geology and flow type.

However, for the purposes of the River Channel Typology R & D selection of this sub-set may give a somewhat distorted view of English and Welsh rivers as a whole. It is not a random sample of RHS sites but heavily over-representative of rivers in the North and West of England and Wales and under-representative of rivers in the South and East Anglia. This is apparent from Figure 7.1 which shows the distribution of channel substrate types among semi-natural sites and all others. In Figure 7.1 channel substrate types have been determined as the majority substrate size in each reach. Where substrate types are equally abundant sites are classed as *mixed*. There is over-representation of gravel/pebble and cobble-bedded rivers and under-representation of silt/clay/chalk substrate rivers. This is to be expected as a result of the fact that lowland rivers are more likely to have had engineering works for flood defence purposes.

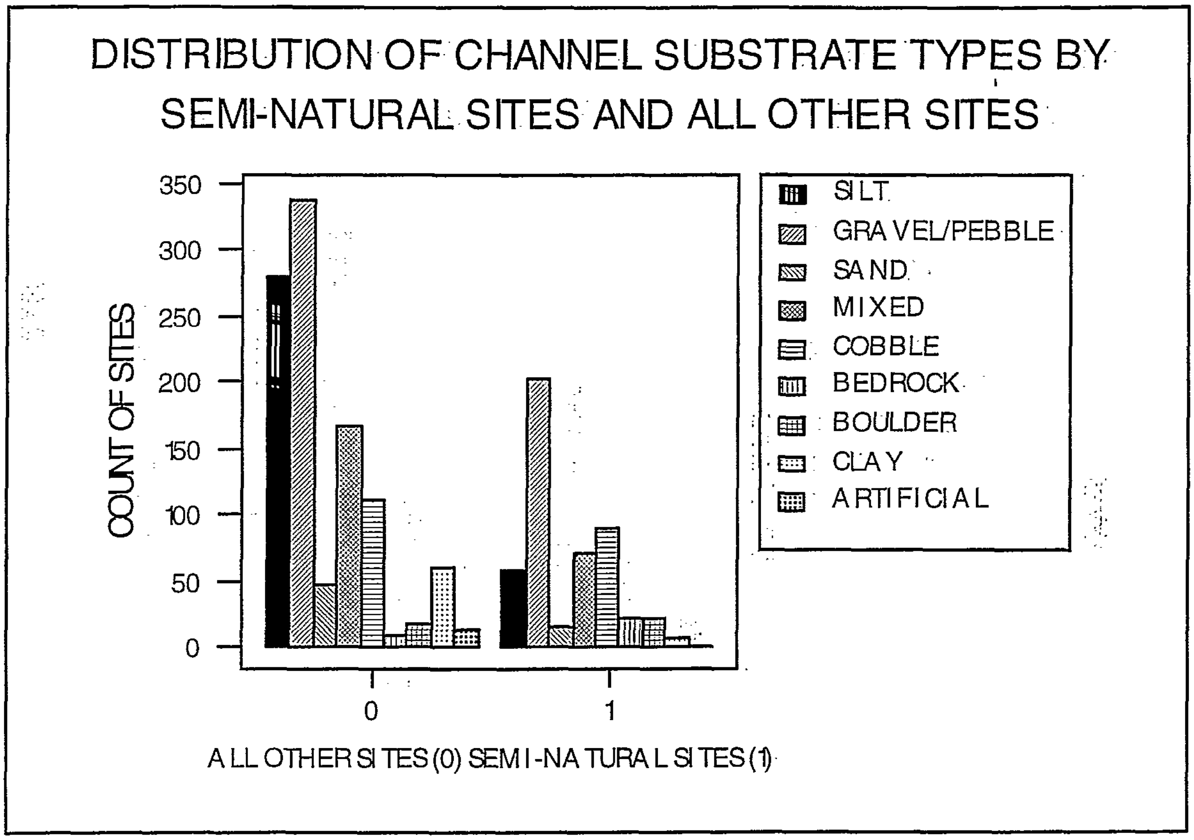


Figure 7.1: **Distribution of channel substrate types among semi-natural sites and all other sites.**

The bankfull widths of the semi-natural sites and all other sites are remarkably similar, the means being 10.1m and 10.4m respectively. This might be surprising in view of the disproportionate number of rivers with coarser substrate. However, the reason for this may be twofold. Firstly, the sampling method of RHS tends to discriminate against the selection of sites on larger rivers and secondly, silty rivers in the east of England may in many cases have been overdeepened and so are relatively narrow in relation to their position on the river network.

Table 7.1: **Comparison of bankfull widths of semi-natural and all other sites**

BANKFULL WIDTH	Number of sites	Mean	Median	Q1	Q3
Semi-natural sites	484	10.5m	6m	3m	11.5m
All other sites	1039	10.1m	7m	4m	12m

8. SELECTION OF VARIABLES FOR CLASSIFICATION

It has already been established that the aim of the River Channel Typology was that a classification should focus on the "driving variables" of fluvial geomorphology. To that end, a list was produced (shown below in Table 9.1) of these drivers and the dimension variables considered fundamental to defining geomorphological character, although it was accepted that it would be unfeasible to collect many of these datasets. Consideration was given to whether each variable would be available from the RHS dataset, whether suitable proxies were available or whether the data might have to be collected separately. A number of variables were subsequently dropped because of time restraints and because interpretation from photos was problematic. A list was then drawn up of those variables not available from the RHS which could feasibly be provided by the GeoData Institute, Southampton University within the timescale of the project.

Taking into account what was available in the RHS, in order to achieve a minimum list of driving variables, the GeoData Institute was asked to provide the following data:

- Catchment area from 1:25,000 maps
- Improved measurement of channel slope from 1:25000 maps
- Improved measurement of sinuosity from 1:25000 maps
- Mean annual flood by calculation from the Wharton (1992) method

9. DEVELOPMENT OF THE METHODOLOGY

While these data were being collected, TWINSPAN classification of sites using the dependent variables (mainly geomorphological features) was carried out to establish a methodology for the type of mixed data which the RHS dataset contained. The original concept had been to use clustering methods to group together rivers with similar driving and geomorphological characteristics and then to generate a set of rules to predict class from the variables used. However, it would be difficult to interpret the classes generated without being able to relate them to a purely geomorphological classification of river channels, i.e. a classification of the dependent/dimension variables. Therefore it was decided to fully develop a classification of the channel morphological variables and then to examine the relationship between the driving variables and the classes derived from the dependent variables.

The relationship between the drivers and dependent variables could be tested in one of a number of ways:

- Redundancy Analysis could be used to test how much of the variance in the dependent variables is accounted for by the driving variables;
- Discriminant Analysis could be used to test how far the driving variables predict -class membership derived from dependent variables;

During the course of the data analysis it has become clear that the classification using dependent variables is determined largely by channel substrate size or the various combinations of substrate type that commonly occur, e.g. cobbles, pebbles and gravel or boulders and bedrock etc. Therefore, if discriminant analysis is used to predict morphological class from the driving variables then it will effectively be predicting substrate size, which is not an unrealistic expectation. One would expect to find that some sort of relationship between stream power, geomorphology and substrate size is an important element of geomorphological characteristics (for example: Ferguson, 1981).

9.1 Variable selection for TWINSPAN - dependent variables

Working from the base list of fundamental variables above, the significant geomorphological variables were compiled from the RHS database. These are shown in Table 9.2 below, and the outline methodology is indicated in Figure 9.1. Having chosen the set of variables some data transformation was then required for TWINSPAN to be able to use them as classification indicators. For the first attempt at classification the transformations shown in Table 9.2 were used.

Table 9.1: Fundamental driving and dimension variables

	CANDIDATE INDICES	*APPARENT PARTINGS*	*INVENTORY, CLASSIFICATION ALLOCATION*	*ACHIEVABLE SURROGATE*
DRIVERS				
ENERGY	Stream power	7.5 for deposition, 35 for instability	none	Derive from MAF - calculated from Wharton (1992) and slope
	Channel slope (maps) Field gradient (reach)	Rosgen (1994) uses 0.5, 2, 4, 10%	Allocation of some	Exists on RHS but re-measured by GeoData on 1:25,000 maps
	Network power (see 'location')	none	Classification	Not available from RHS, use SF or network size.
	Bankfull channel area	Relate to 'flood classes'	Classification	Surrogate - bf width and bf depth
RESISTANCE (to erosion and flow)	Roughness	As for substrate	Allocation	Feasible from RHS photos + USGS guidebook
	Hydraulic mean depth	Continuous variable	Not feasible	Not feasible
	Substrate size	International scales/ Φ	Classification	Exists in RHS but as categorical size
	Relative roughness	Bathurst has scaled	Inventory	Not feasible
	Width or width/depth	Rosgen (1994) uses W/D 12, 40	Classification	Exists (low and bf flows) on RHS
LOCATION (network location, catchment size, x/y)	Catchment area	No partings, deviations	Classification	
	Mainstream length		Classification	Exists in RHS
	Stream order, SF, DD	Helpful to kill of wet/dry contrasts	Classification	Available - calculated from map
	Grid co-ordinates	UK schemes often use	Beware EC use of RHS	Exists on RHS
DIMENSIONS				
PATTERN (historical overlay and valley floor and long profile)	Sinuosity	Schumm related to W/D Leopold + to S v Q	Classification	Exists on RHS - poorly defined - re-measured by GeoData
	+/- floodplain/ confined		Allocation	Exists (qualitative) on RHS
	pool/ riffle spacing	Related via width, to 'natural' mean	Allocation	Can be derived from RHS
	+/- bars and spacing	Relate to supply-or transport limited interference?	Classification?	Can be derived from RHS
CONDITION (current dynamics)	Stable/eroding/ aggrading	GeoData already classed	Allocation	Possible from RHS photos?
	Sediment supply	Schumm/Kellerhals relate to load, slope W/D ratios etc.		Not feasible to use RHS sites in u/s d/s order
	Substrate size	International scales/ Φ	Classification	Exists in RHS but as categorical size
	Naturalness/ intervention	Parting devised in RHS	Basis of RHS	Semi-natural sites defined in RHS

Table 9.2: Initial list of variables for TWINSPAN analysis

Variable	Transformation	• New variable/s
Bedrock	convert to % of reach	• Bedrock %
Boulders	convert to % of reach	• Boulders %
Cobbles	convert to % of reach	• Cobbles %
Gravel/pebble	convert to % of reach	• Gravel/pebble %
Sand	convert to % of reach	• Sand %
Silt	convert to % of reach	• Silt %
Clay	convert to % of reach	• Clay %
Artificial	convert to % of reach	• Artificial %
Rapids	transform to 2 dichotomous variables	• rapids present (0,1) • rapids extensive (0,1)
Cascades	transform to 2 dichotomous variables	• cascades present (0,1) • cascades extensive (0,1)
Slacks	transform to 2 dichotomous variables	• slacks present (0,1) • slacks extensive (0,1)
Glides	transform to 2 dichotomous variables	• glides present (0,1) • glides extensive (0,1)
Sinuosity	transform to 3 dichotomous variables	• sinuosity1 (0,1) • sinuosity2 (0,1) • sinuosity3 (0,1)
No. riffles	multiply by 2 (a range of 0~140)	• N_riffle index
No. pools	multiply by 2 (a range of 0~140)	• N_pool index
Eroding cliffs	convert to %	• eroding cliff %
Side-bars	convert to %	• side-bar %
Point-bars	convert to %	• point bar %
Mid-channel bars	convert to %	• mid-channel bar %
Bankfull width	multiply by 4 (a range of 0~300)	• bankfull width index
Left-bankfull ht.	multiply by 10 (range of 0~70)	• bankfull ht left-bank index
Right bankfull ht.	multiply by 10 (range of 0~70)	• bankfull ht.left-bank index

The initial classification derived from TWINSPAN is shown in Figure 9.2 below. Only 441 of the 478 semi-natural sites could be used in the analysis as the remaining sites had missing data, which is inadmissible for TWINSPAN analysis. The Figure shows the dichotomous key that allocates sites to classes. These are generated by TWINSPAN in the formation of the classification. TWINSPAN is a divisive method of clustering, starting with all observations in the same group and then creating divisions in the hierarchical manner shown. A score is generated from variables it selects as indicators at each stage and then individual observations are allocated to the left (negative group) and right (positive group) sides of each division depending on their score in relation to a threshold value that the program generates. The threshold values for each decision box are shown. This decision tree could be used to allocate any new reach to the classes shown.

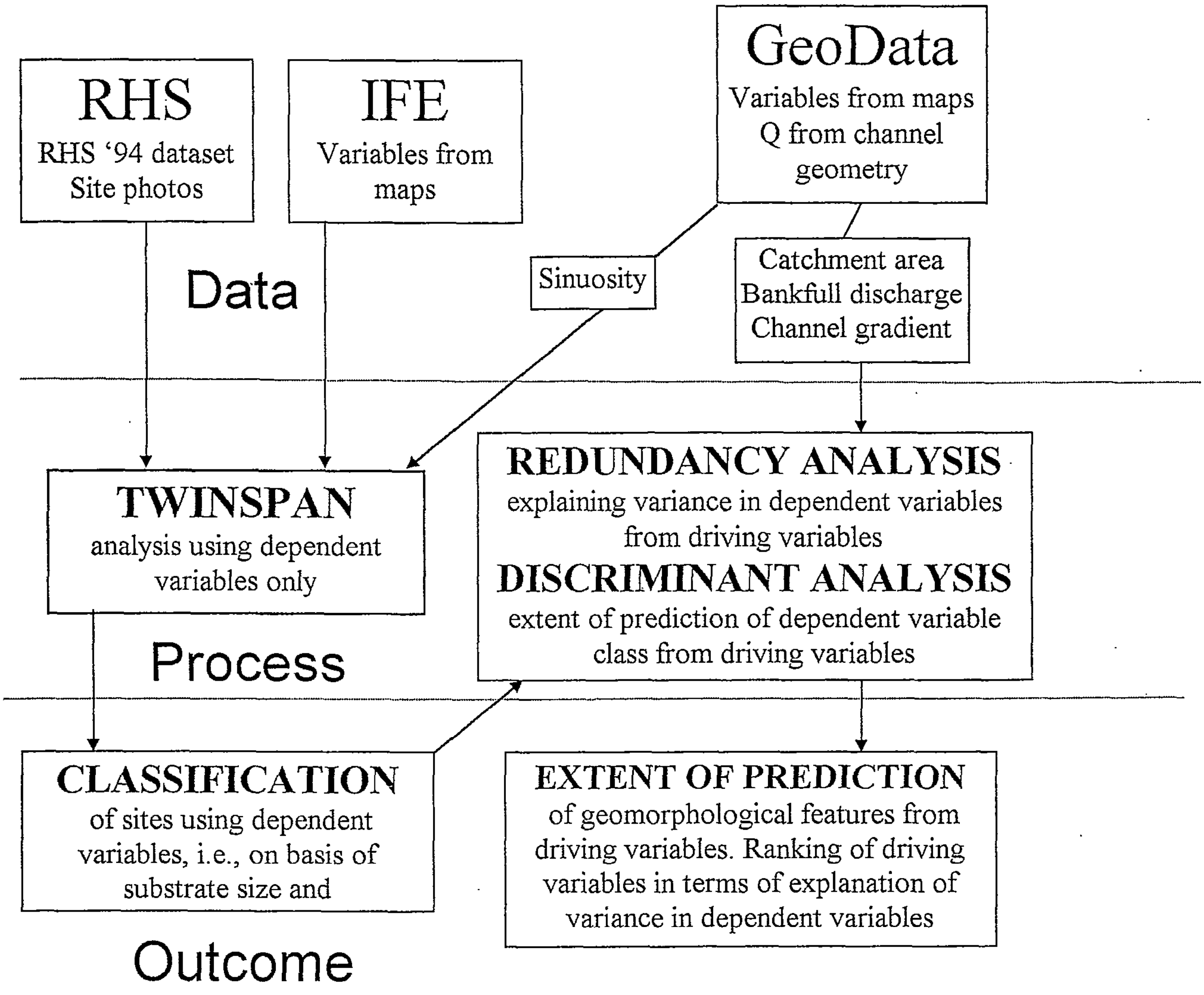


Figure 9.1 **Data sources, Processes and outcomes for the RCT Project**

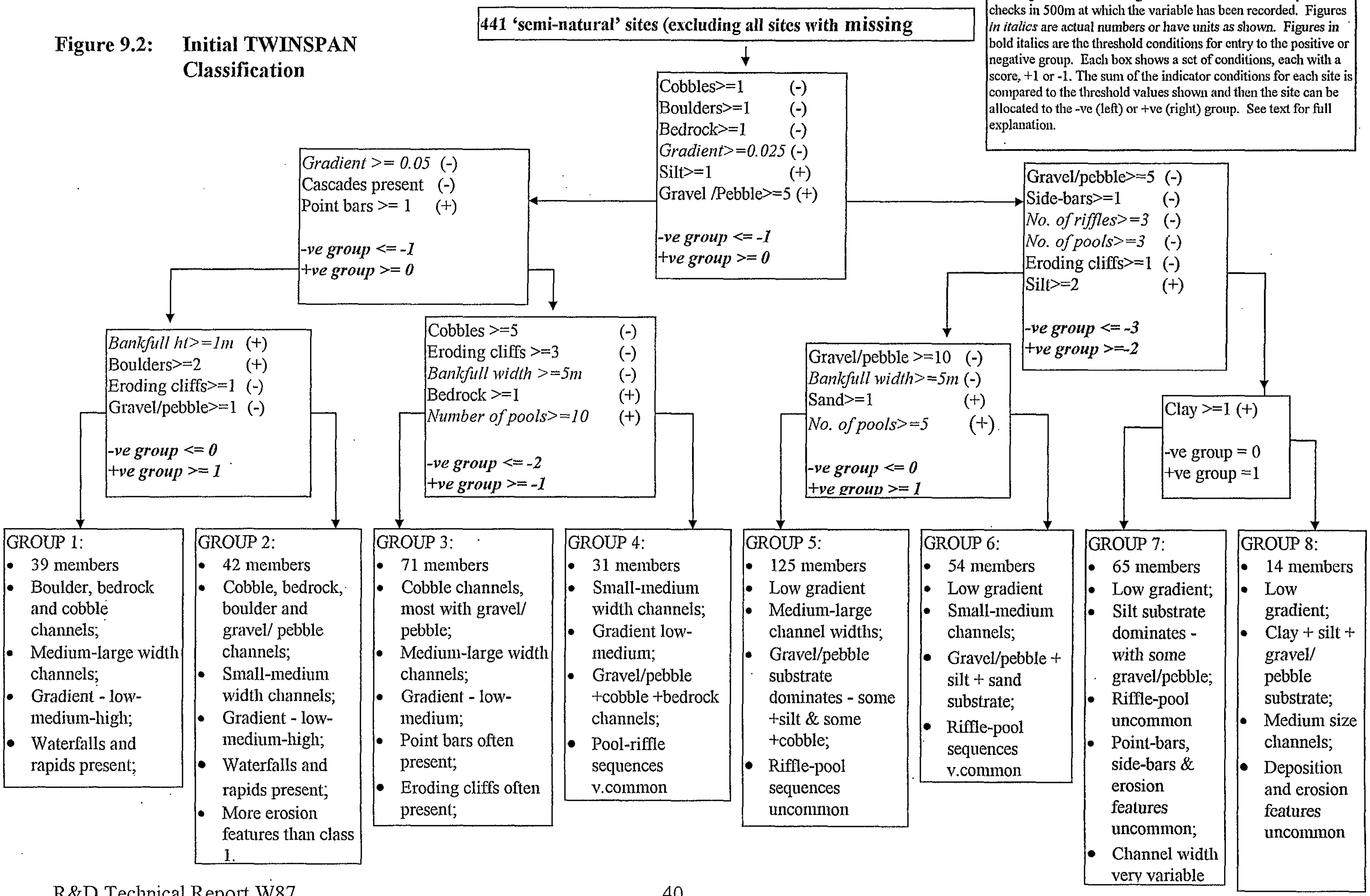
9.2 Discussion of initial classification

It is clear that the major determining variables in this classification are substrate classes. There is clearly a large degree of association between substrate classes, channel gradient, and the presence of rapids and cascades and this tends to order the groups from left to right. Groups 1-8 have progressively finer substrate, beginning with boulder and bedrock channels in group 1 and ending with clay in group 8. In fact, it is quite remarkable how the classification orders sand (group 6), silt (group 7) and clay (group 8) in order of their respective grain size. Substrate is important in terms of biological habitat and so there may be some useful relationship between a physical classification of this type and biotic/environmental habitat value.

After generating the initial classification it was decided that some of the variables were unsuitable to contribute to the classification. During a series of subsequent TWINSPAN classifications a number of modifications were made:

- The categorical measure of sinuosity available in the RHS database did not contribute to any of the indicator scores in the first four levels of the TWINSPAN hierarchy and had not been measured in a satisfactory way so it was excluded from the analysis. The categorical measure was replaced with a measurement of sinuosity provided by the GeoData Institute for all semi-natural sites measured from 1:25,000 OS maps.
- Side and point bars were considered to both be features of channel sediment storage and so were combined into one variable - *twobars* - this had the advantage of having fewer zero values.
- The substrate class *"artificial"* has been excluded from the analysis as it was regarded as being irrelevant for the purposes of classification, and nearly all the values were zero.
- Bankfull dimensions were removed from the dependent variables classification because when these were related to the driving variables, including specific power, there would be a circular argument since bankfull flow was calculated from bankfull dimensions.
- Gradient was removed from the dependent variables because it is also strongly related to specific power.
- The number of riffles was found to be a more accurate indicator of riffle-pool sequences than the less reliable number of pools after discussion with RHS 1994 surveyors. Thus the number of riffles alone was used in the dependent variable classification. In order to remove the effect of channel width on the number of riffles in a reach this was multiplied by bankfull width to give a *riffle index* since the number of riffles in a 500m reach is accepted as being inversely related to channel width.

Figure 9.2: Initial TWINSPAN Classification



Most figures in the tree diagram refer to the number of spot-checks in 500m at which the variable has been recorded. Figures *in italics* are actual numbers or have units as shown. Figures in bold italics are the threshold conditions for entry to the positive or negative group. Each box shows a set of conditions, each with a score, +1 or -1. The sum of the indicator conditions for each site is compared to the threshold values shown and then the site can be allocated to the -ve (left) or +ve (right) group. See text for full explanation.

9.3 Further data transformation:

Distributions of the above variables were examined to decide if transformations were necessary to run in TWINSPAN. One of the most important data requirements of TWINSPAN is for all the variables to be able to be put into classes with common cut-off levels, e.g., 0, 5, 10, 25, 50, 100. This type of logarithmic cut-off pattern is often suitable for environmental data to divide the data up into roughly equal classes. Thus, variables can usefully be represented as a percentage or standardized to a range of 0-100.

However, after standardization, variables showed a wide range of skewed distributions, typically with a long tail of outliers and no single set of cut-off values was suitable for all variables. This led to a loss of resolution in the analysis and an effective down-weighting of those variables. Transformation of dimension variables was possible to manipulate some of the data towards normality but this would have made it difficult to interpret the classification produced.

Following the methodology used by Moss (1985), sinuosity and riffle index were divided into 5 and 6 classes respectively which were then represented by dummy variables. Splitting a variable into a set of dummy variable classes gives greater control over the TWINSPAN classification. It allows the operator to split the variable into chosen ranges. The output is also easier to interpret as physical patterns of positive values emerge in the two-way table output. These dummy variables are dichotomous (0, 1) variables simply indicating presence/absence of the particular class for each variable. TWINSPAN can use presence as a group indicator but not absence, since two sites both *not* possessing a characteristic does not necessarily make them similar. Magnitudes of other variables which are not transformed in this way can also use be used as group indicators.

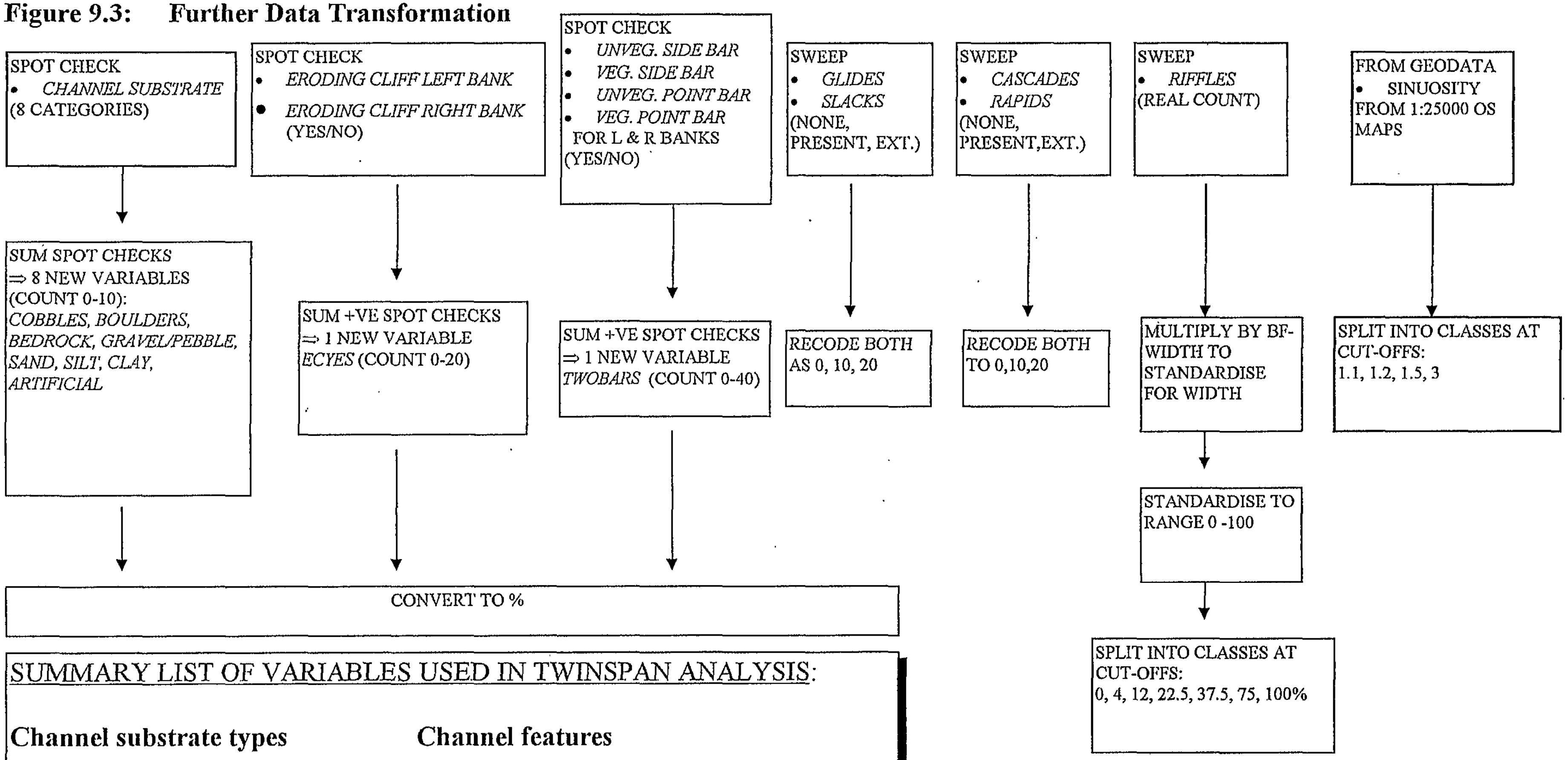
Having transformed *riffle index* and *sinuosity* into classes, it then became straightforward to manipulate the remaining variables with the TWINSPAN cut-offs to produce greater resolution. The smallest possible value for data originating as spot-checks was 10%, i.e. 1 spot check multiplied by 10 to convert to %. Therefore, this was taken to be the lowest cut-off value. The full-range chosen was 0, 10, 20, 30, 50, 100. Other variables such as slacks, glides, rapids and cascades, being ordinal/ranked data, were simply mapped onto the relevant values, e.g. 0, 1, 2 ⇒ 0, 10, 20.

The flow diagram in Figure 9.3 (overleaf) summarizes the improved data transformations used to prepare the data for TWINSPAN analysis.

9.4 Stability index:

A stability index was produced by GeoData which was to be added to the dependent variables. This, it was hoped, would contribute a measure of erodibility or resistance to stream power. However, it proved difficult to classify a large number of sites or to develop a scale of stability that could be interpreted easily. A scale was devised relating to the stability of bank and channel substrate. However, the vast majority of sites fell into only two categories as Figure 9.4 (below) shows.

Figure 9.3: Further Data Transformation



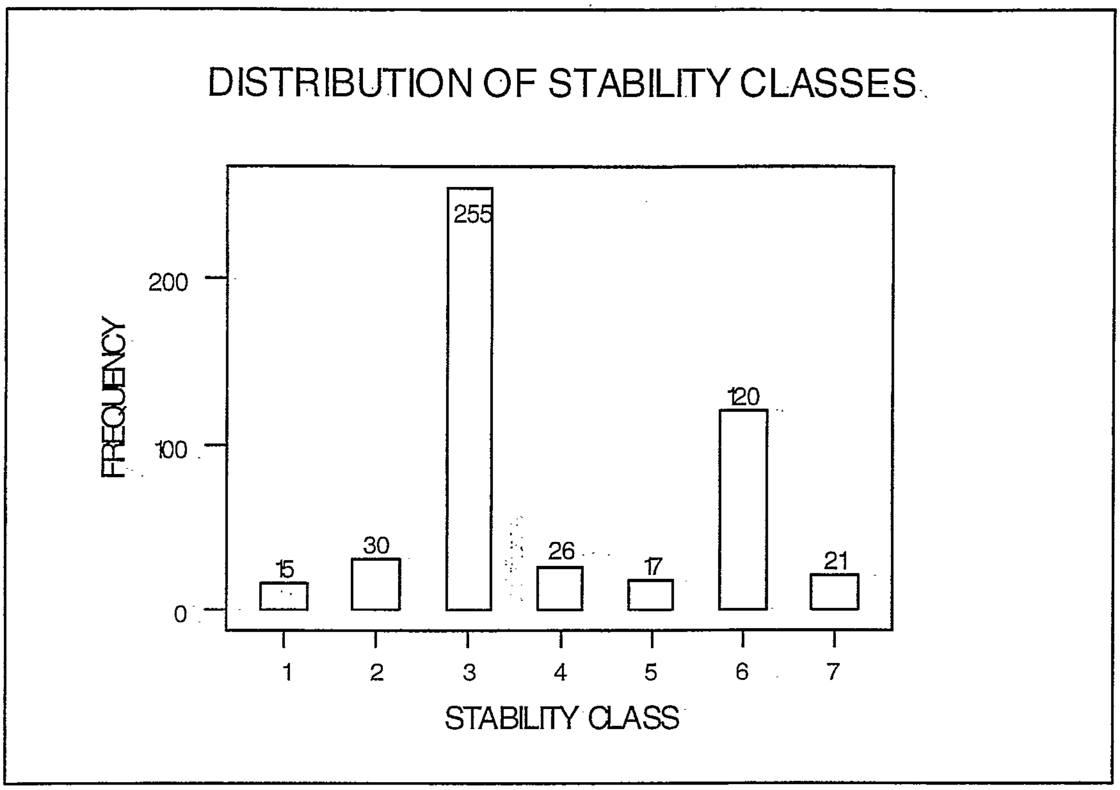
<u>SUMMARY LIST OF VARIABLES USED IN TWINSPAN ANALYSIS:</u>

Channel substrate types

BEDROCK (%)
BOULDERS (%)
COBBLES (%)
GRAVEL/ PEBBLE (%)
SAND (%)
SILT (%)
CLAY (%)

Channel features

TWOBARS (%)
ECYES (%)
GLIDES (0,10,20)
SLACKS (0,10,20)
CASCADES (0, 10, 20)
RAPIDS (0, 10, 20)
SINUOSITY01..05 (CLASSES)
RIFFIDX01...07 (INDEX CLASSES)



Legend for Figure 5:	
1	Bank stable & substrate stable
2	Bank stable & substrate unstable
3	Bank unstable & substrate unstable
4	Bank unstable & substrate stable
5	Bank stable & substrate stable and unstable
6	Bank unstable & substrate stable and unstable
7	Bank stability unclassifiable & substrate stability unclassifiable

Figure 9.4: Frequency of Stability Classes

The classification was generated using a set of rules to identify bank and substrate stability and instability (see Appendix 2). Classes 5 & 6 (both with "substrate stable & unstable") arise as a result of sites fulfilling the criteria for instability and that for stability. Interpretation of such classes is not really possible. This makes the index difficult to use because stability index 6 in particular contains about 25% of all sites. The underlying problem is that the information available in the 1994 RHS survey was not suitable to derive a stability index.

Despite the inherent problems in the stability index a trial was undertaken to assess its impact on the TWINSPAN classification of dependent variables. The stability index was added to the list of dependent variables as a series of seven dichotomous dummy variables. A TWINSPAN analysis was carried out and the output was compared to the previous output without the index. Virtually no change whatsoever resulted from the inclusion of stability index. A total of about 10 sites were re-allocated to different classes. This was mainly as a result of the fact that over 75% of cases fell into only two categories which were evenly distributed over the classes.

These results do not at all invalidate the reasons for developing a stability index. Rather, they highlight the requirement for data collection suited to geomorphological research, as a stability index or measure of erodibility would be an extremely powerful variable in analysis of reach stability. It has been interesting, for example, to examine those channels thought to be unstable against the frequently quoted threshold for instability of 35 W m^{-2}. Although this ideally requires more thorough data collection to give reliable information on stability, the analysis is discussed in section 11.2 below.

10. IMPROVED TWINSPAN CLASSIFICATION RESULTS AND KEY

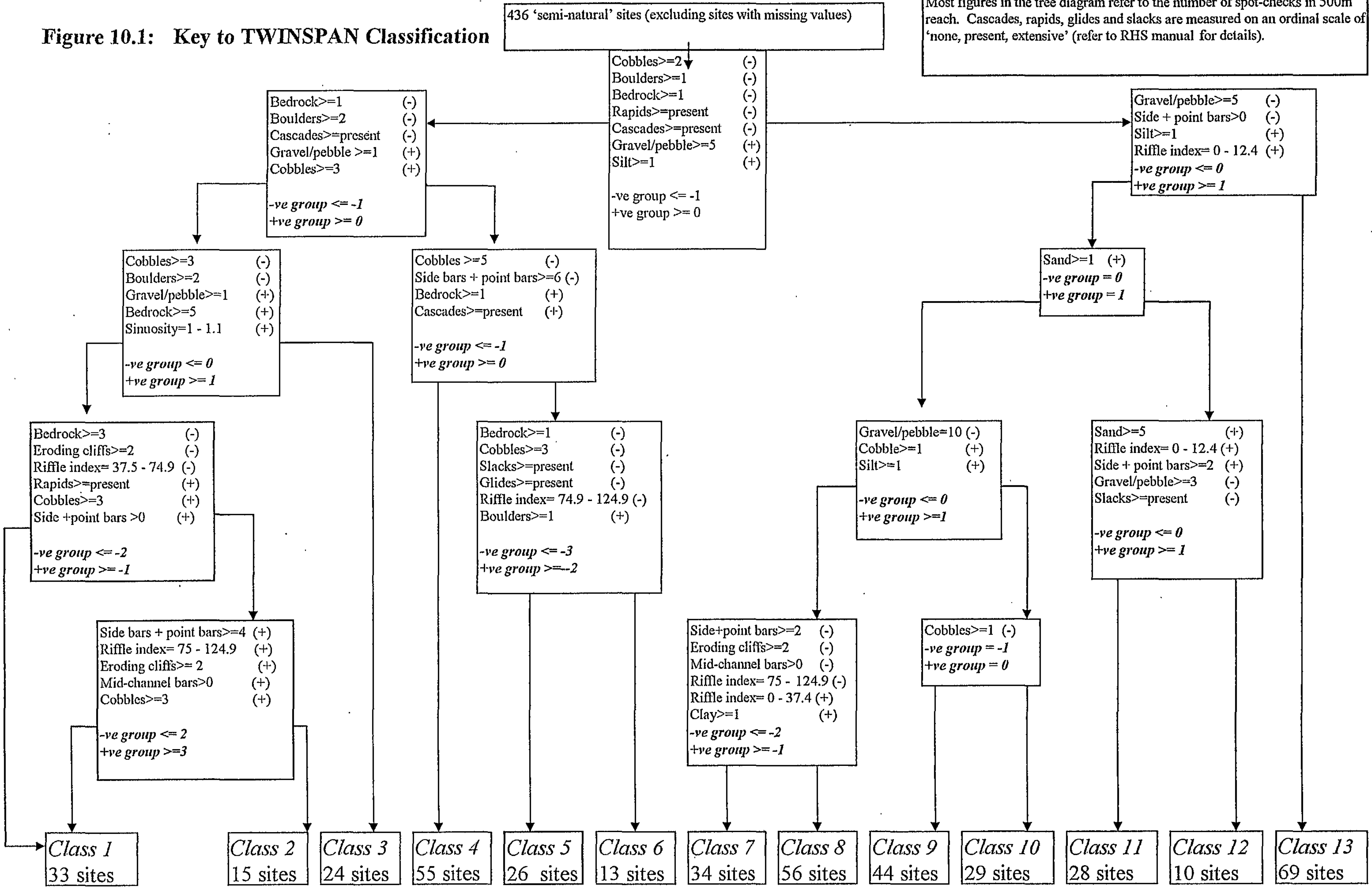
Successive refinement of the choice of variables and the data transformation as described above led to an iterative process of TWINSPAN analysis, inspection of the resulting classification, further manipulation of variables to improve resolution and then further TWINSPAN analysis. After 12 such iterations the set of variables used was thought to be as reliable as could be achieved with the data available. The resulting classification is shown as a dendogram in Figure 10.1. Only 436 sites are included in this classification because the added variable sinuosity supplied by GeoData had some missing values. This can be used as an allocation key for new cases where the appropriate data is available. This is believed to be more robust because of the process of refining the variables used in the TWINSPAN analysis. It can be compared with the initial classification in a cross-tabulation of class shown in Table 10.1. This shows that the classifications remain similar, even after the considerable adjustments were made to the form of the data. Most reassignments of class occur close to the 'diagonal', top left to bottom right, i.e. any movement is to adjacent groups. This is mainly a result of the fact that the groups continue to be based largely on substrate and therefore it is unlikely for a river to be re-classified far from its substrate class.

Table 10.1: Re-assignment of classes

	OLD CLASS							
NEW CLASS	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	25	7	0	1	0	0	0	0
2	6	7	1	1	0	0	0	0
3	7	13	0	4	0	0	0	0
4	0	1	52	0	2	0	0	0
5	1	7	4	13	1	0	0	0
6	0	5	7	1	0	0	0	0
7	0	0	0	1	33	0	0	0
8	0	0	0	0	44	4	6	2
9	0	1	6	8	21	5	3	0
10	0	0	0	1	6	15	6	1
11	0	0	0	1	10	17	0	0
12	0	0	0	0	6	4	0	0
13	0	0	0	0	1	8	49	11

Figure 10.1: Key to TWINSPAN Classification

NB: Negative groups are always on the left hand side and positive groups on the right. *Riffle index* and *sinuosity* are calculated values (refer to text). Most figures in the tree diagram refer to the number of spot-checks in 500m reach. Cascades, rapids, glides and slacks are measured on an ordinal scale of 'none, present, extensive' (refer to RHS manual for details).



Substrate size/category is clearly a persistently dominant feature in classifications developed to-date. This is useful because there is a *de facto* classification of rivers based on predominant channel material. Rivers are often described by fluvial geomorphologists as, for example, boulder, cobble, gravel or sand-bedded, alluvial or clay channels as the first, most basic, level of description. While there is great variety within these simplistic classes, this serves to locate the river within a broad range of geomorphological types. The classification developed here refines and adds scientific rigour to this common description by determining "partings" between classes and by integrating important geomorphological variables with substrate types. It is apparent that most of the classes have distinctive geomorphological characteristics, though perhaps many of these are not available for analysis in the RHS database.

10.1 Summary of class characteristics:

Summary statistics are given for all classes in Appendix 3. A description is also given below of class characteristics. It is useful to refer to Figures 10.2-10.24 which show boxplots of all the variables discussed by stream class.

The summary of class characteristics below includes descriptions of classes in relation to driving variables, although these were not used to generate the classification. For a summary of variables used to generate the classification see Figure 9.3. References made below to statistically significant differences between median values of each class are derived from 95% confidence interval boxes. The abbreviation "ssd" stands for "statistically significantly different".

- **Classes 1 & 2** are both dominated by a combination of boulders, cobbles and bedrock. There are no statistically significant differences between channel substrates in classes 1 & 2 but class 2 tends to have a higher proportion of cobbles whereas class 1 has a higher proportion of boulders, both in combination with bedrock. The main distinguishing differences in geomorphological features between classes 1 and 2 are as follows: the riffle index for class 1 channels is relatively low compared to class 2 (ssd). There are also fewer side bars (ssd) and fewer eroding cliffs (ssd) in class 1. Cascades and rapids are usually at least "present" in both classes. Channel gradients, bankfull channel widths and specific power are very similar between classes 1 & 2 (not ssd). These classes have the highest median specific power of all classes but it is only statistically significantly different from classes 8, 10, 11 and 13.

- **Class 3** is dominated by bedrock and boulder channels with some gravel/pebbles (ssd compared to classes 1 & 2 which were not ssd). It has the highest proportion of bedrock spot-checks (ssd) of all classes. Median channel sinuosity is the lowest of all classes (ssd compared with most other classes). Rapids and cascades are usually present. Channel gradient and specific power is statistically no different from classes 1 & 2.

- **Class 4** rivers are dominated by cobble-bedded channels, usually with gravel/pebbles. The median proportion of cobbles is ssd from all other classes. They have a relatively high number of side bars in comparison to other classes (ssd from classes 1, 8, 9, 11, 13). Cascades are almost completely absent. Rapids are present in more than 50% of the class, similar to classes 1, 2 & 3 and unlike classes 5 through to 13. Median channel sinuosity is

2nd highest of all classes but only ssd from class 3. Median riffle index is the 2nd highest of all classes, ssd from all classes except 2, 5, 6 & 7. Median bankfull width is the largest of all classes (ssd from all classes except class 5). As one might expect, distance from source is also relatively large and from the distribution of stream orders by class it can be seen that class 4 has the greatest absolute number of 5th order rivers. Channel gradient is lower (ssd) than classes 1, 2 & 3. Specific power is relatively high compared to all classes and not ssd from classes 1, 2 & 3. The description implies that this is a powerful class of rivers and so one might expect marked erosion activity. From the spot check of "eroding cliffs" one finds that this group have a relatively high score on this variable, none of these channels having less than 2 "eroding cliff" spot checks.

- **Class 5** rivers are dominated by a combination of cobbles and gravel/pebble and nearly always with some bedrock. They appear to have a relatively high number of point bars and relatively low channel sinuosity (although they are not ssd from most other classes). Riffle index is similar to class 4. The median channel gradient is similar to class 4. Specific power appears lower than class 4 channels but, again, the difference is not ssd. The prevalence of cascades appears more widespread in class 5 compared to class 4. Nearly 50% of channels have such a feature whereas they are almost absent from class 4.

- **Class 6** rivers are dominated by a combination of cobble and gravel/pebble beds and are nearly always found in combination with boulders. These rivers tend to be located further up the river network than rivers in other classes. This can be seen by inspection of the boxplots of distance from source (Figure 10.6) and reach altitude (Figure 10.5). There are no channels greater than 3rd order. They are the smallest width channels of all classes (ssd from most of the other classes) and they have the highest median gradient. Because of this the median specific power is relatively high, similar to classes 1, 2 & 3. However, the class also has one of the lowest counts of eroding cliffs, with a median of 0. This apparent stability may be because of the coarseness of the channel substrate and the resistance provided by boulders in the channel bed.

- **Classes 7 & 8** are almost exclusively gravel/pebble bedded rivers. The proportion of gravel/pebble spot checks in both classes is ssd from all other classes. Class 7 rivers have a marked tendency to have steeper channel gradients than class 8 although they are not ssd. Cascades are completely absent from class 7 (even though it has higher gradients) but do occur occasionally in class 8. Rapids occur but are uncommon in both classes. Bankfull widths also appear to be slightly greater in class 7 and this is reinforced by the fact that there are a significant number of 5th order rivers in class 7 but none in class 8. The geomorphological differences between the two classes are that class 7 rivers have (a) much higher riffle indices (ssd) than class 8, (b) higher number of point bars (ssd) and (c) higher number of side bars (ssd). Median sinuosity is similar between the two classes although class 8 has a large number of outliers with much higher sinuosity than class 7. Eroding cliff spot checks are markedly higher in class 7 (ssd) than class 8 reflecting, perhaps, the higher median specific power in this group.

- **Class 9** are rivers dominated by gravel/pebble substrate with some cobbles. The number of gravel/pebble spot checks is ssd from all classes except 10 and 11. In geomorphological terms, this class is very similar to class 8 in many respects. The differences are that side bars are more common in class 9 rivers (ssd), and secondly that slacks are present or extensive in over two-thirds of sites in class 9, whereas in class 8 slacks are relatively uncommon. Class 9 rivers tend to be slightly larger rivers than class 8 although they are not ssd in respect of bankfull width or catchment area .

- **Class 10** is also dominated by gravel/pebble bedded rivers in combination with silt. There is significantly more silt (ssd) in class 10 than all other classes except class 13. Class 10 is distinguished from classes 8 and 9 by a greater prevalence of mid-channel bars (not ssd) and a greater number of point bars (not ssd).

- **Class 11** are dominated by gravel/pebble bedded rivers in combination with sand. This group is also characterised by a very infrequent occurrence of side bars (ssd from class 10). In other respects it is similar to class 10.

- **Class 12** is a group of sand-bedded rivers with some gravel/pebble substrate. The proportion of sand substrate spot checks is statistically significantly greater than in all other classes of river. The flow regime in class 12 rivers is dominated by glides with very infrequent slacks. Mid-channel bars and eroding cliffs occur with greater than average frequency (for all sites). Side bars are very frequent by comparison with other classes, and median channel sinuosity is higher than is the case in all other classes (although it is not ssd from any of them). Riffle index is joint lowest with class 13 (ssd from all other classes). Reach altitude is lower than for any other class (ssd from classes 1-6). The lowest median specific power of all classes (but not ssd from classes 8 through to 13). Bankfull width is also relatively large in comparison to classes 8 - 13 as is distance from source although these differences are not ssd.

- **Class 13** is a relatively large group (69 members) of silt substrate dominated rivers. Riffle index is joint lowest with class 12. Sinuosity is relatively high compared to other classes as one would expect in lowland channels. Side bars, point bars, mid-channel bars and eroding cliffs all have median values of zero suggesting relatively stable fluvial systems with little deposition and little erosion. Alternatively, fine sediments produced such features by they are either submerged, difficult to see or are rapidly vegetated. Median gradient is low (statistically similar to classes 8, 9, 10, 11 and 12) and so specific power is also low. Only class 12 has a lower median value.

These characteristics are summarized in Figures 10.2 to 10.24 below, which depict the distribution of characteristics within each class.

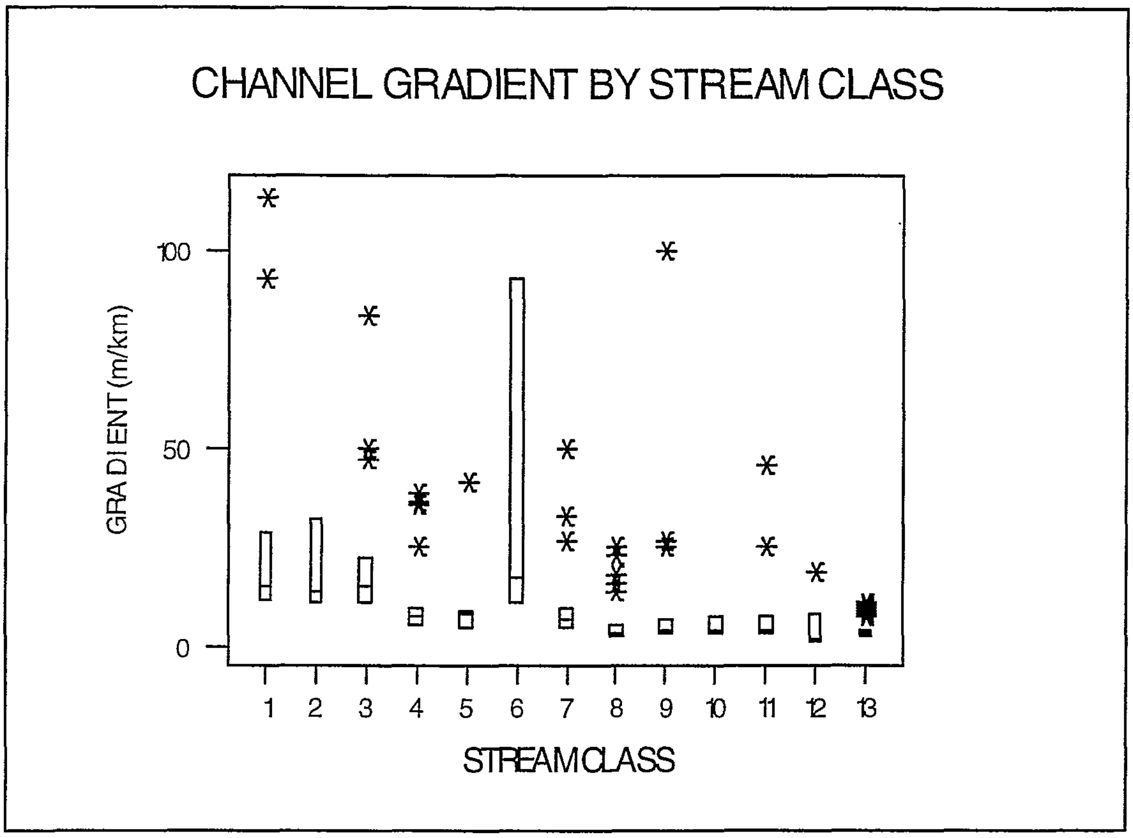


Figure 10.2: Channel Gradient by Stream Class

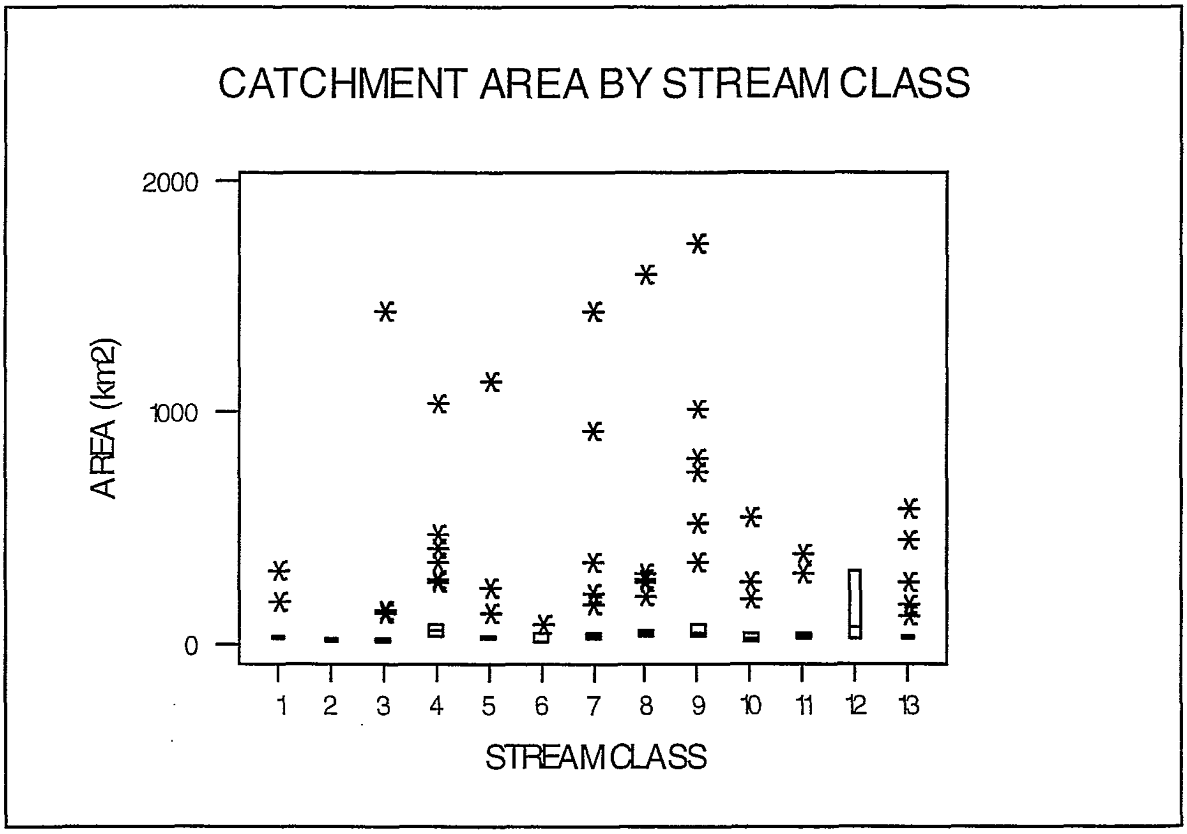


Figure 10.3: Catchment Area by Stream Class

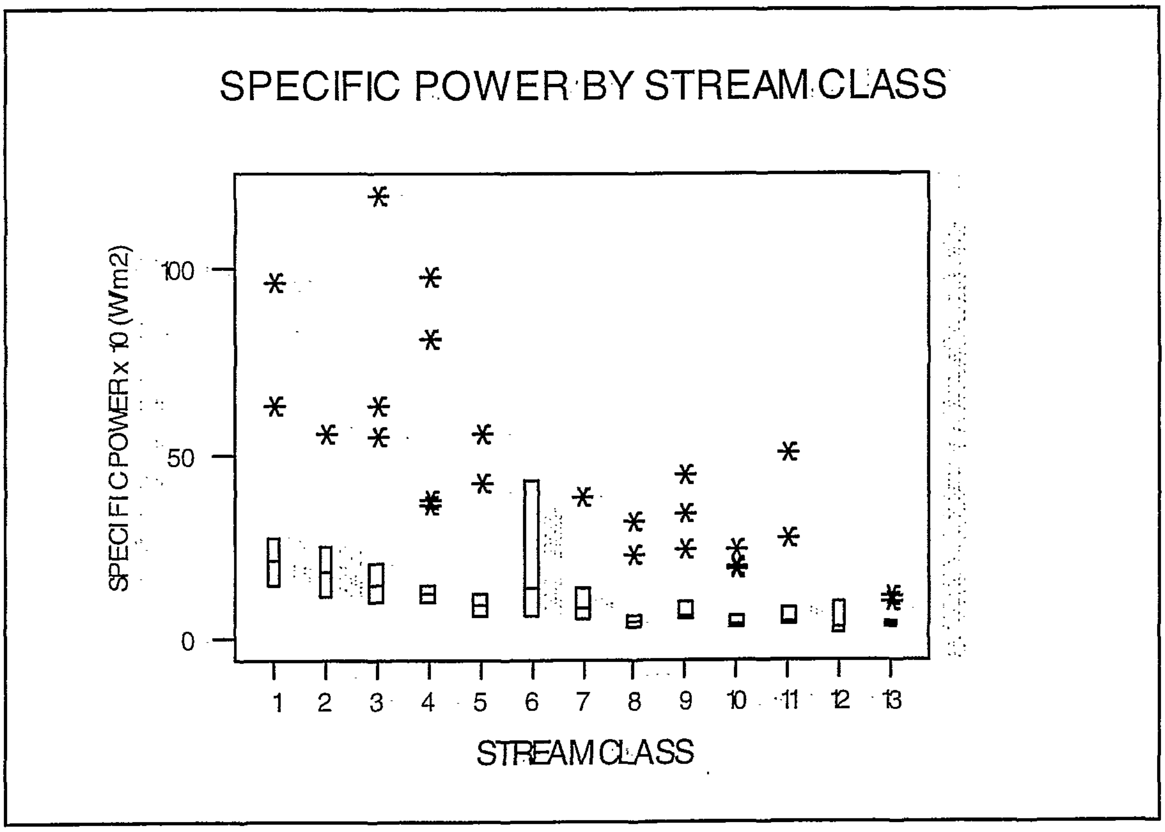


Figure 10.4: Specific Power by Stream Class

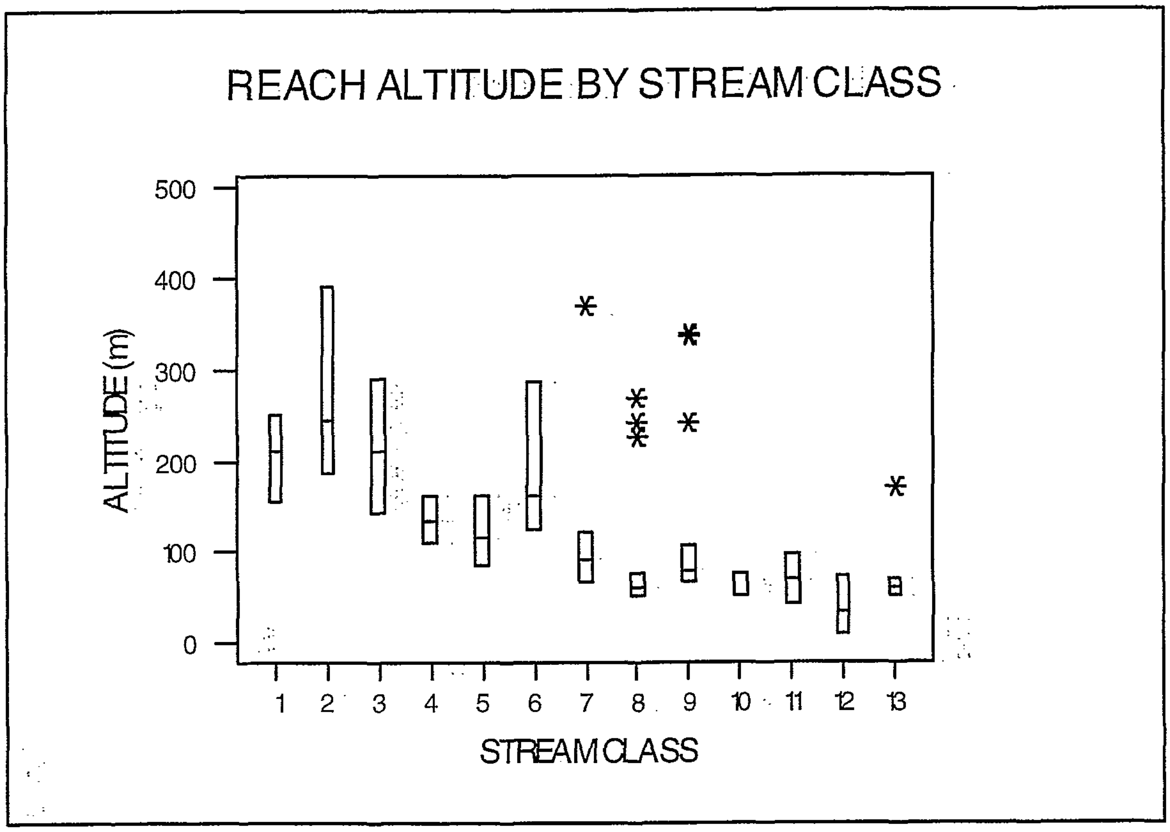


Figure 10.5: Reach Altitude by Stream Class

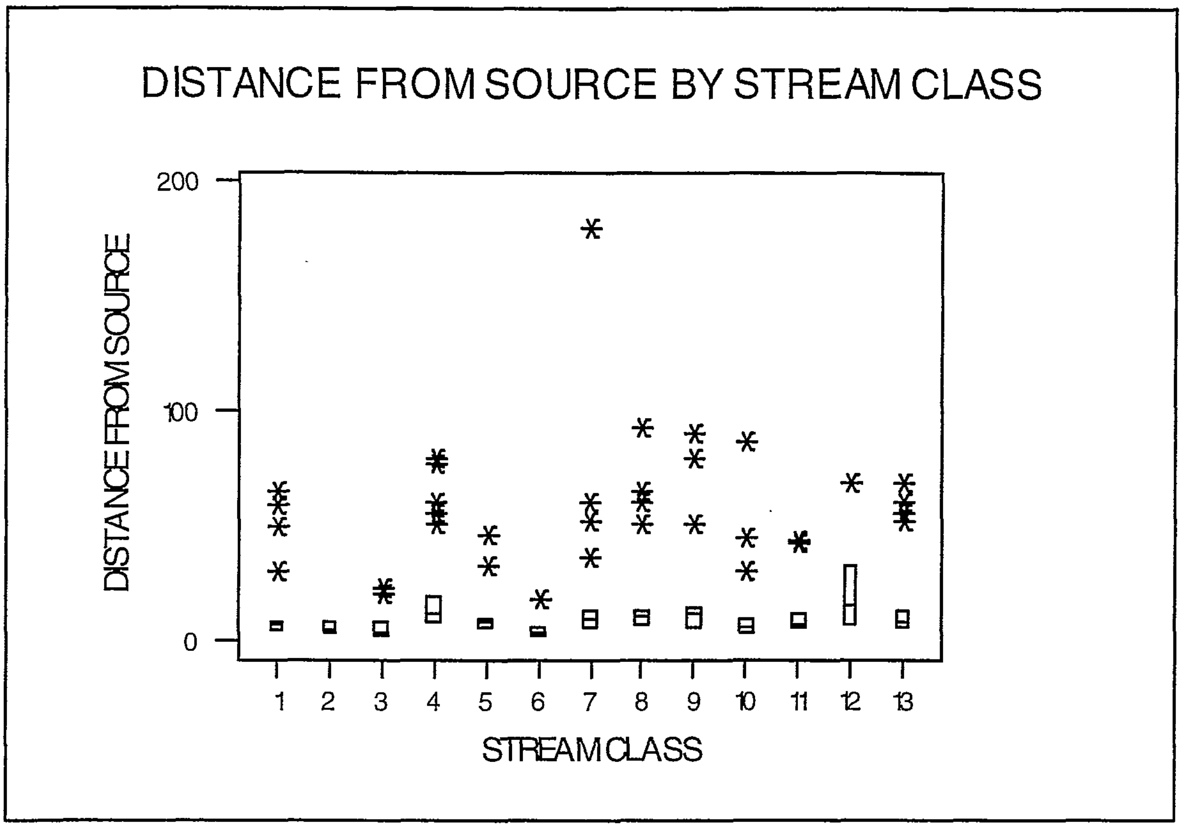


Figure 10.6: Distance from Source by Stream Class

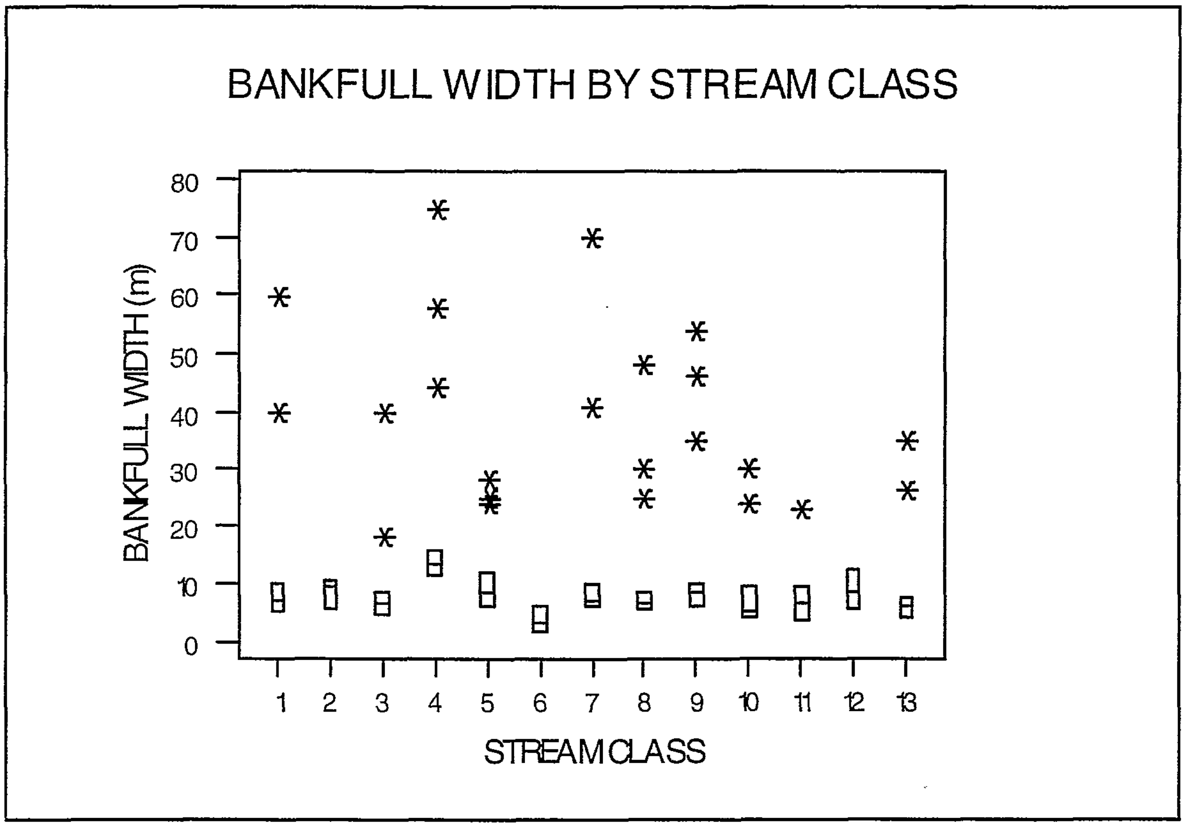


Figure 10.7: Bankfull Width by Stream Class

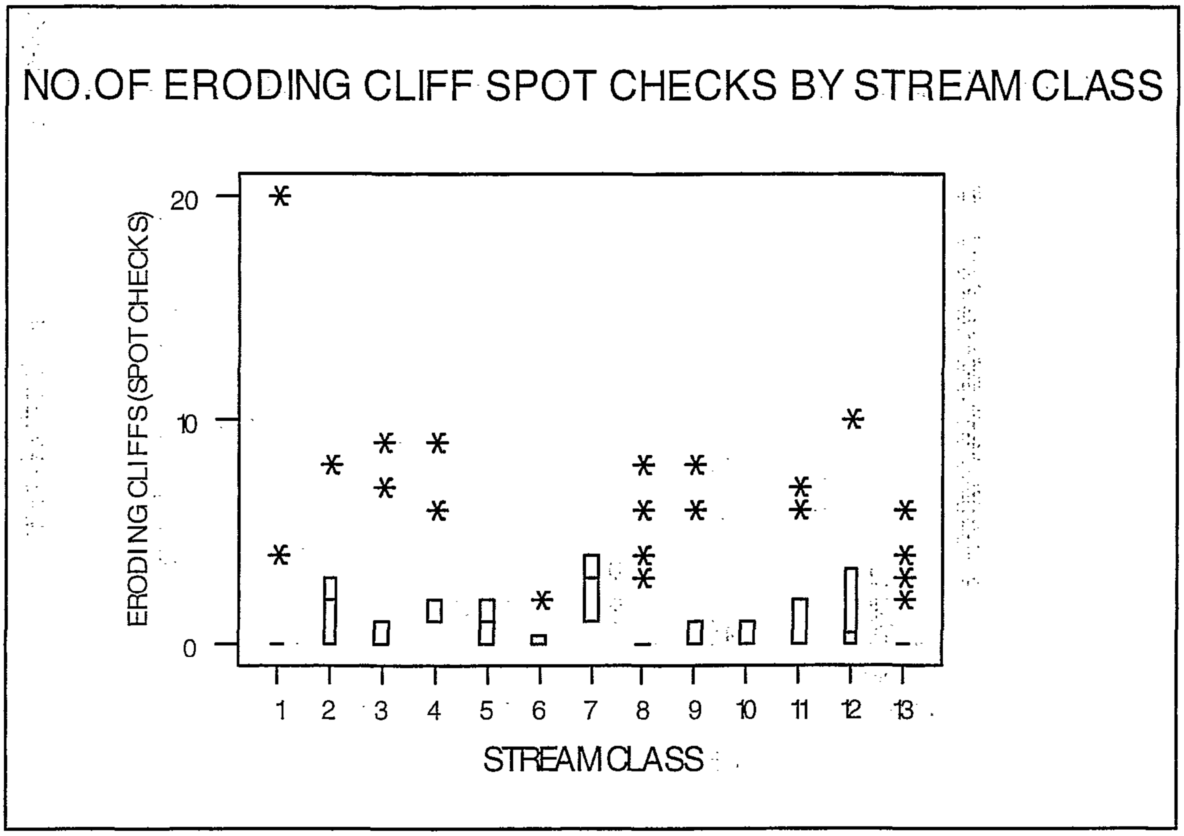


Figure 10.8: **Number of Eroding Cliff Spot Checks by Stream Class**

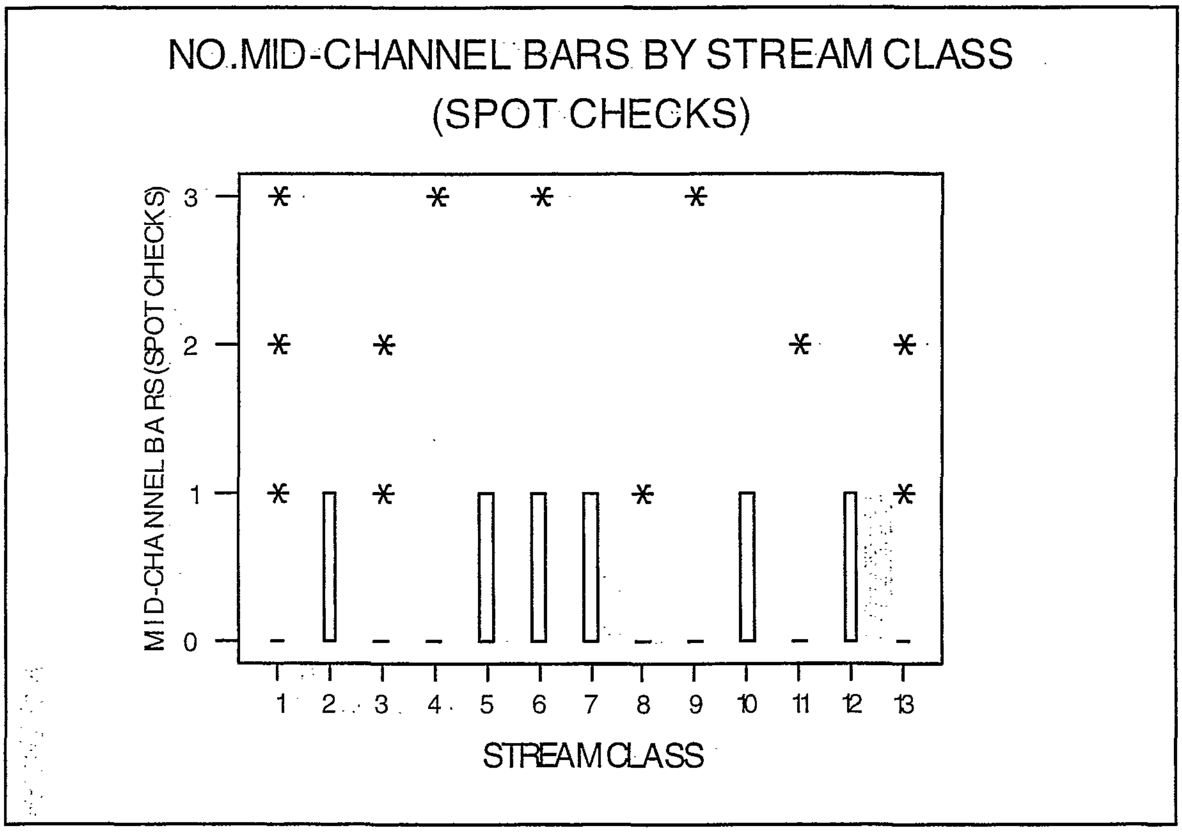


Figure 10.9 **Number of Mid-channel Bar Spot Checks by Stream Class**

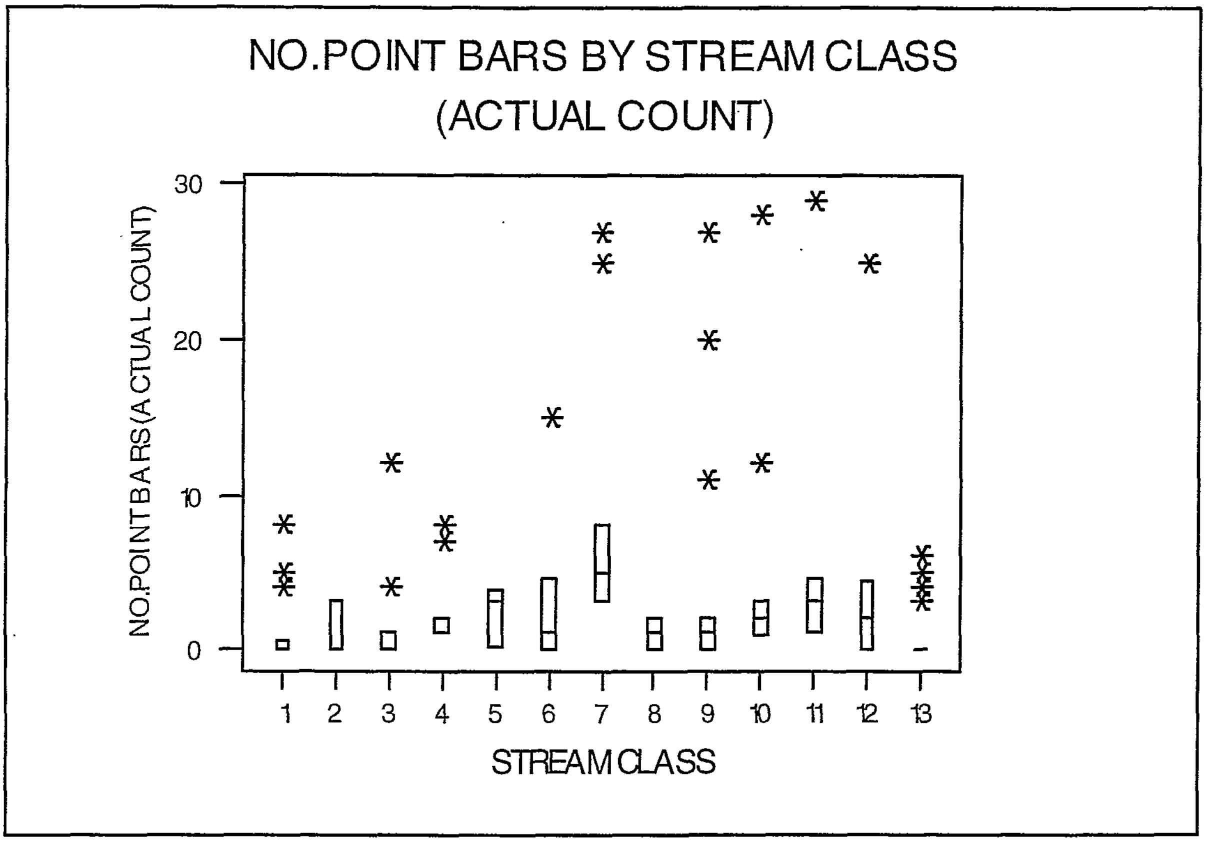


Figure 10.10: Number of Point Bars (Actual Count) by Stream Class

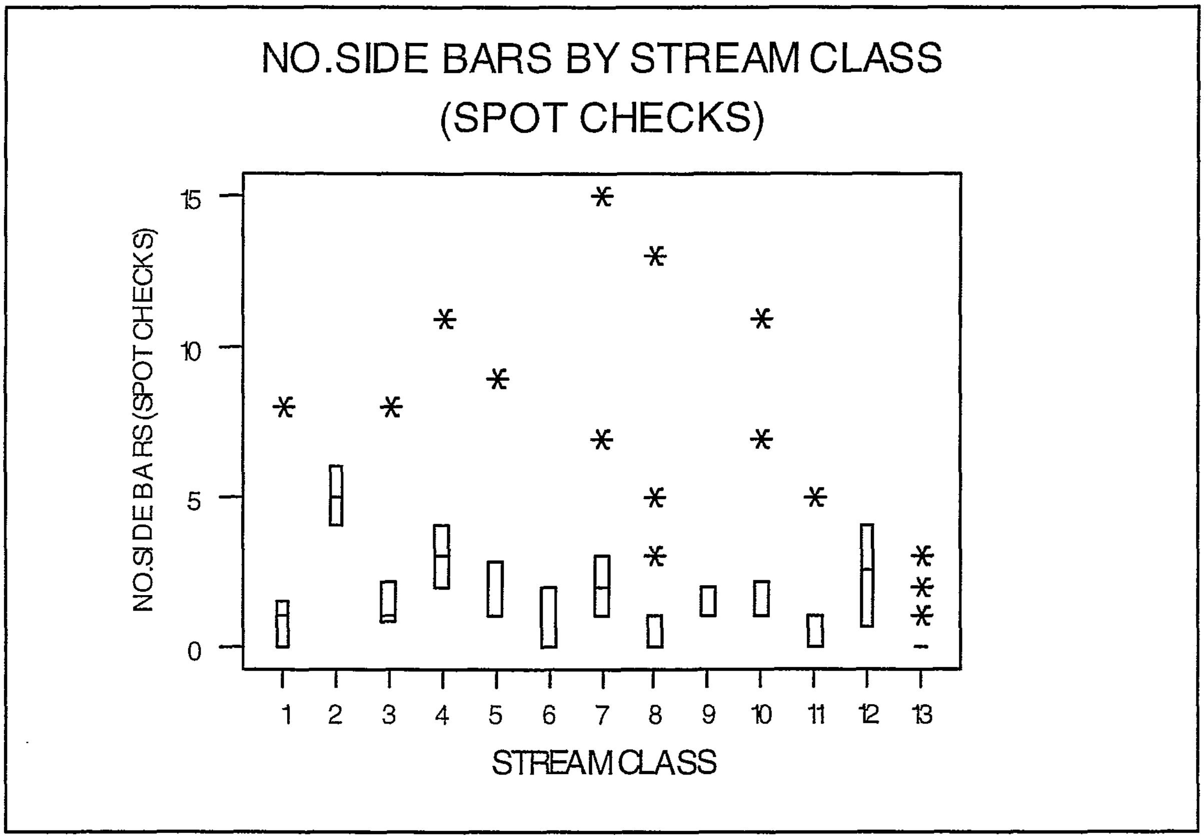


Figure 10.11: Number of Side Bar Spot Checks by Stream Class

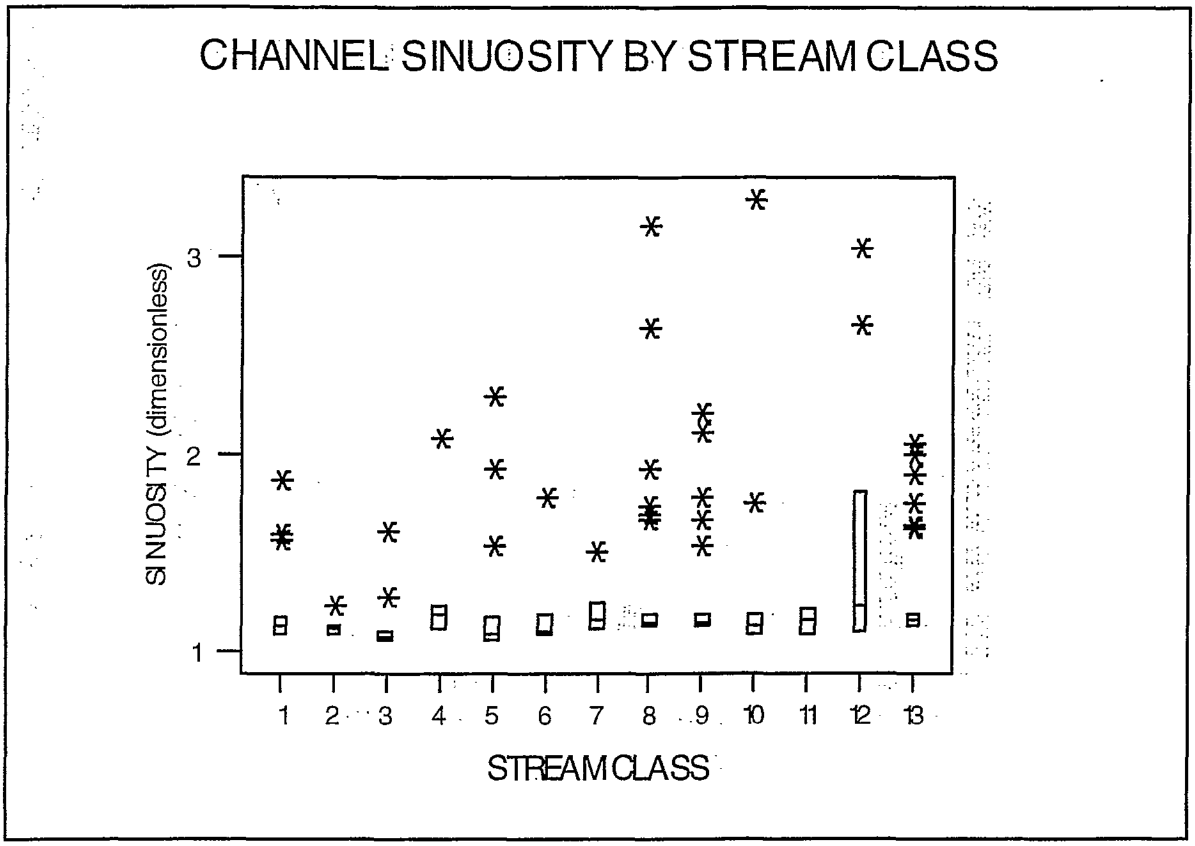


Figure 10.12: Channel Sinuosity by Stream Class

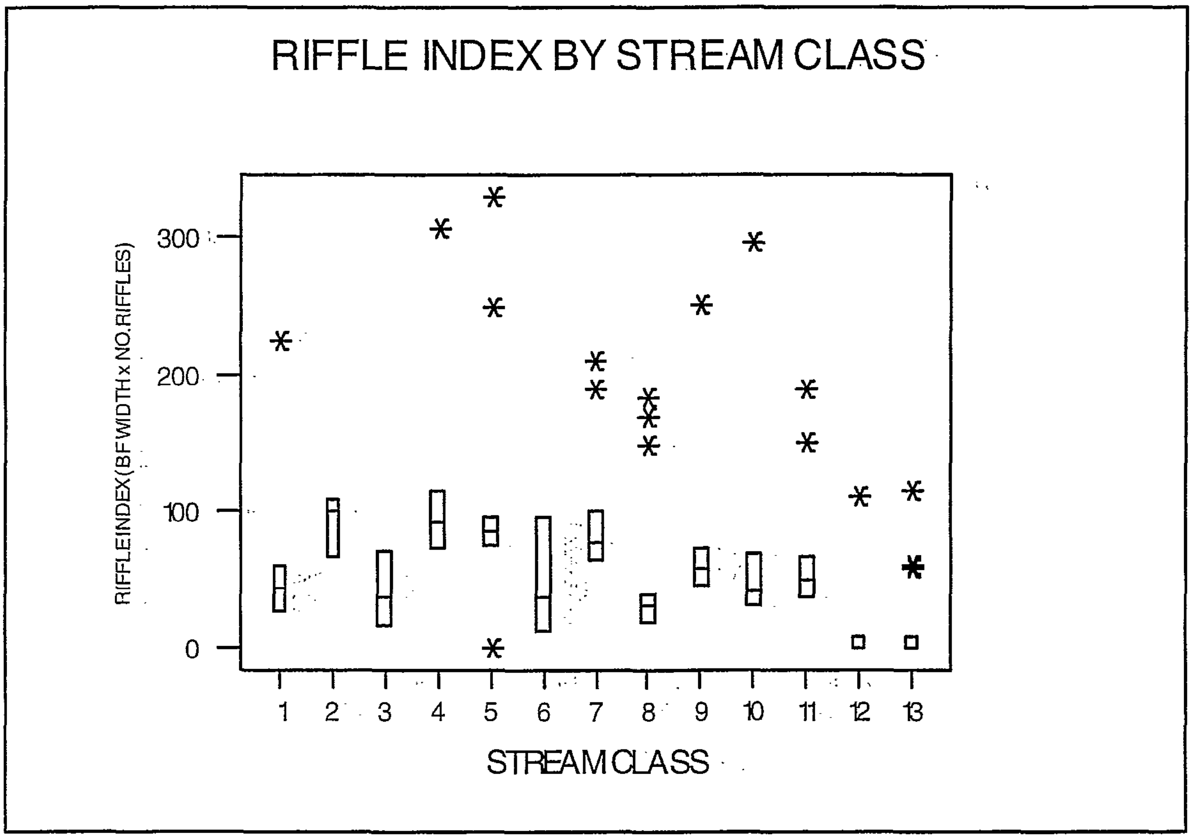


Figure 10.13: Riffle Index by Stream Class

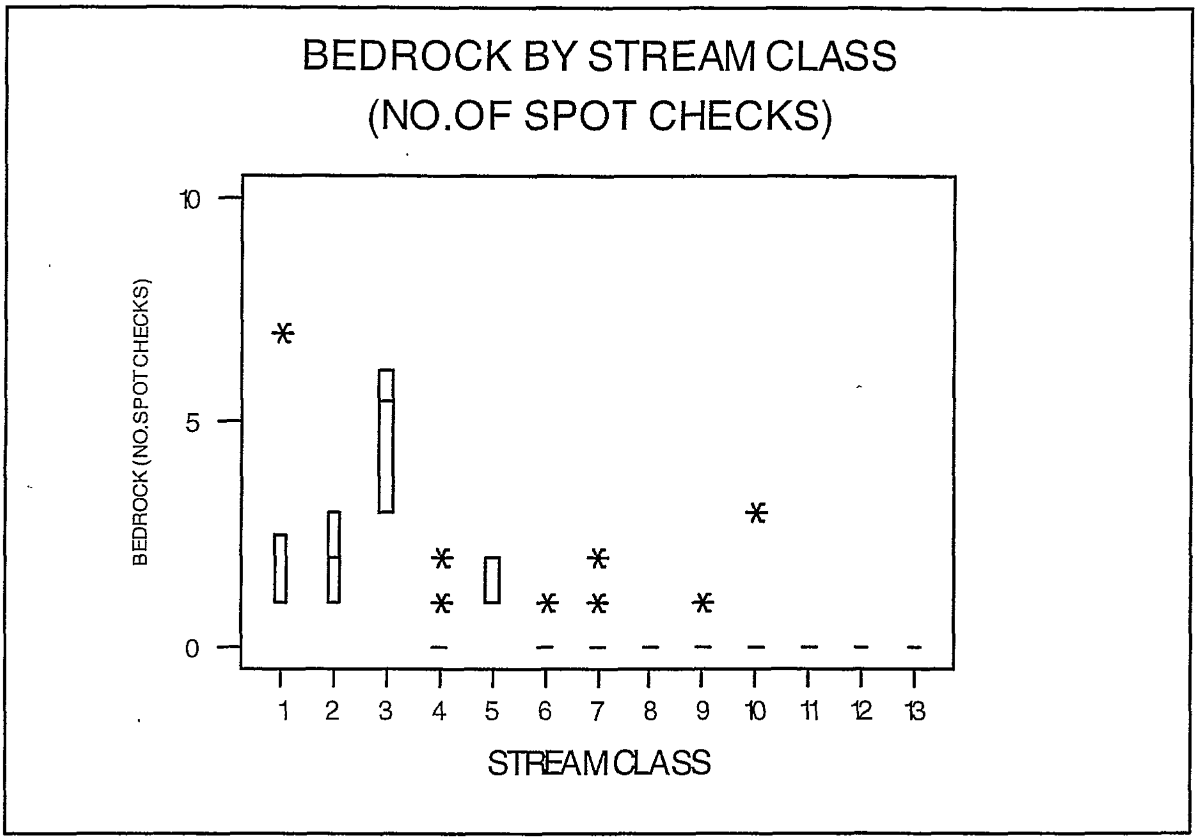


Figure 10.14: Number of Bedrock Spot Checks by Stream Class

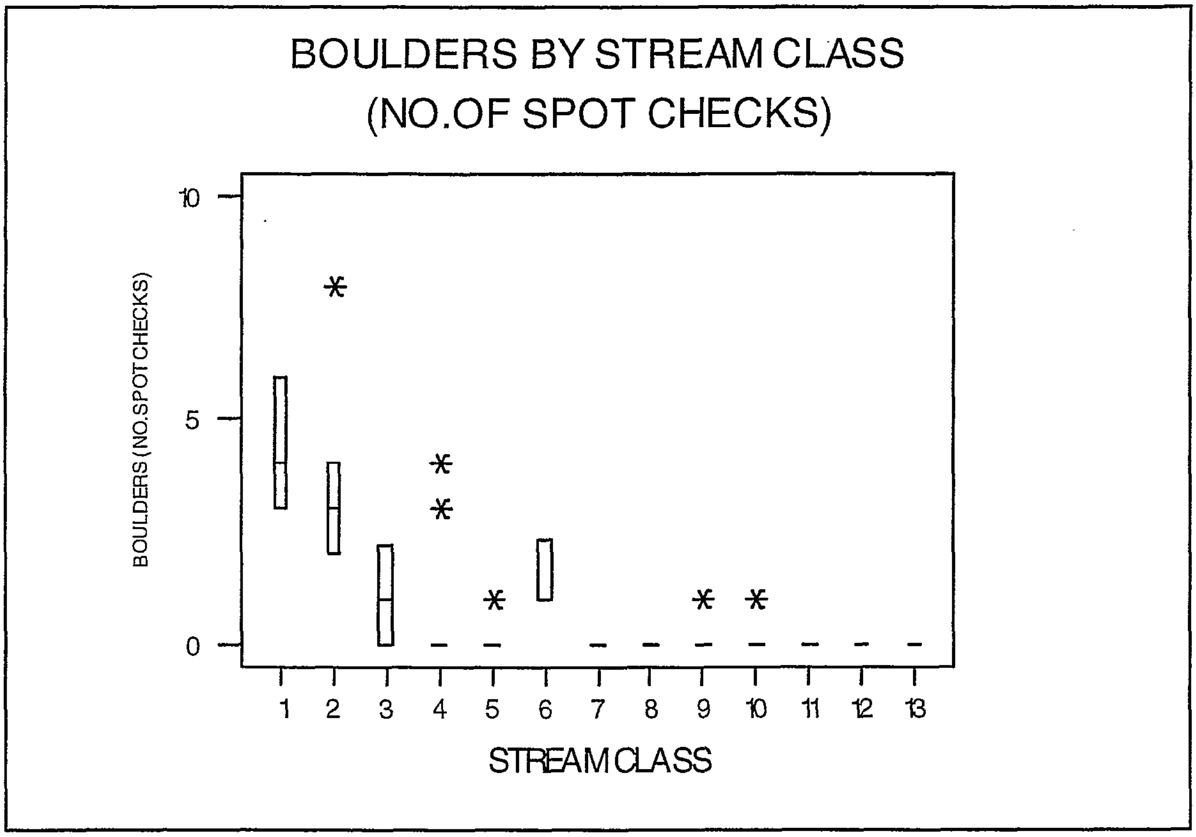


Figure 10.15: Number of Boulder Spot Checks by Stream Class

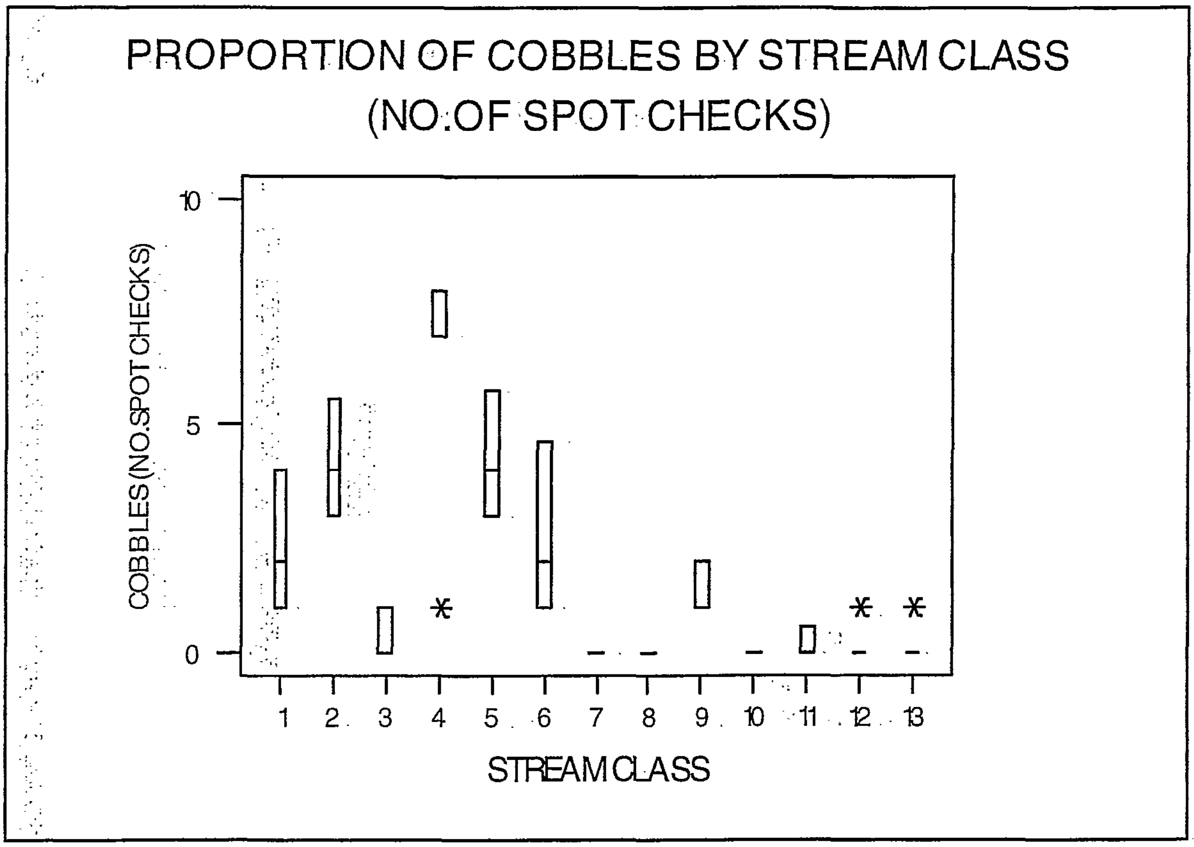


Figure 10.16: Number of Cobble Spot Checks by Stream Class

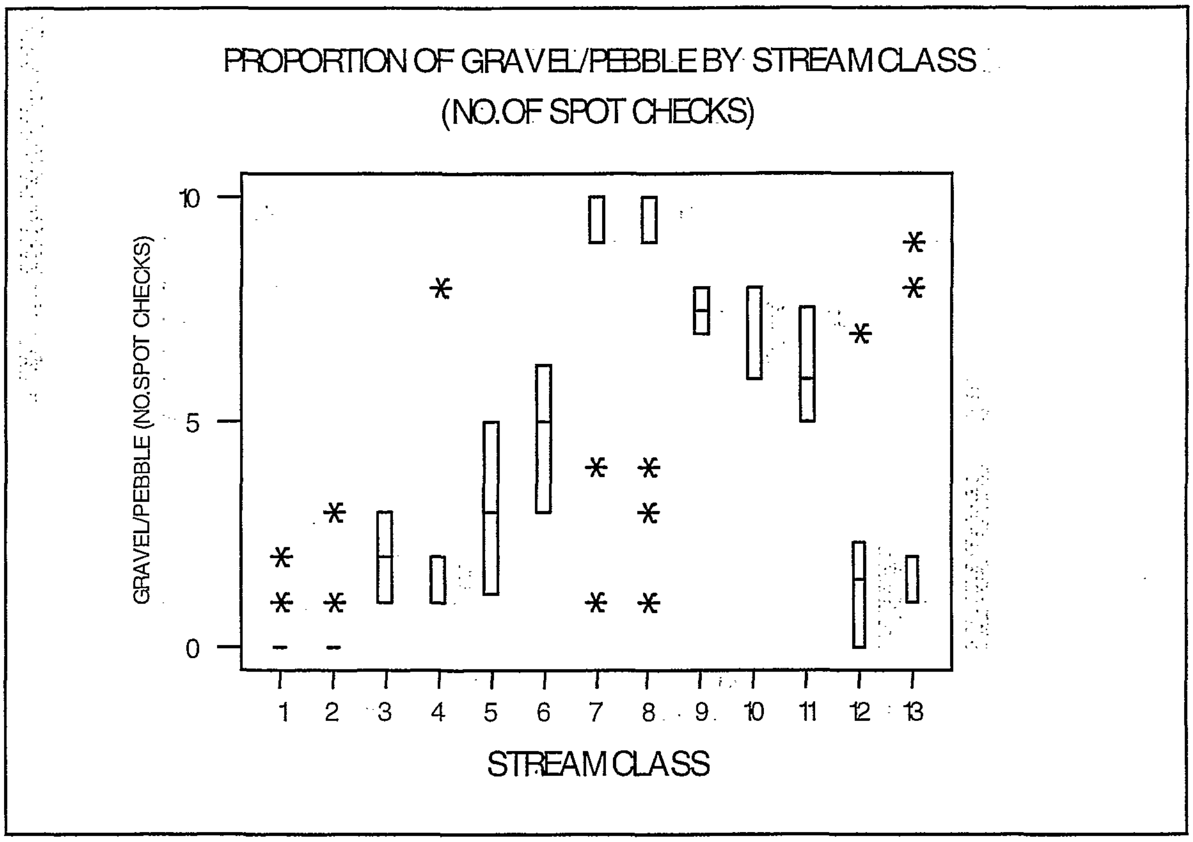


Figure 10.17: Number of Gravel/Pebble Spot Checks by Stream Class

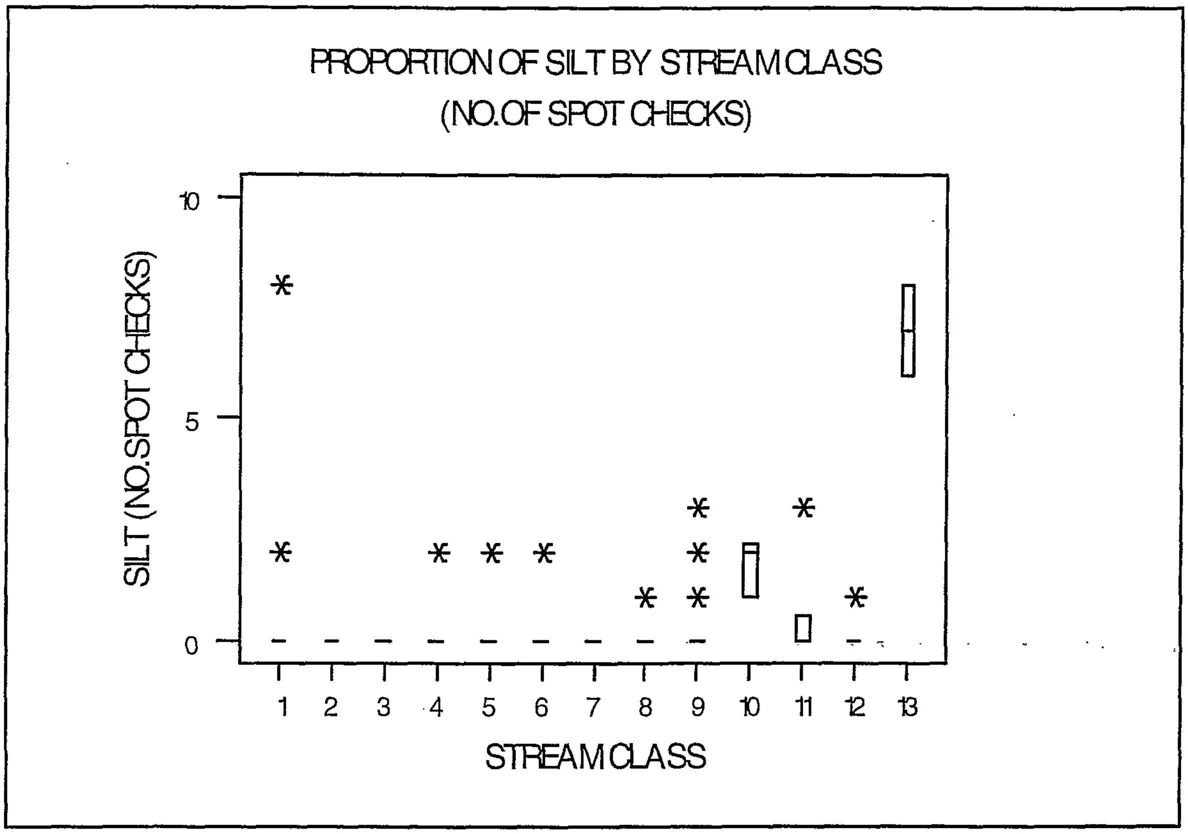


Figure 10.18: Number of Silt Spot Checks by Stream Class

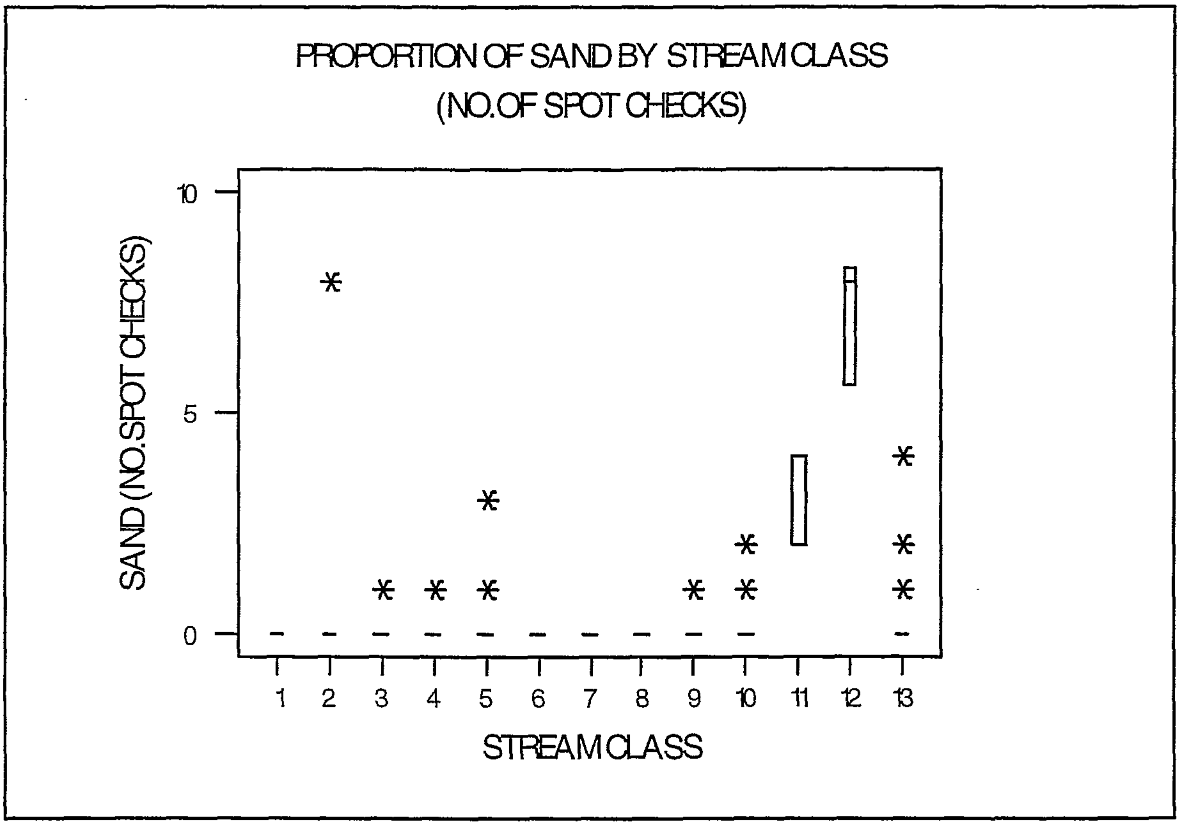


Figure 10.19: Number of Sand Spot Checks by Stream Class

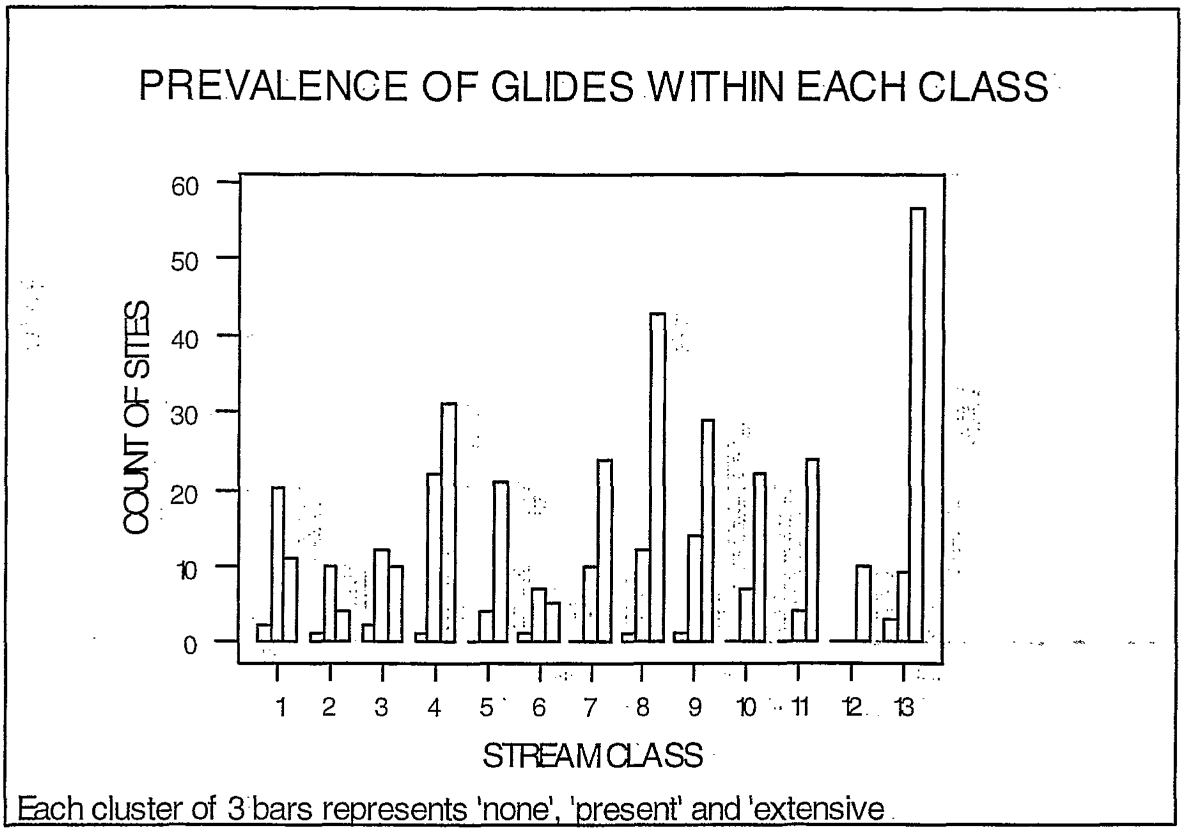


Figure 10.20: Prevalence of Glides within each Class

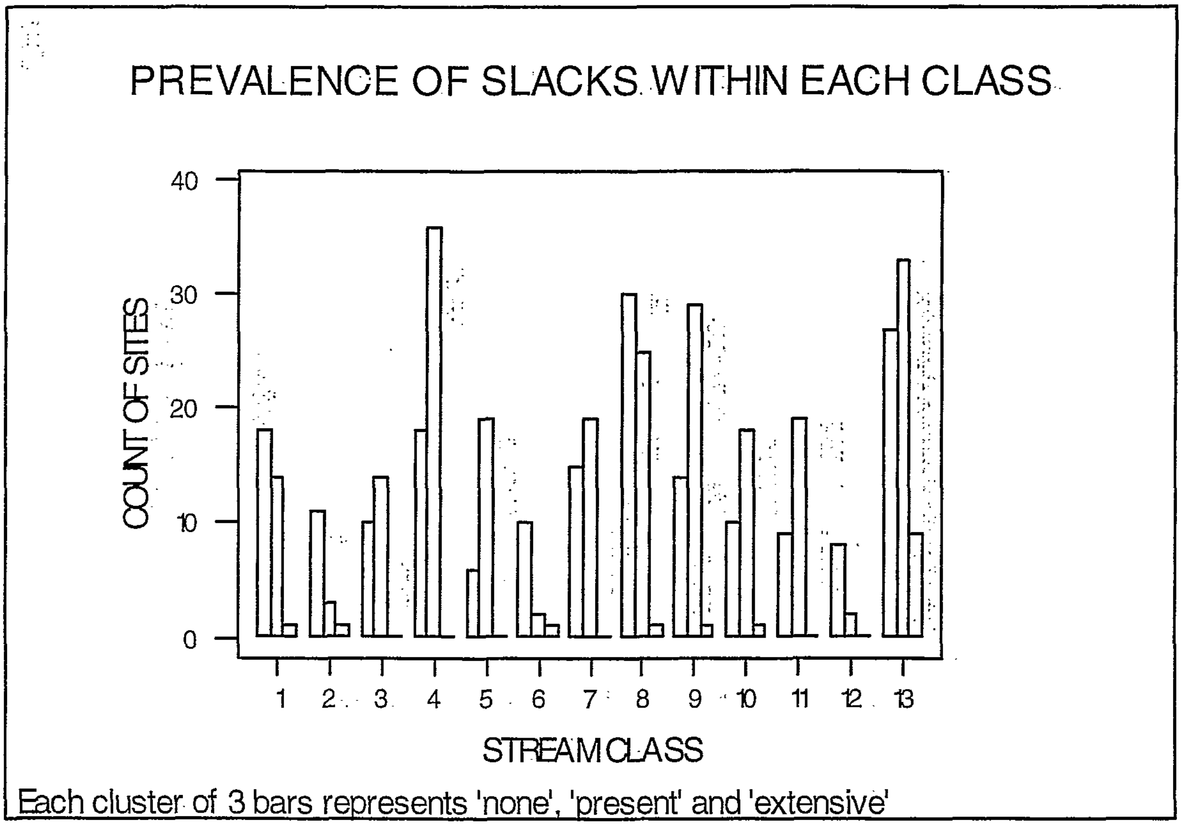


Figure 10.21: Prevalence of Slacks within each Class

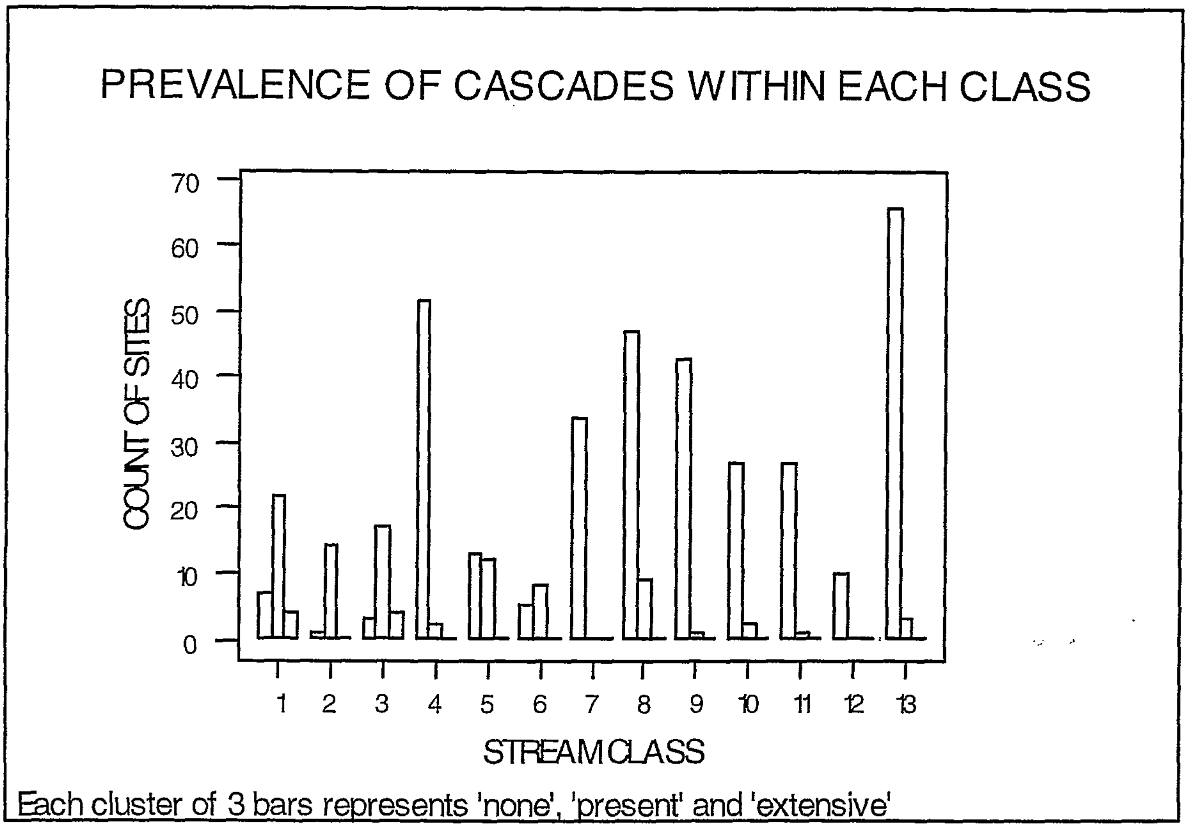


Figure 10.22: Prevalence of Cascades within each Class

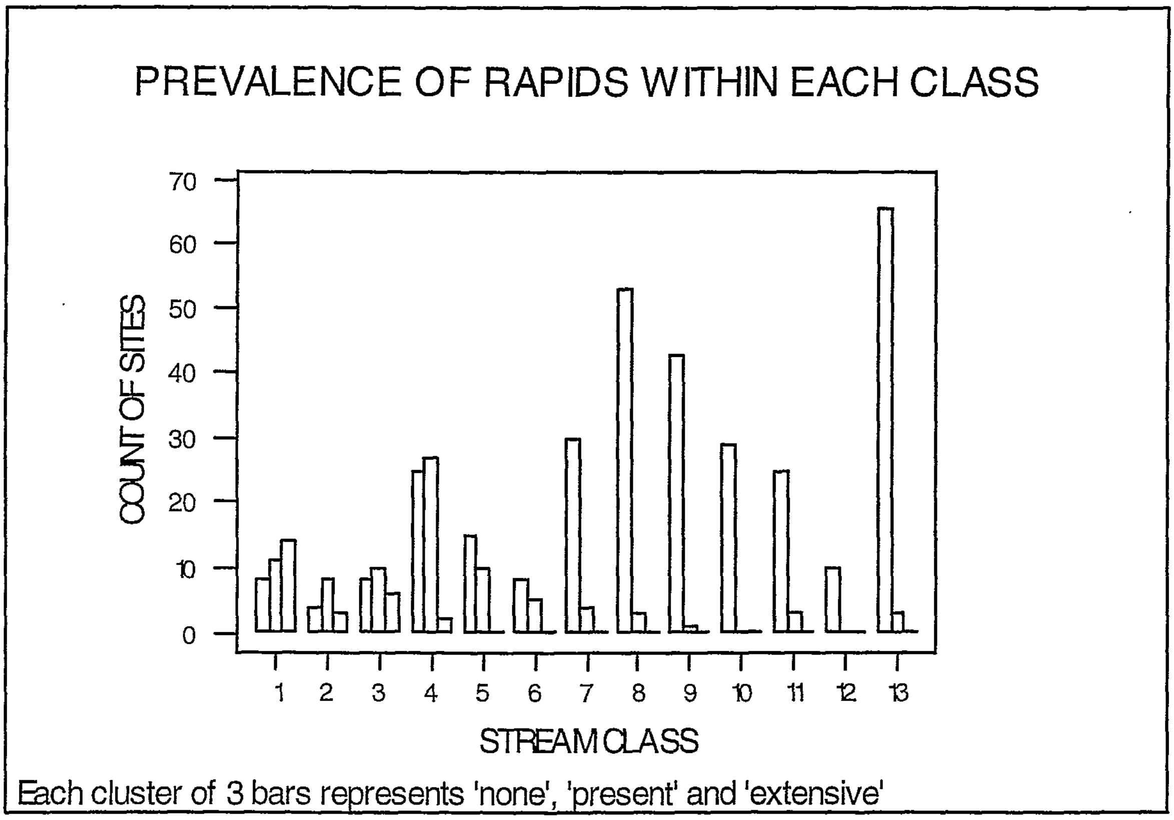


Figure 10.23: Prevalence of Rapids within each Class

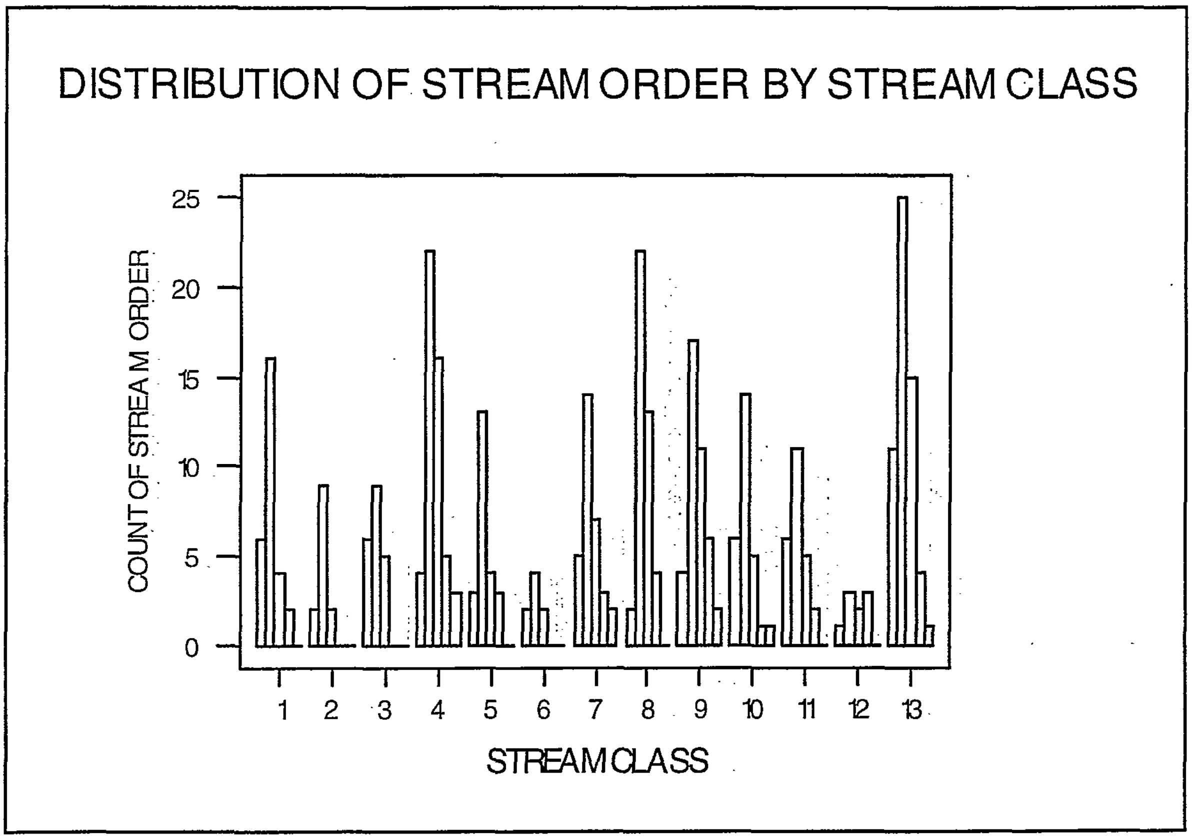


Figure 10.24: Distribution of Stream Order by Stream Class

10.2 Validation of the classification and other methods of clustering

Assessing the success or validity of the classification produced is a largely subjective process. To some extent it has been possible to find statistically significant differences between variables by class which gives an element of objective validity to the classes but in many cases this is not possible. A further technique that gives some idea of the separation of classes is ordination.

Figure 10.25 shows the results of detrended correspondence analysis with sites coded by classes produced in the classification. This demonstrates the "proximity" of classes to one another and locates misclassified or outlying sites for further investigation. The groups are relatively distinct which adds confidence to the classification. There is, however, a degree of circularity in this argument as TWINSPAN is also based on correspondence analysis and so one would expect such a plot to show relatively good definition of classes.

Other methods of clustering were also investigated to compare with TWINSPAN. For this we use a minimum variance clustering of a matrix of Gower's similarity co-efficient calculated between all sites. Classes derived from this clustering are also shown on the DCA in Figure 10.26.

The result was markedly less visually successful than the classes produced by TWINSPAN. The main problem was that sites with little similarity to any others tended to be classed together, i.e. "dumped". In order to make sense of the

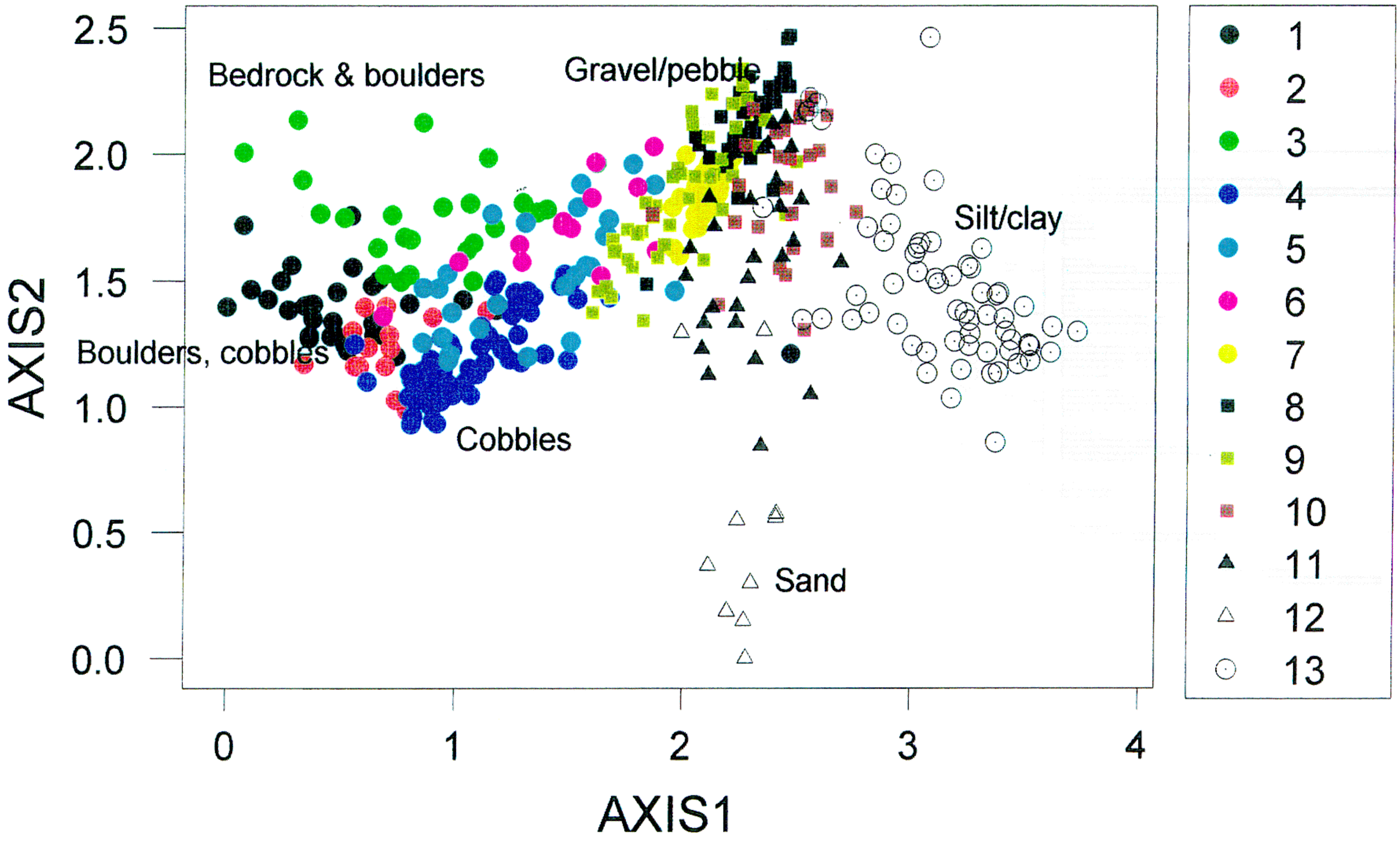


Figure 10.25: Detrended Correspondence Analysis Biplot of first two axes class derived from TWINSPAN

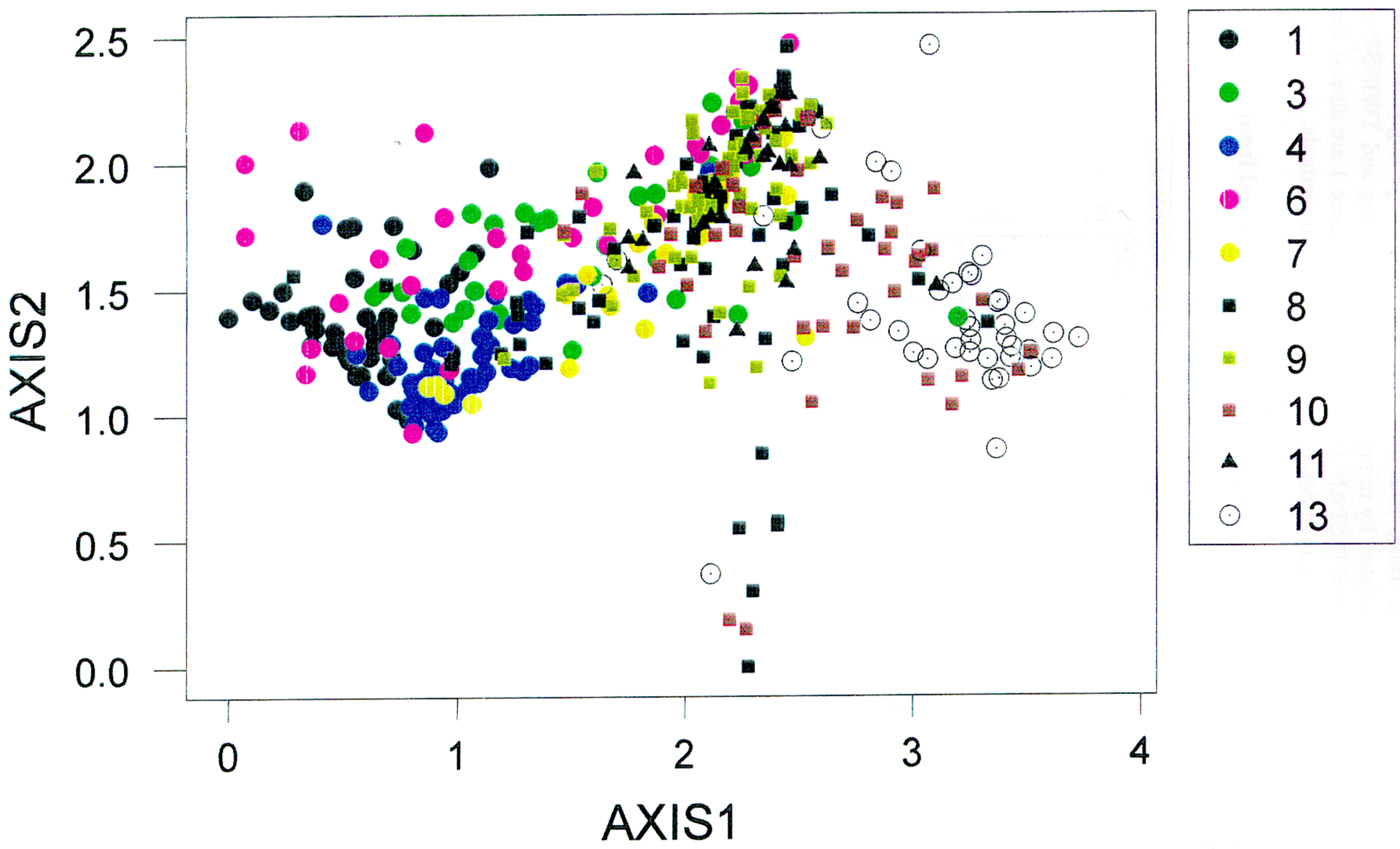


Figure 10.26: Detrended Correspondence Analysis - Biplot of first two axes class derived from minimum variance clustering

classification these sites would need to be re-classified into other groups - a highly subjective operation. The other advantage of the TWINSPAN analysis over other clustering techniques is that it produces a key to allow allocation of new cases to classes.

The cross-tabulation of class in Table 10.2 shows that there is a large degree of similarity between the classifications generated by minimum variance clustering and TWINSPAN. A number of classes, for example TWINSPAN 13 and minimum variance 1 are almost identical due to the dominant effect of substrate in determining classes in both methods.

Table 10.2: Cross-tabulation of class derived from TWINSPAN and from a minimum variance clustering method

	CLASS DERIVED FROM GOWER SIMILARITY COEFFICIENT AND MINIMUM VARIANCE CLUSTERING											
CLASS FROM TWINSPAN	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
1	1	4	1	0	0	1	0	0	0	20	5	1
2	0	2	1	0	0	0	0	0	0	10	0	2
3	0	7	1	0	0	0	0	0	0	6	9	1
4	0	2	3	2	0	4	0	6	1	2	0	35
5	0	2	2	0	1	1	1	2	1	1	8	7
6	1	5	0	2	1	0	0	0	0	2	2	0
7	0	1	6	6	0	5	3	9	3	0	0	1
8	0	7	15	8	5	7	6	0	4	0	3	1
9	1	1	5	7	6	5	6	4	8	0	1	0
10	0	1	3	4	5	3	4	4	4	0	1	0
11	0	0	4	5	5	3	6	0	4	0	1	0
12	1	0	7	0	2	0	0	0	0	0	0	0
13	39	0	3	1	22	1	1	0	0	0	1	0

The identification of classes from the TWINSPAN output is, however, also a subjective process. In some cases sub-divisions may be made to reveal distinct groups with similar geomorphology but there comes a point, not least because of unjustifiably small class size, when further division of groups is not valid. To decide on the justifiable division and sub-divisions consideration has been given mainly to creating groups, large enough to have statistical validity, with apparently similar geomorphological features as well as similar substrate types. The first seven divisions were largely dictated by substrate type and then, further sub-divisions have been allowed if there appeared to be geomorphologically distinguishable sub-groups. The value of the boxplots in Figures 10.2-10.24 is that it is possible to see in which variables the classes are statistically significantly different.

There is some similarity with Rosgen's (1994) classification procedure which is also a hierarchical decision tree. His typology first determines a general class of channel geomorphology on the basis of planform, degree of entrenchment and width/depth ratio and then proceeds to sub-groups of this class determined by slope class and substrate. What is being proposed in this study is approximately the reverse of this: the initial class being determined by substrate and then sub-groups being allocated by other distinctive geomorphological features. The fact that groups have a physical relation to one another is an advantage in that rivers that are undergoing geomorphological change may move between adjacent groups. Therefore, there may be some degree of 'succession' between groups as substrate compositions and geomorphological features develop in fluvially active reaches.

11.0 NUMERICAL TECHNIQUES TO RELATE DRIVING VARIABLES TO DEPENDENT VARIABLES

As was discussed above, one of the primary aims of the RCT project was to relate driving variables to dependent variables and to examine how far it might be possible to predict geomorphological features from driving variables. To recap, the driving variables available were stream order, catchment area, gradient, bankfull discharge, and, from these variables, specific power (stream power per unit width) could be calculated. The dependent variables were those used to generate the TWINSPAN classification. In general, they are geomorphological features (for a summary see Figure 9.3).

The aim of this part of the project was to use numerical techniques to quantify the relationship between the driving variables and the dependent variables or channel features. There were two aspects to this (i) to see how far it was possible to predict TWINSPAN-derived dependent variable class from the drivers and (ii) how much of the total variance in the dependent variable set could be explained by the drivers and which of the drivers were most important in accounting for variance.

11.1 Limiting data:

The subset of sites used for this analysis was reduced even further to only 371 sites as the bankfull discharge data calculated by GeoData was limited to those sites for which the Wharton (1992) channel-geometry method was suitable. Sites could only be used in the analysis which had no missing values. This may have introduced some further bias to the subset used as the method is scale dependent.

11.2 Discriminant function analysis:

Discriminant function analysis was used to try to predict dependent class from driving variables. The correct prediction rate was low - only about 17% of sites could be correctly allocated to class by the driving variables. Some classes could be predicted relatively well compared to others as shown in the classification summary in Table 10.1.

Specific Power was the most important predictive variable among the drivers. This was determined through a stepwise Canonical Correspondence Analysis of driving variables against stream class (transformed to dummy variables). This can also be illustrated via a boxplot of specific power by class (Figure 10.4) which shows that some classes have a relatively small range of specific power and are therefore more easily identifiable.

Table 11.1: Results of Discriminant Analysis - Predicting Class from Driving Variables

CLASS	*TOTAL IN CLASS*	*CORRECTLY CLASSIFIED*	*PROPORTION*
1	56	23	0.41
2	20	2	0.1
3	50	23	0.46
4	28	1	0.04
5	22	0	0
6	8	3	0.38
7	24	0	0
8	9	3	0.33
9	13	2	0.15
10	31	0	0
11	41	0	0
12	40	4	0.1
13	26	3	0.12
TOTAL	368	64	0.174

11.3 Redundancy Analysis:

Redundancy analysis is a technique for relating many independent variables to many dependent variables. It can be viewed as an extension of multiple regression which relates many independent variables to one dependent variable. It can be carried out in a stepwise fashion in the same way as multiple regression to build a model using the best sub-set of variables that explain, in a statistical sense, the variance in the dependent variables. Monte-Carlo permutation tests were used to test the significance of the proportion of variance that is accounted for by each driving variable. Variables that do not add to the explanation of variance in the dependent variables become redundant, although this does not necessarily mean that they had no explanatory power over the dependent set.

Table 11.2: Explanation of variance by driving variables

VARIABLE	*% OF VARIANCE EXPLAINED (CUMULATIVE)*	*SIGNIFICANCE LEVEL (P)*
Log_{10} Specific Power	6.2	0.01
plus Log_{10} Catchment Area	8.0	0.01
plus Log_{10} Gradient	8.5	0.01

The results of the redundancy analysis (Table 11.2) show that about 8.5% of the variance in the dependent variables can be accounted for by the driving variables. Specific power is by far the most important single variable, explaining about 6.2% of the total variance. This may seem a very weak relationship but a result of this order is common in environmental data where there is a lot of "noise" and where the dataset is an eclectic collection of variables. More important is the statistical significance of these relationships. Permutation tests show that the relationship between specific power and the dependent variables is significant at the 99% confidence limit. Catchment area and gradient are also statistically significant drivers but account for a very small proportion of variance in the dependent variables.

Specific power is apparently a more powerful explanatory variable than its two main components, gradient and discharge per unit width, as the above results were obtained from an analysis using all of these variables as 'drivers'. These results add weight to the results of the Discriminant Analysis that specific power is the single best predictor of class. It should also be noted that gradient accounts for a proportion of variance over and above its role as a component of specific power.

The biplot shown in Figure 11.1 is a redundancy analysis ordination of sites in terms of dependent variables and drivers. It shows the vectors of the driving variables in relation to this. Classes are shown as different symbols. For clarity, the classification has been simplified to 8 classes, i.e., classes generated by TWINSPAN after the first seven divisions. It can be seen that there is a progression of classes in the direction of the 'specific power' vector. This implies that if engineering works caused changes in specific power (straightening meanders, altering channel dimensions or roughness) this could cause transformations in a river reach from one class to another. This can also be further illustrated by plotting '$Q_{1.5}/W$' against Gradient (the product being proportional to specific power) and coding by 8 'main classes' (Figure 11.2). This shows 'banding' of classes at different levels of specific power.

11.4 Role of Channel Substrate:

An important conceptual problem in the above procedure is whether channel substrate type should be considered as a dependent variable. In terms of channel processes it is not completely satisfactory to restrict channel substrate to being *either* an independent *or* a dependent variable. Substrate size and roughness play a part in determining a river's flow regime and therefore ability to transport material and to erode new material. However, it is sometimes difficult to disentangle channel "features" from substrate type. For example, rapids, cascades and step-pool sequences are almost invariably associated with boulder or bedrock dominated channels and riffle-pool sequences tend to be associated with cobble or gravel-bedded channels.

Considering the problems outlined above, the conceptual model was altered by accepting substrate type as one of the driving variables rather than a dependent variable. In a redundancy analysis this marginally improved the explanatory power of the driving variables with respect to the dependent variables. In total, they account for about 12% of the total variance in the dependent variables. The two most important driving variables were substrate types; the proportion of boulders and silt. These represent the two most extreme ends of the spectrum in terms of river features. The relatively small proportion of variance that is explained may be accounted for by only one or two features that are highly associated with these extremes; for example, sites with a high proportion of boulders are almost exclusively associated with rapids and cascades, whereas sites with a high proportion of silt are associated with relatively low numbers of riffles.

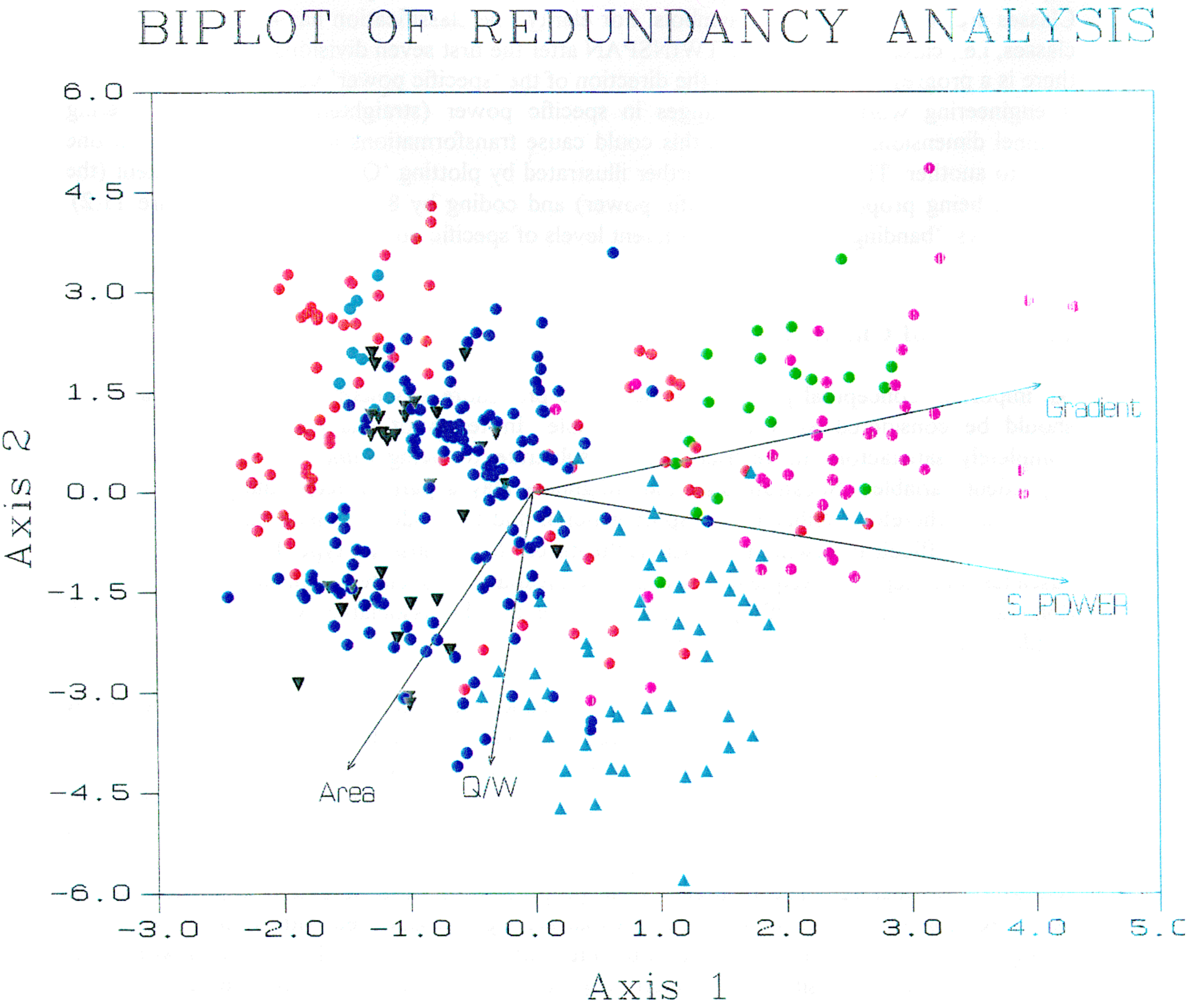


Figure 11.1: Biplot of redundancy analysis

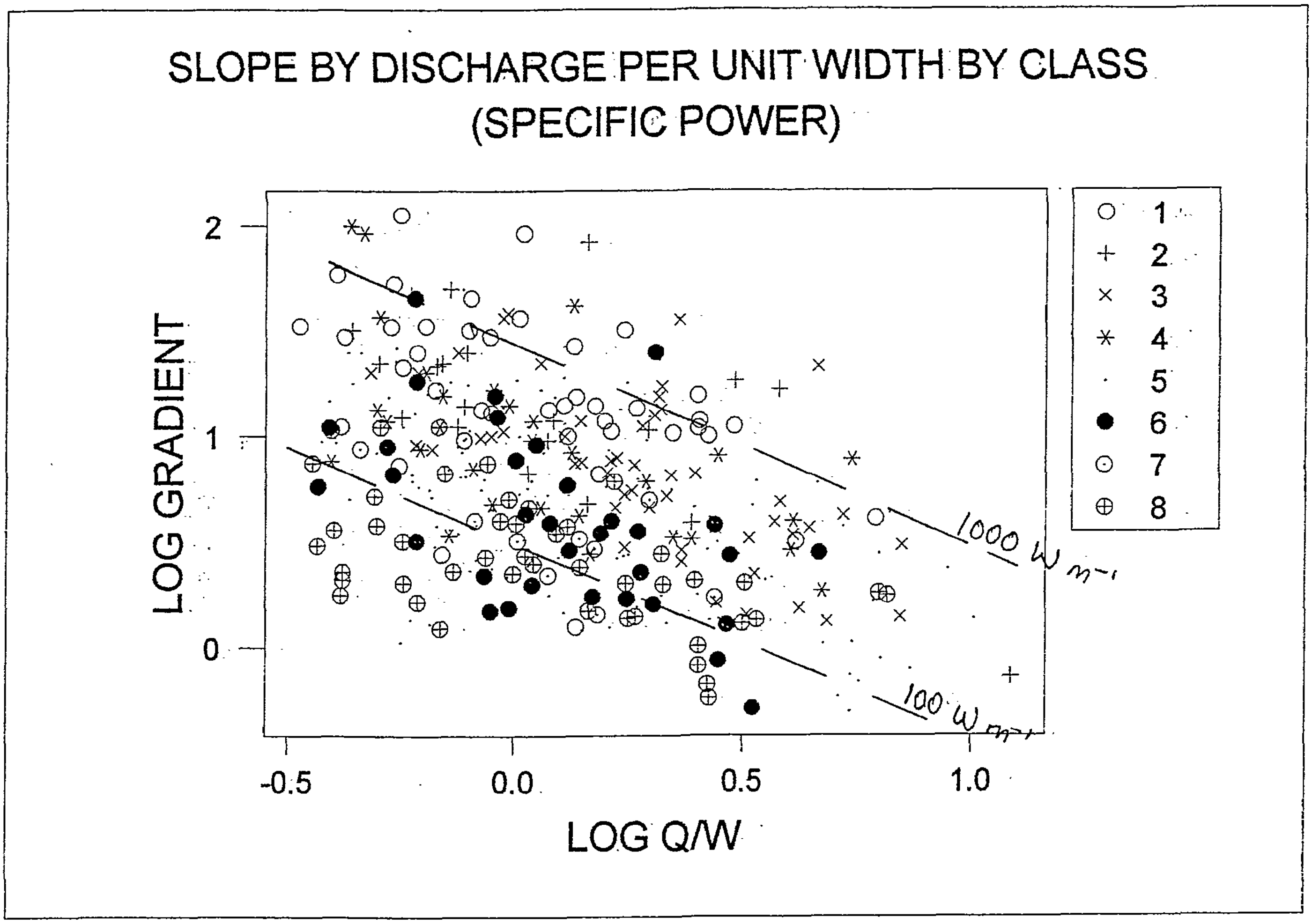


Figure 11.2: Slope by discharge per unit width by class (specific power)

11.5 Redundancy Analysis After Stratifying Dependent Variables by Substrate Class:

Since transferring the substrate types from dependent to independent variables did not seem significantly to improve the model and it detracted from the relatively successful classification work, this approach was not pursued any further. Instead, sites were stratified into three broad bands of dominant substrate type, in order to control the effect of substrate type in determining features.

A separate redundancy analysis was carried out for each stratum between the dependent variables and the drivers. The result of this was that the driving variables accounted for only 5 - 7% of the total variance within each stratum. Log_{10} Area, $\log_{10}$ gradient and $\log_{10}$ $Q_{1.5}$ /bankfull width (discharge per unit width) were in most cases found to be statistically significant in accounting for this small proportion of variance. Specific power, as a variable in itself, was made redundant in the analysis. This is probably because having stratified by substrate type the range of specific power within any one strata was very much reduced. However, the variation in the components of specific power, discharge per unit width and gradient then become more important in accounting for variance within the strata. This is equivalent to the spread of sites within classes along iso-power lines. Catchment area also remains an explanatory variable within two of the strata (Table 11.3).

Table 11.3: Explanation of variance in strata by driving variables

STRATA	*NO. IN STRATUM*	*SIGNIFICANT VARIABLES ACCOUNTING FOR VARIANCE*	*% VARIANCE EXPLAINED (CUMULATIVE)*
Bedrock, boulder & cobble	142	Log_{10} Gradient Log_{10} Area Log_{10} $Q_{1.5}$/width	4.4 5.7 7.4
Gravel/pebble	146	Log_{10} Area Log_{10} Gradient Log_{10} $Q_{1.5}$/width	3.2 4.4 5.5
Sand, silt and clay	83	Log_{10} Gradient Log_{10} Area no other significant	3.5 6.1 -

11.6 Observations on the Analysis:

In summary, a geomorphological classification of semi-natural rivers from the "dimension" variables has been developed through a TWINSPAN analysis. While there is inevitably a large subjective element in this procedure the classes produced have some statistical validity and are recognisable as identifiable types of rivers. This gives a good basis for comparison with any further classifications derived from "driving" variables and demonstrates clearly the character of the river sites in the survey and the quality of the data set available. The classification is also useful in its own right as a logical process of delineation of rivers on the basis of substrate type and it has the potential to further classify channels as sub-groups of substrate types on the basis of geomorphological features, particularly if there were a larger and improved dataset. The fact that it is based on substrate size makes it relatively easy to conceptualise for the casual user. It also demonstrates that the TWINSPAN technique has applications for deriving classes from this type of mixed data as opposed to other clustering methods.

The techniques used to relate driving variables to the dependent variables demonstrate that specific power is the single most important variable available to explain reach geomorphology and substrate composition. The relationship between the dependent and driving variables revealed by redundancy analysis suggest that changes in specific power (which could be effected by river engineering) have the potential to transform a reach to an adjacent class and therefore, theoretically to alter its geomorphological features. While the relationship is statistically significant, the ability to predict dependent variables or class membership from driving variables is extremely limited. Furthermore, any transformation of a river from one class to another will be constrained by the dominant effect of channel substrate size on class. This might be considered to be relatively fixed. However, river maintenance often alters the roughness of the channel perimeter in some cases as well as modifying the flow regime through removing obstructions and vegetation. This, therefore may conceivably encourage transformation from one class to another.

11.7 Review of classification using channel photographs

On the basis of analysis of the photographs taken by RHS surveyors of the field sites, there appears to be a small number of rivers reaches that do not fit easily within the TWINSPAN class that has been allocated to them. Table 11.4 indicates the site numbers concerned and the nature of the apparent classification discrepancy. No attempt has been made to put these aberrant channels into other more appropriate classes.

Table 11.4: RHS sites which deviate from their allocated channel class

Channel Class	RHS sites	Reason for discrepancy
1	89, 126	wider
2	(77), 92, 142, 143	eroding banks; no trees; little floodplain interaction; appears to be a sub-class 2b
3	201, 1485	Closer to class 1
	198	closer to class 2
	840	finer bedload; pebbles and cobbles
4	23	closer to subclass 2b
9	29	upland (equivalent to class 4)
	188	dry channel with cobbles
11	1161	vertical alluvial banks with slumping
	1451	? chalk stream with dense flora
13	378	modified channel (corrugated iron)
	408	boulder bed

Table 11.5 provides an assessment of additional channel attribute information that can be drawn from the site photos, and that was then taken forward to be used alongside the TWINSPAN semi-natural channel classification process.

Table 11.5: Channel attributes derived from site photographs

Class	Surroundings	Planform	Bed	Bank	In-channel
Codes	FP (Floodplain) 1=narrow, 3 = wide	S (Sinuosity) 1=low, 3=high	BE-bedrock, BO-boulder, CO-cobble, PE-pebble/gravel, SA-sand SI-silt fs-fluvially sorted		P/R-pools/riffles, SB-side bar, VMCB-vegtd mid-channel bar, MCB-mid-channel bar
1	FP=1	S=1, generally narrow	BE, CO, BO, step pools	Stable, trees	Rock bar
2	FP=1	S=1	BO, CO, fs	Eroding	Long riffles
3	FP=2	S=1	BE, BO, CO, fs, step pools		Rock bar
4	FP=1	S=1, wide	BO, CO, fs	Trees	P/R, SB, MCB, vegetation
5	FP=1	S=2, generally narrow	CO, PE, fs	Eroding, trees	P/R
6	FP=1	S=1, narrow	CO, PE, BO, fs	Moorland (no trees)	P/R, VMCB, braided
7	FP=2	S=2, narrow	CO, PE	Eroding/stable, trees	P/R, MCB, PB
8	FP=3	S=2, narrow-mid width	PE	Low banks, closely vegetated	P/R
9	FP=2	S=1, mid-narrow width	PE	Shallow banks, closely vegetated	P/R, SB
10	FP=2	S=2, narrow	PE	Trees/vegetation	P/R
11	FP=2	S=2, narrow	PE, SA	Vegetation	P/R
12	FP=2-3	S=2, narrow	SA, SI	Vegetation	
13	FP=2-3	S=2, narrow	SA, SI	Alluvial banks	In-stream veg., P/R

The review of the channel classification against the additional evidence provided by the site photographs allows further insight into the characteristics which separate the broad channel lasses. It is also possible to comment briefly on what appeared to be missing classes that field experience suggests might be needed within a comprehensive river channel typology for England and Wales:

- No large rivers are represented within the classification. This is unfortunate since there are significant numbers of semi-natural wide-channel sites in England and Wales. In principle it appears surprising that channel width is not a variable with a strong influence on the classification, although it is recognised that this may be due to the lack of wide channel within the sample.

- There may be an under-representation of some riparian vegetation types in lowland rivers.
- There may be a missing classes representing freely meandering rivers in floodplain sites in unconfined situations.
- There does not appear to be a class representing less-freely meandering classes of channels in confined situations.
- There is questionably an under-representation of upland rivers within the photoset.
- Lack of headwater streams on non-bedrock sites (peatland sites).

Parameters that appeared from the photographic analysis to be visually distinguishing in identifying the differences between river channel classes include:

- Bed material
- Degree of fluvial sorting of materials
- Bank material
- Floodplain interaction
- Pool/riffle sequence
- Step/pool sequence
- Steepness
- Sinuosity
- Bank vegetation

Of lesser importance were features such as bars and features of erosion and deposition.

12.0 APPLICATIONS OF THE RIVER CHANNEL TYPOLOGY

12.1 Application contexts and implications in the Agency

River Channel Typology (RCT) should be a routine and significant component in Agency decision-making and operations, and it will therefore need to play a distinctive and inherently justified role alongside other classificatory approaches including River Habitat Survey (RHS), River Corridor Survey (RCS) and large-scale conservation evaluation (SERCON). The effective coexistence of such evaluative and operations guidance systems within the Agency represents a strength rather than a weakness, provided that each component is applied at the appropriate stage and in appropriate circumstances without creating overlapping survey requirements. The river channel information needs of the Agency are many and varied, and it is inconceivable that they could or should be met by a single descriptive, interpretative and predictive protocol. But equally, it would in practical terms be unacceptable to introduce conflicting or overlapping classificatory systems within a single organisation, and the RCT has thus been devised specifically to offer the benefits of geomorphology's powerful indicative and predictive capability without overlapping or confusing the similarly important roles of other established systems. The basis for, and rationale of, this coexistence of distinct approaches is discussed below.

River Channel Typology is in effect a device for instilling basic geomorphological inference into routine Agency investigations and operations, and as such its role and context are both determined by the nature of geomorphology in relation to other sciences of the river environment. Channel geomorphology (which incorporates materials, forms and processes) is a significant component of habitat, and thus at one level represents a standard input to ecological conservation facilitating systems such as RHS and to ecosystem management for fisheries enhancement. At the same time, however, it is important to note that geomorphology is a constituent part of the environment in its own right. On that basis, RCT may have independent significance as an indicator for geomorphological conservation and landscape enhancement quite apart from its inter-relationship with ecology. The symbiosis of geomorphology and ecology in such contexts is already catered for in the geomorphological inputs to RHS, and geomorphology could also potentially be added to an extended SERCON approach. Similarly, RCS currently includes descriptive elements which could be regarded as geomorphological, but with its rather different purposes it has relatively rarely been used for geomorphological inference or prediction. Manifestly, there are many contexts in which geomorphology and ecology do relate so closely that they can appropriately be handled within a common survey, analytical and decision-support approach - but this is neither the whole story, nor necessarily the most important part of the story.

It is clear, nevertheless, that in conservation (and associated habitat quality) terms, RHS carries the core role of integrating geomorphology with ecology. As will become apparent later in this report, both RHS and RCT recognise channel substrate to be a potent overall diagnostic of geomorphological characteristics, with strong spatial and attribute inter-correlations which reflect the underlying control of river power. In part, this convergence may owe something to the fact that both classifications have been generated from the same data set, but the common outcome from two separate analyses is an encouraging sign that the distinctively different purposes of RHS and RCT can be served by a single approach to channel typology.

At first sight, this could be taken to imply that the RCT classes should be incorporated within RHS, and for basic reporting or classificatory purposes there may be some merit in this suggestion. However, a complete fusion of the two systems is neither a necessary nor a desired conclusion. In the role that is envisaged (below) for the RCT, the RHS national database serves a valuable purpose in providing an initial basis for identifying the primary channel characteristics which can best be used to designate channel classes and define the boundaries between them. Operationally, however, it is expected that the use of RCT in circumstances such as Catchment Management Planning or the predesign scoping phase of a Flood Defence Project will utilise data collected outside the RHS framework. It is important, therefore, that the implementation of the RCT (as opposed to its initial designation) must be free to benefit from being able to adjust to this broader information-gathering and inferential basis. Although both RCT and RHS are likely to serve a broad range of purposes, there are some distinctions inherent in their titles - the River Habitat Survey focuses specifically on habitat, environmental quality and conservation, while the River Channel Typology is a generic device which has equal relevance to almost all sectors of Agency activity.

The clear parallels between RHS and RCT thus far identified are rooted in a common concern with conservation, and thus with the overall evaluation and classification of environmental quality. However, it has already been stressed that the purpose of RCT is in no way limited to conservation. Given the hydraulic significance of geomorphology, the task of providing indicators of channel behaviour which can underpin decisions and operations based on the function of the channel in conducting water and sediment flow, is of equal or greater importance. Channel forms and materials interact with the processes of water and sediment flow in such a way that modification of either component has significant impacts on the other. By recognising this association, the Agency has in recent years pioneered the development of river management and "soft" engineering principles which enhance the land drainage effectiveness of the channel while maintaining or improving its overall environment, to the ultimate benefit of landscape and conservation as well as flood defence. RCT should be seen primarily as a technique for supporting such enlightened river maintenance, engineering or restoration. Its close links with RHS thus become welcome bonuses rather than the main design requirement, and in this context the two systems stand alongside one another rather than being fused. The need for compatibility and the efficiency gains of close co-operation are undiminished, but the drive for complete integration is much reduced.

Inherent in this distinction of purpose is an important contrast of nature between RHS and RCT. The conservation management purpose of RHS is predicated on the need to supply indicators of conservation status which can underpin investment prioritisation and act as a basis for performance monitoring. The habitat quality concepts involved permit channels with enhancement capability to be identified, and offer valuable guidance as to the type of enhancement that might be viable. The same indices highlight areas of particular quality which should be protected from adverse impacts from management tactics or development projects. A similar range of functions can be specified for RCT, reinforcing the comparability and interaction between the systems. However, in the case of RCT the core function is actually quite different - it is to predict channel dynamism and thus serve as an indicator of potential morphological and sedimentary instability and vulnerability, aspects which are specifically addressed in the Report below. Geomorphology is dominated by in-channel and down-channel links which transmit physical impacts, and which therefore must be regulated or protected as part of the river management process. Thus it is the task of RCT to characterise channels in such a way that simple observable diagnostics may be used to infer past process dynamism and predict future process dynamism. In this aspect of its function, RCT will usually be employed quite separately from RHS.

Although it was not the remit of Phase I of the RCT Project to create an implementation infrastructure, it is highly instructive to give flesh to the above discussion of the relationships between RCT, RHS and RCS by considering the possible RCT implementation contexts. Without doubt, an important and routine function of the data (and perhaps derived map) outputs of both RHS and RCT will be to provide an initial indication of ecological and geomorphological status in response to queries at the sub-catchment scale. In this reactive mode, much of the information communicated will be of attributes (including overall classifications) already assigned to rivers and stored in the archive, and in this respect there is much to be said for instituting a single query structure incorporating RCT within RHS so that all pertinent data are yielded by a single extraction. To be effective, the combined information system will need to be actively managed, both to ensure that information is updated and to reap the associated benefits of developing an ability to monitor change. In the fullness of time, update may be effected by a repeat national survey. In the meantime, there is much to be gained from ensuring that ad hoc observations undertaken in support of individual projects or planning exercises should be fed back to the RHS database. This presupposes that the RHS survey procedure (enhanced periodically as appropriate) should become the routine standard for this scale of observation.

In the case of RCT, particularly where channel dynamism is the main focus, an equally important context for implementation is likely to be systematic queries driven by Agency procedures such as Local Environment Agency Plans and river restoration. In both these contexts, the national data archive would offer an initial indication of likely status and dynamism, as well as providing the best available estimate of national (or regional) statistical norms for any particular attribute within a given channel class. RCT would be expected to become a standard initial query mechanism for these purposes, but would not be geared in itself to providing local (reach and sub-reach) indicators, for which purpose the existing procedure of Fluvial Audit would be the preferred approach (Fluvial Audit is a national procedure adopted by the Agency specifically for Flood Defence purposes, which provides a detailed local-scale survey and interpretation of geomorphological status and dynamics: its role is in some senses similar to that of River Corridor Survey providing sub-reach detail in the context of a broader RHS query). Similarly, with major river engineering projects RCT would provide review data to place the proposals in context, but Fluvial Audit would be necessary to provide a design and impact evaluation input.

The conceptual and practical links between geomorphology and river engineering in the Agency have become well-established and effective during the 1990s, and this move is to be applauded. The various components of the Agency's emerging set of national procedures thus fit neatly together, and the selection of the appropriate approach for a particular purpose could be assisted by a simple procedural guideline until familiarity is acquired by the "intelligent client" co-ordinating or commissioning the work. Through such a set of implementation contexts and approaches, RCT should become accepted as a powerful geomorphological technique in its own right, while at the same time fitting effectively into the broader conservation strategy of the RHS procedure.

12.2 Approaches to channel stability assessment

As was noted in Table 4.1 and Section 9.4, river channel stability is a fundamental attribute for incorporation into a channel typology, and an important concept through which such a typology can be applied to the practical needs of the river manager and engineer. Channel stability refers to the propensity of a river to change its morphology in time and space. This may either be achieved by deposition or erosion or both, and may be manifested in either vertical or lateral changes in channel form or combinations of both. Stable channels are often laterally or vertically inactive, but may also retain some degree of dynamism that over time does not alter the dimensions of the channel. In this latter case the channel is said to be in equilibrium. From a river management viewpoint, stable or equilibrium channels are the easiest to live with, since they do not incur expensive intervention to maintain channel capacity or prove little threat to structures or services in or adjacent to the river.

Unstable channels are those that exhibit mobility across the floodplain or within the channel, produced by the uneven throughput of sediments. Channels that exhibit both stable and unstable tendencies are identified as undergoing change and are by definition unstable. Unstable channels often provide varied habitat and have high conservation value but require expensive maintenance if attempts to enforce stability is pursued at the local level (e.g. bank protection or de-shoaling). A characteristic of the natural river channels is a discontinuous trend of stability. Reaches of channel may exhibit lateral erosion and the storage of sediments in bar forms only to be superseded by a stable reach of relative inactivity. The arrangement of these reaches is by no means predictable, but is important to consider when developing management strategies of any kind for the whole catchment. The implication of this fact is that for any one river, there may be many types of river reach and many types of individual management scenario, but it is only when they are revealed in continuity that the links between cause and effect may be identified and an appropriate management strategy formulated. To achieve this will require contiguous data collection such as that carried out for RCS, or the fluvial auditing procedure developed in Agency R&D project C5/384/2. These methodologies are better suited to providing this information. As it stands, RHS data collection methodology provides an impressive sample of discontinuous river reaches. Use of the stability evidence contained in this sample cannot identify cause and effect, but may be used to develop a typology of river instability. Subsequent re-surveys of these sites in 5 - 10 years time will provide important evidence of national trends towards river stability or instability within this sample. With this limitation borne in mind this Section will attempt to:

- Develop a methodology for interpreting river stability using RHS data;
- Identify the limitations and assumptions of the methodology;
- Examine the patterns revealed in the RHS semi-natural dataset from the 1994 survey and comment on their significance;
- Identify areas where RHS data collection may be improved if a stability criterion is desired as part of the data analysis procedure for RHS;
- Suggest areas of fruitful further research (Section 12.3).

Stability indicators and RHS data: Indicators of channel stability are well known in geomorphology and are based on field identification of diagnostic factors combined with assessments of historical change, usually derived from air photo or historic map analysis. Field evidence may also be used to identify historical instability and involves analysis of sediments exposed in the river bank or floodplain, as well as identification of floodplain features. Clearly with RHS data, one is limited to the use of field indicators, and these are further constrained by those specifically collected for habitat survey.

Table 12.1 presents some of the field indicators that have been used by geomorphologists to assess channel stability and this list in itself is not totally comprehensive. Of these only half are really available in the RHS dataset, with most of the omissions in the floodplain column. This in itself provides some information on future additions to the RHS data collection methodology which is discussed below.

Table 12.1 Field indicators of stability used by geomorphologists

Channel Features		Bank Features		Floodplain Features	
Braiding - Multiple channels separated by unvegetated, uncompacted bars of exposed riverine sediments	US	Large or frequent eroding cliffs of unconsolidated sediments delivering sediment directly to channel	US	Cut-off channels - recent or old depending on state of preservation and type/degree of infilling and vegetation. Size of cut-offs compared to present channel (smaller, larger).	US
Actively meandering - large frequent point bars with mid-channel bars all composed of unvegetated, uncompacted exposed riverine sediments. Cut-offs imminent and recent.	US	Erosion of both river banks for over 50% of reach Slabs, blocks, overhangs indicate scour by fluvial processes. Slumping, slips and presence of small terraces half-way up bank face indicates geotechnical failure of banks.	US	Old boulder dumps, or bar forms on floodplain (note sediment type and degree of cover by moss/lichen/vegetation)	US
Meandering - point bars of unvegetated, uncompacted exposed riverine sediments	US/S	Erosion of outer banks at meanders (type of bank erosion significant)	US/S	Old bank lines / cliffs on floodplain terraces or valley sides	US/S
Meandering - point bars and berms of fine sediments with seasonal vegetation growth	US/S	State of fence lines, embankments, and arboreal vegetation - collapse indicative of lateral instability	US/S	Presence of terraces - number, proximity to channel, relief, clarity of feature and composition if evident. Age of vegetation/structures	US/S
Large, unvegetated, unstained, uncompacted bars immediately downstream of tributary input	US	Generally unvegetated banks with old slump scars	US	Age / location of structures, field systems, boundaries with respect to present channel	US/S
Loose, uncompacted, unvegated sediments showing evidence of fluvial sorting (e.g. dunes, ripples in fine sediments; structures, alignment, sheets in coarse sediments)	US/S	Age of bankside trees and structures		Land use of floodplain and vegetation type of riparian zone	US/S
Shallow pools filled with loose, unvegetated mixed-size sediments	US	Presence / state of bank protection and structures	US/S	Presence, type and extent of recent overbank deposits	US/S

Dissected riffles of loose, unstained mixed-sized sediments	US	Bank materials cohesive clays tend to be stable or fail through slumping. Gravels and sands are unstable and may scour or slump. Boulders tend to self-heal when fallen to foot of bank.	US/S	Vertical structure of sediments exposed in river banks or terraces / ditches on floodplain.	US/S
Any of the above but with vegetated, compacted, dark-stained sediments. Large trees on bars and berms.	S	Exposed gravels at toe of bank	US	Extent of floodplain estimated in channel top-widths.	
Undermined / buried structures in bed	US	Gravels overlying fine sediments and/or organic sediments can indicate incision	US	Valley type - narrow-V, U-shaped, Flat-floor steep sides, Wide, terraced, channel confined by valley sides, channel unconfined,	
Contracting / undermined bridge openings / footings	US	Vertical banks of significant height	US		
Old structures in position	S	Gently sloping banks well vegetated	S		

US = Unstable, S = Stable

Stability indices were identified from the RHS data collection sheets and from the rules for field identification contained in the RHS guidelines. Much of the data contained in the RHS data sheet can be used for geomorphological interpretation providing that this is based on assumptions of:

- correct identification of geomorphological features
- consistent identification of features across all RHS survey groups
- scaled data in relation to channel width (e.g. pool-riffle spacing, number of point bars)

Of these the latter is significant, since the adherence to a static reach length (500m) does not account for the lateral scale of the river which has been shown to be significant in the scaling of morphological features. This can be illustrated by the following. Assuming that meander and pool riffle spacing conform to a bankfull width scaling function of 12W and 6W respectively then for rivers of varying width, the number of geomorphological features sampled will vary according to Table 12.2 below. This is important if any form of reach stability is to be derived from RHS surveys across all river types. What it does suggest is that for channels wider than 20m, coverage of one or less meanders may represent very local processes and not more general reach characteristics.

Table 12.2: The effect of channel scale on the theoretical number of geomorphological features surveyed

Mean bankfull width (m)	Potential number of meanders sampled / 500m	Potential number of pool-riffle units sampled / 500m
2.0	20.0	40.0
6.0 (RHS semi-natural average)	6.0 - 7.0	13.0
20.0	2.0	4.0
100.0	<< 1.0	< 1.0

One of the important aspects of geomorphological channel stability analysis based on field data is the description of the site in spatial terms. It is not sufficient to provide simple listings of features, but rather it is necessary to interpret these in relation to each other, both downstream, across the channel and vertically. This presented a significant problem for analysis of RHS data, since although SPOT data is recorded for 10 cross sections, these do not readily permit the reconstruction of spatial associations between bed, bank and floodplain features. The further data-split into SPOT and SWEEP data types renders further spatial analysis impossible. The data manipulation required to produce a workable spatial dataset took up much of the project time. However, there is an opportunity to improve the spatial reconstruction of RHS geomorphological data but this must form part of further research.

Generating channel stability indicators from RHS survey data: The broad aim of this procedure is to develop criteria for discriminating between those channels that exhibit stable geomorphological properties (e.g. stable perimeters, vegetated deposits) and those which are dynamic (eroding perimeters, numerous unvegetated bars). In addition an attempt has been made to develop interpretations of the stability categories so that the type and direction of river channel change may be quantified. In the end, the dataset was impoverished in some categories and this necessitated the lumping together of stability classes. Table 12.3 illustrates the division of data used to differentiate between stable and unstable types of channel feature as permitted by the RHS94 semi-natural dataset. The analysis used the dataset generated by Newcastle University. The classification was subjective, rules-based and was carried out using ORACLE relational database. Rules were establish using a suite of queries which grouped the data according to Table 12.3. Problems were encountered where there were missing data recorded for categories, or where unique datasets occurred. Despite these problems almost 68% sites were allocated to one or more of the stability groups constructed.

Table 12.3 Provisional allocation of RHS sites into stability classes

Stable or Equilibrium	**Bank Material**	**Substrate**	**Bank Feature**	**Channel Feature**
	Bedrock *	Bedrock *	Continuous Trees (E)	VPB (>3)
	Boulder/ Cobble *	Boulder *	Eroding Earth Cliff (<2)	VSB (>3)
	Sticky Clay *	Clay *		VMCB (>3)
	Peat *	Liverworts Mosses *		Mature island *
		Consolidated (SWEEP)		Exposed bedrock/ Boulder *
Unstable or Dynamic				
	Gravel/Pebble/sand *	Unconsolidated (SWEEP)	Eroding Earth Cliff *	UVPB (>3)
	Earth *		Vertical/Undercut(SWEEP) (E)	UVSB (>3)
	Bare *		Vertical+Toe (SWEEP) (E)	UVMCB (>3)

* is SPOT values >=5 (E) is SWEEP values where abundance is >33%

Stability Classification Procedure - Substrate classification: The geomorphological indicators of channel instability recorded in the interim report included most of the substrate categories. After due consideration it was clear that these were not true indicators of instability except in a few cases such as bedrock or sticky clay where there is a degree of certainty about the resistance offered to erosion by the materials in situ. Nevertheless, substrate is an important classifier of river type, and clearly has a significant role in determining the morphology of river channels and the basic scaling of channel form (e.g. width/depth ratio).

The stability analysis was applied to the semi-natural RHS sites whose spatial distribution is shown in Figure 12.1. The first procedure in stability analysis is to break down the data set into substrate groups. This removes the substrate element from the classification process directly, whilst simultaneously allocating instability type to substrate group. Six substrate groups were used, based on those available in the RHS 1994 dataset. These were Cobble, Gravel & Cobble, Gravel, Gravel & Sand, Sand, Silt. Boulder-bed channels, bedrock channels and clay channels were kept as indicators of channel stability based on the subjective expert decision that these were unlikely to provide erodible boundaries. Following this procedure, classification was conducted using the rules outlined in Table 12.3 above. The frequency allocation of initial stability classes for semi-natural RHS94 sites independent of substrate groups is shown in Table 12.4 below. A total of 323 out of 484 (66.7%) sites have been allocated to a stability group, leaving some 161 sites unallocated. These unallocated sites occur where there are missing data in one of the stability index classes.

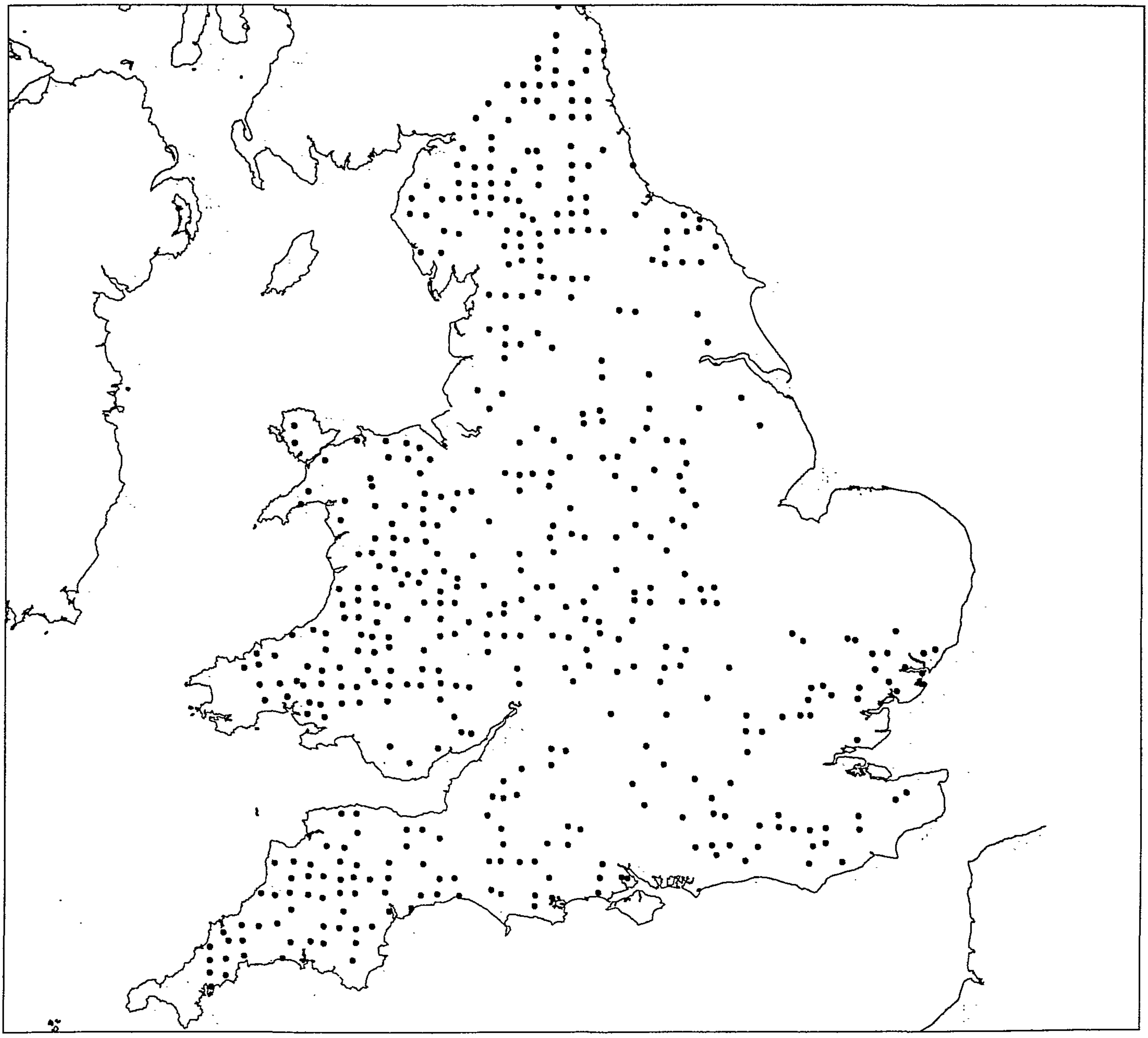


Figure 12.1 Location of semi-natural sites

Table 12.4: Stability groupings and number of sites allocated per group

Group Number	Bank Material	Substrate	Bank features	Channel features	Number / group
1	S	S	S	S	0
2	U	U	U	U	117
3	S	S	S	U	5
4	S	S	U	U	6
5	S	U	U	U	21
6	U	U	U	S	40
7	U	U	S	S	33
8	U	S	S	S	7
9	S	U	U	S	4
10	U	S	S	U	5
11	S	U	S	U	11
12	U	S	U	S	0
13	S	S	U	S	3
14	U	U	S	U	62
15	S	U	S	S	3
16	U	S	U	U	6

The spatial distribution of classed channels is shown in Figure 12.2 below. On the basis of these stability groupings there are no reaches that exhibit wholly stable indices, although there are 18 with dominantly stable indices (Groups 3 & 8). Conversely, there are 117 channel reaches that exhibit wholly unstable indices and a further 129 with dominantly unstable indices. Figure 12.3 shows the spatial distribution of unstable channels in the sample. This leaves some 65 reaches of semi-natural channel classified as exhibiting both stable and unstable indices. Nevertheless, the rules-based classification suggests that in the majority of cases allocated, instability of the channel bed and banks is a natural feature, and that channels with wholly stable boundaries are comparatively rare. The detail recorded in these 16 classes can be broken down further into four main stability scenarios. These are illustrated in Table 12.5 below, together with a provisional operational interpretation.

Table 12.5 Provisional interpretation of allocation to four stability scenarios

Stability Scenario	Interpretation
Stable banks + Unstable bed	Sediment entering reach: monitor features and banks (maintenance necessary for capacity)
Unstable banks + Stable bed	Incision / Sediment starvation (monitor structures for exposure of footings, bank protection necessary)
Unstable banks + Unstable bed	Aggradation - dynamic geomorphology (Avoid intervention - conserve)
Stable banks + Stable bed	Stable channel currently in equilibrium (Intervention unnecessary - conserve)

This condensing of the dataset was conducted to provide meaningful sample sizes to test for the predictive ability of stream power in allocating river reaches to stability groups. Stream power is a composite hydraulic term that describes the potential for the river at bankfull flow,

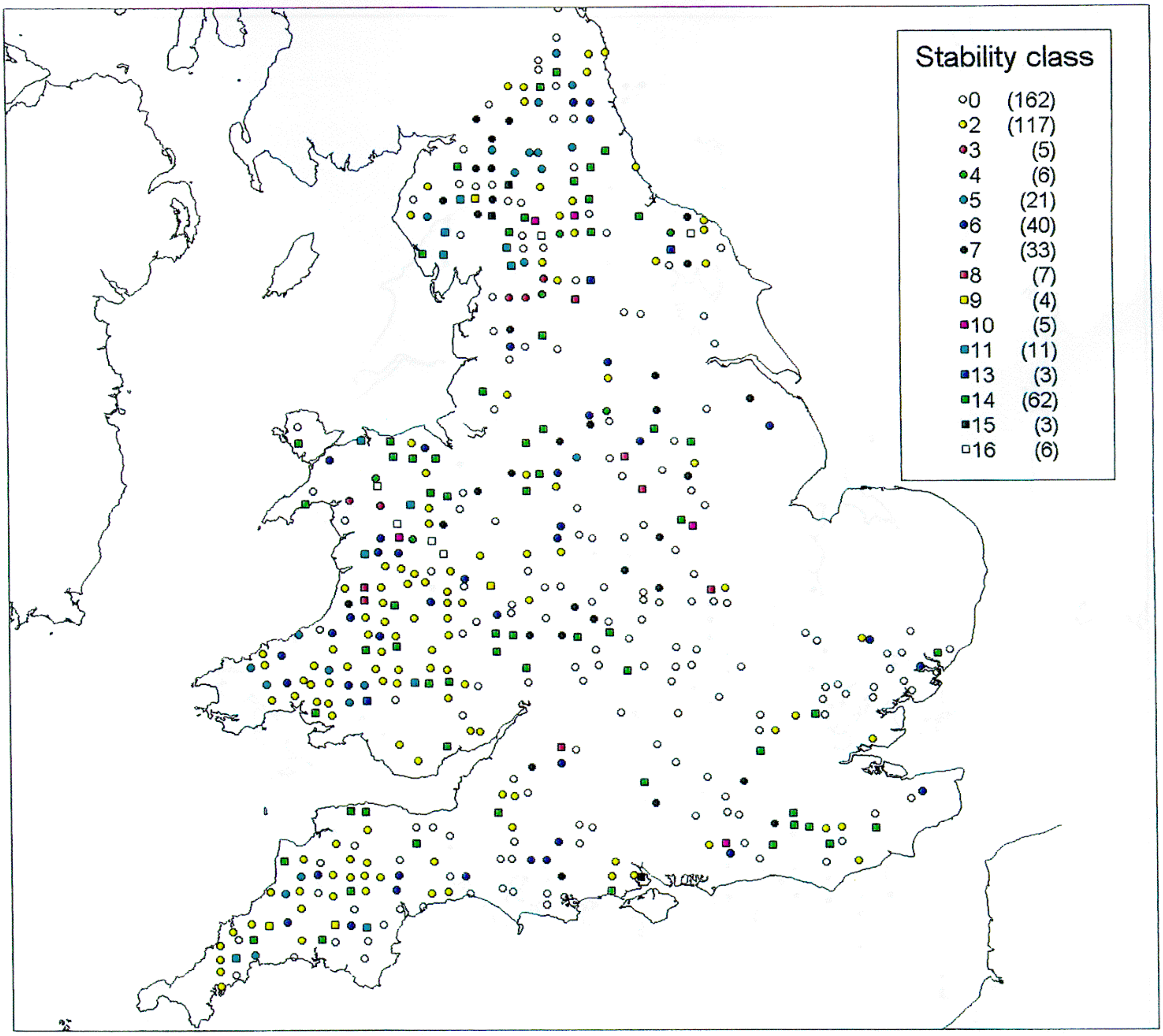


Figure 12.2 Stability Classification

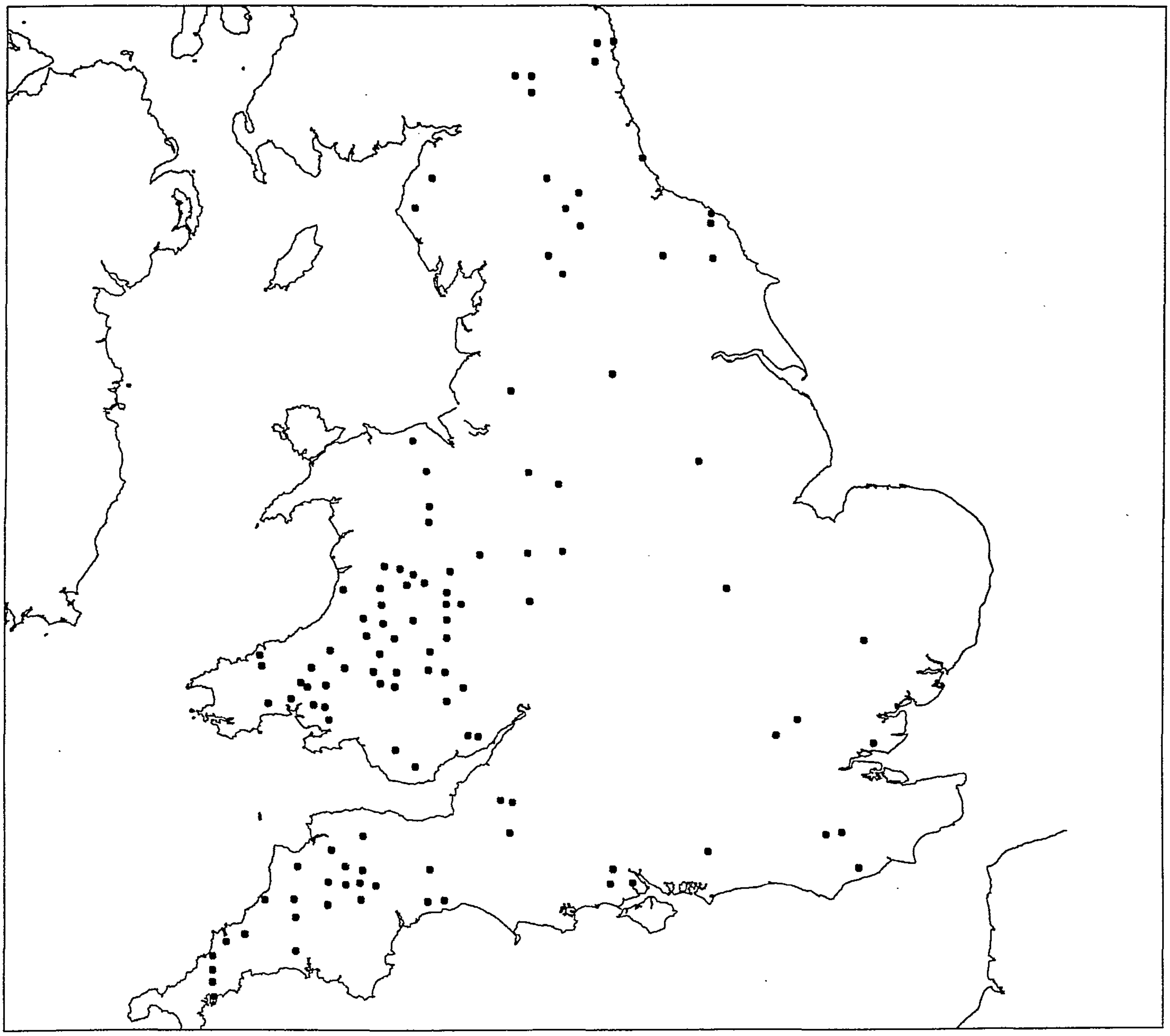


Figure 12.3 Preliminary instability indicator

to undertake work in eroding and transporting its boundaries. It has been used by geomorphologists to predict the tendency for a river to meander, braid or to erode or deposit. Given its generally accepted utility in delimiting gross channel stability, the four indices derived from the RHS dataset were tested against a value of stream power. The values of stream power were calculated according to the formula:

$$\Omega = \gamma QS/b$$

where Ω is specific stream power in Watts per square metre (W/m^2), γ is the specific weight of water (9800 kg/s) S is channel slope obtained from 1:25000 OS maps, w is channel bankfull width derived from the RHS database and Q = bankfull discharge estimated from the average of Wharton's (1992) equations using RHS values for bankfull Width and Depth and applied only within the ranges used in the original analysis. The data used in the calculation are presented in Appendix 5.

The values of stream power calculated in this way are subject to significant errors, conflated through errors derived from using map values for channel slope, tape estimates of bankfull width based on only one cross-section, and reconstructed bankfull discharges. Correlation of stream power with the individual variables showed that slope dominated the distribution of values. This fact accounted for a number of sites that had low values of bankfull discharge and channel dimensions, but high values of stream power. These represent steep upland, headwater streams.

Conversely, the larger lowland rivers tended to have low values of stream power, but large values of bankfull discharge. Values of stream power were available for only 362 sites and covered a range from 2 - 1815 W/m^2. The broad distribution of stream power was hoped to provide some assessment of predictive ability despite the known errors in this technique.

Table 12.6: Stream power values associated with substrate groupings of stability class

	Stable				Bank unstable Bed stable				Bank stable Bed unstable				Unstable			
	n	**med.**	**range**	**o**	**n**	**med.**	**range**	**o**	**n**	**med.**	**range**	**o**	**n**	**med.**	**range**	**o**
Silt	2	47.5	13.8 - 81.1	47.6	2	40.8	16.6 - 65.1	34.3	6	37.8	8.0 - 105	40.9	-	NA	NA	NA
Sand	1	NA	NA	NA	4	198	6.3 - 290	123	1	NA	NA	NA	2	112	22.3 - 202	127
Gravel/ Sand	0	None	None	NA	3	103	66 - 139	36.7	2	73.2	36 - 111	52.9	5	63.3	21.3-114	37.3
Gravel	9	107	12-1766	570	12	142	21-1121	371	27	73.3	4 - 489.6	138	55	50.1	4.6-1443	218
Gravel/ Cobble	4	135.6	58.8 - 269.1	97.9	3	135	100 - 225	60.5	6	78.8	57.7-482	167	10	39	23 - 539	159
Cobble	1	NA	NA	NA	2	95.5	53.7-97.9	24.9	13	142	7.2-427	117	30	79.3	9.2 - 2578	493

Table 12.6 illustrates the range of stream powers associated with each substrate ordered, stability group, and Figure 12.4 indicates the spatial distribution of the varying stream powers of the sample sites. There is a broad trend in Table 12.6 indicates an increase in stream power from silt-clay sites to cobble dominated rivers. This was expected given the results of the TWINSPAN classification. What was unexpected was the trend throughout most substrate groupings for the lowest values of stream power to be associated with those rivers exhibiting

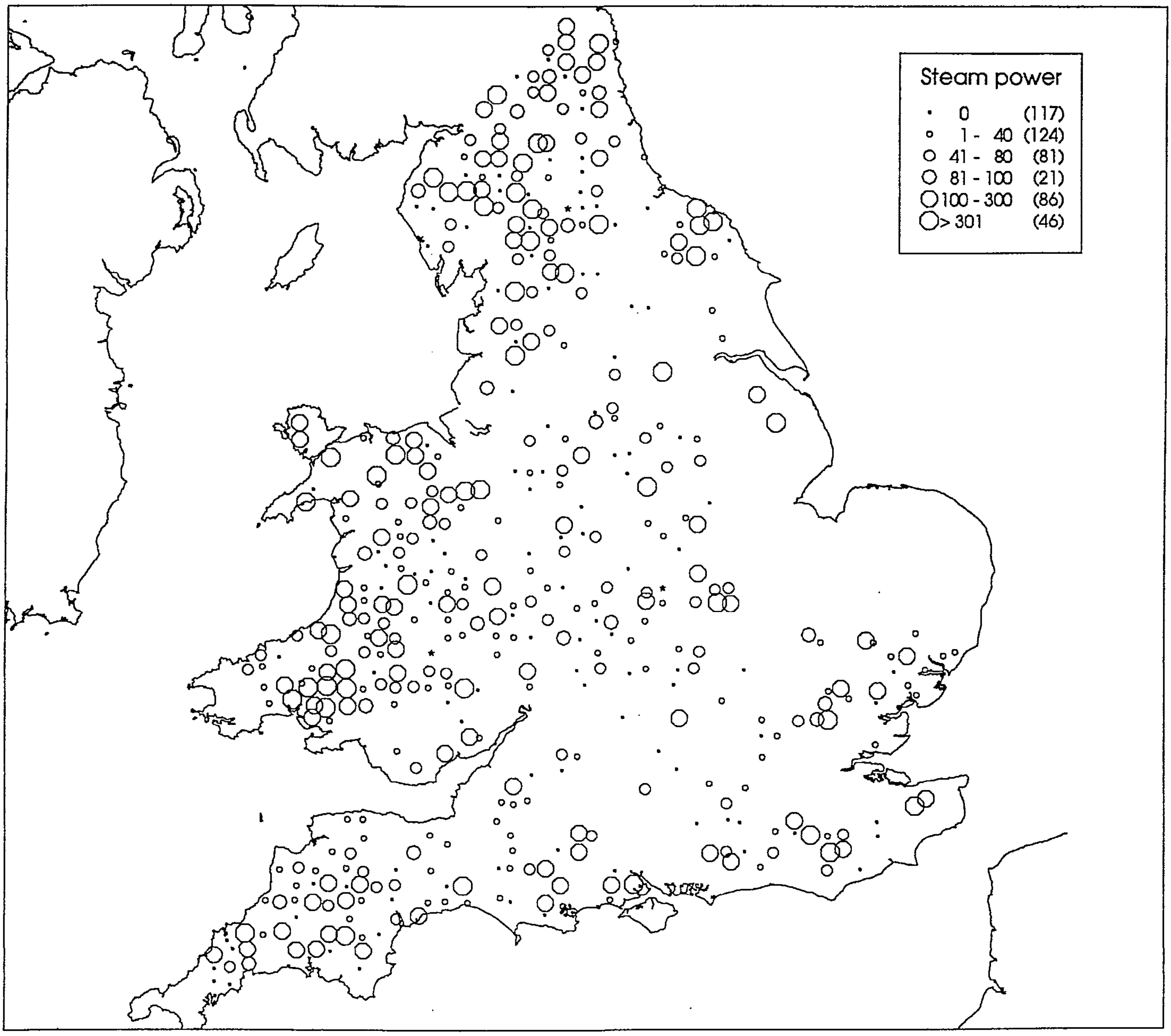


Figure 12.4 Stream Power

the highest incidence of instability indices. This may be an artifact of the data distribution which is heavily weighted towards the gravel, unstable index categories. Analysis of the stream power groups based on the four main stability classes revealed that although significantly different (Mann-Whitney U-Test at 95% confidence limit) the groupings differed as follows; 1 < 2 > 3 and all > 4. One factor each class had in common was a median and average value of stream power over the 35 W/m^2 threshold identified by Brookes (1987) as distinguishing between channels that were able to erode their boundaries, from those that were stable or adjusted their boundaries through deposition. Figure 12.5 displays the site data for the four classes of stability according to stream power.

In most cases the values plot above 35 W/m^2 which might be expected of the unstable categories. However, what requires more explanation is the stability of sites above this threshold, including some that lie above the 1000 W/m^2 value associated with actively braided rivers. The key to the distribution lies in the substrate of those channels that lie below this threshold. Below 35W/m^2 the rivers are characterised by silt, sand and sandy gravel substrate that require relatively low energy for sediment transport. Above the 100 and 1000 W/m^2 thresholds, the rivers are dominated by gravel/cobble and cobble substrates that require higher energies for sediment transport. Although this does not explain the presence of stable river channel reaches it goes some way to explaining the instability observed at low stream powers.

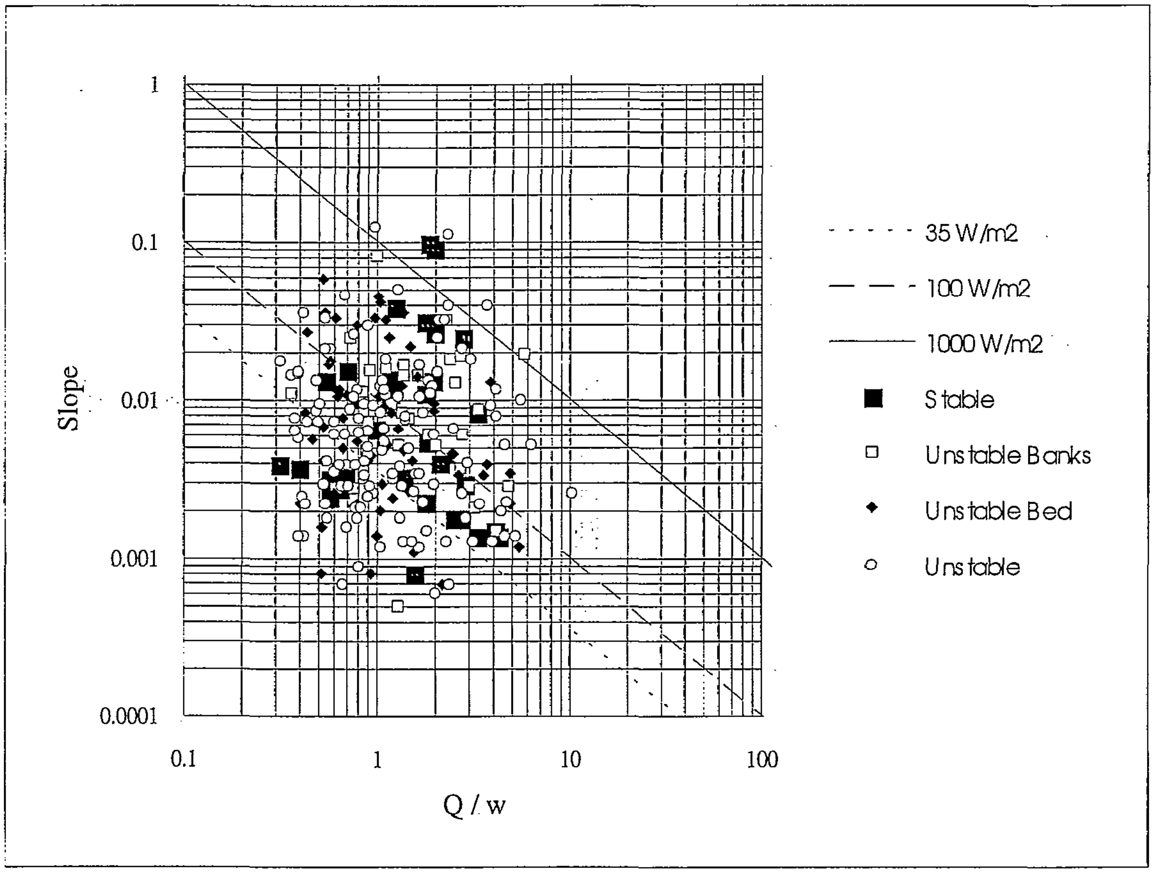


Figure 12.5 **Scatter plot illustrating the relationship between stability indices and specific stream power. Sites below the 35w/m^2 line are dominated by fine sediment substrates.**

In conclusion, it can be seen that it has been possible to conduct a provisional stability analysis using RHS field data and a set of rules-based allocation queries. This procedure is limited and does not possess the important spatial associations generally required for geomorphological assessment. Nevertheless, at broad level, four groupings were identified that should be tested for statistical significance following the inclusion of the 1995 database that will provide a more robust spread of site types, particularly in lowland areas. A test for the predictive ability of stream power showed that although each group was statistically significant, there was not the expected association between unstable sites and high stream powers. This is considered to be an artifact of the data distribution and the errors inherent in the estimation of stream power. Despite these limitations, it is clear that the majority of rivers sampled are of relatively high energy, and exhibit some degree of instability in their bed and or banks. Those channels that have unstable characteristics and low stream powers are dominated by fine sediment substrates.

12.3 Priorities for further action

Further work is required to strengthen the stability analysis which has been identified as an important basis for operational implementation of the river channel typology. This should include:

- exploration of the spatial associations between stability data (particularly SPOT data) that may provide further classificatory indices (e.g. deposition associated with erosion, erosion of both or single banks etc.)
- Further categorical data analysis to test the significance of the stability groupings produced from the rules-based classification.
- Further discriminant analysis of the stability groupings using sinuosity to predict planform instability.
- Incorporation of a specific geomorphological section in future RHS survey based on data outlined in Table 12.1 of geomorphological indicators.

At a more general level, it is possible to identify a range of priorities which would extend the range and applicability of the river channel typology:

- For cause and effect of river instability to be identified, RHS methodology should be applied to contiguous reaches of the same river in order to provide the link between upstream and downstream channel behaviour.
- Updating the information using 1995 data will undoubtedly improve the quality of statistical analysis that could be performed and help to clarify the reality of some of the groupings. In particular, further low gradient, fine substrate sites are required to typify the natural stability trends of lowland rivers.
- Consideration for future RHS of a morphological-based reach or a reach length scaled on average channel width that would have geomorphological (and habitat) significance and provide a greater consistency between surveys of rivers of different size.
- Incorporation of a specific geomorphological section in future RHS surveys along the lines of those outlined in Table 12.1.
- Consideration of how to improve the ability to spatially associate data collected from an RHS site. This could include a minimum of 5 photos per site covering bank erosion, channel features, exposed river sediments, floodplain/riparian zone, cross-section.

- Methods to improve the accuracy of measured data such as width, slope and depth. A surveyed cross-section or average of three per site would greatly enhance the database at relatively little cost in time and resources. Values of surveyed slope, cross-section area at bankfull, and a photo with scale of the substrate would enable more accurate estimation of hydraulic variables such as stream power.
- It has repeatedly been indicated that there is a need to expand the dataset used for the river channel typology to include the 1995 RHS survey that contains specific examples from lowland rivers together with a site value of channel slope and improved geomorphological feature recognition.

Overall, then, progress in the refinement of an operational river channel typology appears likely to be best achieved by focusing on:

- **Enhanced data,** particularly the prospect of using RHS 1995 data collected on the improved geomorphological specification. There may also be an opportunity to employ some more site-specific information such as that already gathered for Thames Region sites, both to assist in generating the typology and in providing calibration or testing.
- **Enhanced information handling,** perhaps by exploiting the advantages of replication by maintaining the TWINSPAN analysis of 1995 data (and possibly combined 1994/1995 data), but supplementing this with other visualisation or analytical techniques. In addition, a core refinement would be a focus on the introduction of simple (probably rule-based) indicators of channel stability. It is felt that an ability to identify both a static geomorphological class and a dynamic indicator would offer the ideal basis for understanding the present/future behaviour of the channel concerned, and for proposing management guidelines.
- A **management focus** for the project output is essential. This could take the form of procedures through which to incorporate River Channel Typology into the standard practices of the Agency, including a role within Catchment Management Planning and a more comprehensive clarification of the working relationship with procedures such as River Habitat Survey (with its Habitat Quality Index) and Fluvial Audit. In the first instance, this implementation thrust could concentrate on Conservation and Flood Defence functions. It would also be necessary to provide an input to any drafting of guidelines on new approaches to river management, and to prepare for the design of a sustained training programme to ensure wide and informed uptake of the techniques devised.

12.4 Implications for data collection

While it may be possible (though not ideal) to envisage simple geomorphological data for incorporation in RHS and RCT being gathered in the short term by non-geomorphologists, this flexibility is clearly not available with Fluvial Audit. Since the role of reach and sub-reach data is to provide a definitive indication of design inputs and impact predictors, observation cannot be delegated to non-specialists without threatening the quality assurance of the output recommendations or decisions.

There can be little doubt that in scientific principle, geomorphological purposes are best served by data collected by surveyors with significant geomorphological understanding. As in every other scientific discipline, trained practitioners are best able to interpret guidelines, achieve consistency, perceive subtle variations and be able to supplement routine observation.

In practice, however, resource limitation implies that such a target may well often be difficult to sustain, and it is expected that in the short term much data collection will continue to be by non-specialists. Nevertheless, since the RHS data will remain the primary national reference archive of channel descriptors, it is important to the Agency that the geomorphological observations within the RHS surveys should continue to evolve so as to maximise their ability to serve the dual function - and these data needs are addressed briefly below. Continued geomorphological enhancement of data collection would be particularly significant if RCT operationally was to be implemented (at least for conservation purposes) as a component of, or supplement to, an evaluative process driven by RHS. However, the appropriateness of regarding RHS and RCT as symbiotic is ultimately dependent on further consideration of the purpose, nature and implementation of the two systems.

13.0 REFERENCES

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Moss D. (1985) An initial classification of 10 km squares in Great Britain from a land characteristic data bank, *Applied Geography*, 5, 131-150.

Wharton G. (1992) Flood estimation from channel size; guidelines for using the channel-geometry method, *Applied Geography*, 12, 339-359

Appendix 1

Master Dataset derived from RHS database

FIELD NAME	*FIELD DESCRIPTION*	*# CASES*	*# MISSING VALUES*
SITE_NO	RHS site number	1523	0
NRA_REG	NRA region	1523	0
RIV_NAME	River name	1523	0
HYD_NO	Hydrological number	1523	0
CATCHMT	Catchment name	1523	0
GRID_SQ	Grid square	1523	0
GRID_REF	Grid reference	1523	0
FLOW_CAT	Flow category	1523	0
SOLIDGEO	Solid geology	1523	0
DRIFTGEO	Drift geology	1523	0
ALTITUDE	Altitude	1523	0
DIST.SCE	Distance from source	1523	0
GRADIENT	Gradient	1523	0
SINUOSTY	Sinuosity	1523	0
RQ85	River quality survey 1985	1523	0
GQA90	General Quality assessment 1990	1523	0
NORTH	Northings	1523	0
EAST	Eastings	1523	0
FLOWTYPE	Flow type	1523	0
GLIDES	Glides	1523	6
SLACKS	Slacks	1523	13
WIDTH	Actual water width	1523	0
DEPTH	Actual water depth	1523	0
L_TREES	Trees - left bank	1523	0
R_TREES	Trees - right bank	1523	0
RBKMODNO	# Spot checks no modifications to right bank	1523	0
RBKRS	# Spot checks resectioned right bank	1523	0
RBKRI	# Spot checks reinforced right bank	1523	0
RBKPC	# Spot checks poached right bank	1523	0
RBKMODMS	# Spot checks right bank modification info missing	1523	0
LBKMODNO	# Spot checks no modifications to left bank	1523	0
LBKRS	# Spot checks resectioned left bank	1523	0
LBKRI	# Spot checks reinforced left bank	1523	0
LBKPC	# Spot checks poached left bank	1523	0
LBKMODMS	# Spot checks left bank modification info missing	1523	0
CHMODNO	# Spot checks no channel modifications	1523	0
CHRS	# Spot checks channel resectioned	1523	0
CHRI	# Spot checks channel reinforced	1523	0
CHCV	# Spot checks channel culverted	1523	0
CHBR	# Spot checks channel bridged	1523	0
CHDA	# Spot checks channel dammed	1523	0
CHMODMIS	# Spot checks channel modification info missing	1523	0
N_RIFFLE	Number of riffles	1523	0
N_POOLS	Number of pools	1523	0
CASCADES	Cascades	1523	8
RAPIDS	Rapids	1523	9
X_BEDROC	Exposed bedrock	1523	15
X_BOULDR	Exposed boulders	1523	9

LBKF_HT	Left bankfull height	1523	0
BKF_WDTH	Bankfull width	1523	0
RBKF_HT	Right bankfull height	1523	0
ARTIFICL	Artificial channel	1523	32
RVERTUND	Right bank vertical undercutting	1523	3
VALYFORM	Valley form	1523	0
CHANFORM	Channel form	1523	0
LVERTUND	Left bank vertical undercutting	1523	3
EA_SUM	# Spot checks earth bank substrate	1523	0
CL_SUM	# Spot checks clay bank substrate	1523	0
PE_SUM	# Spot checks peat bank substrate	1523	0
GP_SUM	# Spot checks gravel/pebble bank substrate	1523	0
BE_SUM	# Spot checks bedrock bank substrate	1523	0
BC_SUM	# Spot checks boulder/cobble bank substrate	1523	0
AR_SUM	# Spot checks artificial bank substrate	1523	0
BK_MISS	# Spot checks bank substrate missing info	1523	0
BE	# Spot checks bedrock channel substrate	1523	0
BO	# Spot checks boulder channel substrate	1523	0
CO	# Spot checks cobble channel substrate	1523	0
GP	# Spot checks gravel/pebble channel substrate	1523	0
SA	# Spot checks sand channel substrate	1523	0
CL	# Spot checks clay channel substrate	1523	0
SI	# Spot checks silt channel substrate	1523	0
AR	# Spot checks artificial channel substrate	1523	0
CSUBMISS	# Spot checks channel substrate info missing	1523	0
ECYES	# Spot checks eroding cliffs	1523	0
MBYES	# Spot checks mid-channel bars	1523	0
PBYES	# Spot checks point bars	1523	0
SBYES	# Spot checks side bars	1523	0
PTBAR2	Count of point bars	1523	0
NAVIG	Navigation	1523	2
CULVERTS	Count of culverts	1523	0
WEIRS	Count of weirs	1523	0
SEMI_NAT	Semi-natural site or not	1523	0
CH_SUB	Predominant channel substrate	1523	2
VPB	# Spot checks vegetated point bar	1523	0
UPB	# Spot checks unvegetated point bars	1523	0
VSB	#Spot checks vegetated side bars	1523	0
USB	# Spot checks unvegetated side bars	1523	0
VMB	# Spot checks vegetated mid-channel bars	1523	0
UMB	# Spot checks unvegetated mid-channel bars	1523	0
ISLAND	Count of mature islands	1523	3
BED_MATL	Code for consolidation of bed material	1523	0

Appendix 2

Criteria used to define Channel Stability Class

Bank stable where:

(BE_sum + CL_sum + BC_sum + PE_sum > 10)

Bank unstable where

(GP_sum + EA_sum > 10)

Substrate stable where

(BE + BO + CL >= 6) OR
(bed_matl = 1)

Substrate unstable where

(GP + SA + SI + CO > 6) OR
(bed_matl = 2)

Description of variables:
BE_sum = sum of bedrock bank substrate spot checks
CL_sum = sum of clay bank substrate spot checks
BC_sum = sum of boulder/cobble bank substrate spot checks
PE_sum = sum of peat bank substrate spot checks
GP_sum = sum of gravel/pebble bank substrate spot checks
EA_sum = sum of earth bank substrate spot checks
BE = sum of bedrock channel substrate spot checks
BO = sum of boulder channel substrate spot checks
CL = sum of clay channel substrate spot checks
GP = sum of gravel /pebble channel substrate spot checks
SA = sum of sand channel substrate spot checks
SI = sum of silt channel substrate spot checks
CO = sum of cobble channel substrate spot checks
bed_matl = compaction of bed material - 1 consolidated
2 unconsolidated

Appendix 3

Summary statistics by River Channel Class

Variable	Class	N	Mean	Median	Tr Mean	StDev	SEMean
AREA (km2)	1	33	72.1	12.3	32.4	191.0	33.3
	2	15	12.1	7.8	11.3	10.0	2.6
	3	24	81.3	7.5	23.0	292.7	59.8
	4	55	116.5	45.8	82.8	193.5	26.1
	5	26	79.2	22.2	38.1	222.7	43.7
	6	13	13.1	4.5	8.0	22.4	6.2
	7	34	127.8	23.0	65.8	297.4	51.0
	8	56	126.8	30.2	71.7	279.2	37.3
	9	44	152.7	34.0	98.9	332.5	50.1
	10	29	60.4	17.8	44.7	113.8	21.1
	11	28	48.3	21.4	37.4	86.1	16.3
	12	10	119.2	48.7	105.2	137.0	43.3
	13	69	52.0	14.6	33.8	105.2	12.7
GRADIENT (m/km)	1	33	27.9	15.4	23.4	30.4	5.3
	2	15	19.2	13.5	18.6	12.4	3.2
	3	24	72.3	15.5	22.0	251.5	51.3
	4	55	9.5	6.7	8.3	8.9	1.2
	5	26	10.9	7.5	9.0	13.7	2.7
	6	13	29.3	13.3	25.1	32.8	9.1
	7	34	9.5	6.0	8.0	10.0	1.7
	8	56	9.5	3.5	6.6	18.1	2.4
	9	44	9.1	4.8	6.8	15.5	2.3
	10	29	7.0	4.6	6.3	7.0	1.3
	11	28	11.1	4.2	9.3	15.6	3.0
	12	10	6.1	2.6	5.0	7.4	2.3
	13	69	3.9	2.8	3.6	3.4	0.4
STREAM ORDER	1	33	1.1	1.0	1.0	0.9	0.2
	2	15	1.0	1.0	1.0	0.5	0.1
	3	24	0.9	1.0	0.9	0.8	0.2
	4	55	1.7	1.0	1.6	1.0	0.1
	5	26	1.2	1.0	1.2	0.9	0.2
	6	13	0.8	1.0	0.7	0.7	0.2
	7	34	1.4	1.0	1.4	1.1	0.2
	8	56	1.5	1.0	1.5	0.9	0.1
	9	44	1.5	1.0	1.5	1.0	0.2
	10	29	1.1	1.0	1.0	0.9	0.2
	11	28	1.1	1.0	1.0	0.9	0.2
	12	10	1.6	1.5	1.6	1.2	0.4
	13	69	1.2	1.0	1.2	1.0	0.1

SPECIFIC POWER (W/m-2)	1	28	24.6	21.1	22.7	19.1	3.6
	2	13	20.1	18.0	18.6	14.1	3.9
	3	20	24.1	14.3	19.8	27.5	6.2
	4	50	17.2	11.7	14.3	17.3	2.4
	5	23	12.4	8.7	10.8	12.7	2.7
	6	8	18.9	13.2	18.9	15.8	5.6
	7	31	11.0	7.8	9.9	8.6	1.5
	8	41	6.0	4.4	5.2	5.8	0.9
	9	40	9.6	5.9	8.4	8.9	1.4
	10	27	6.5	3.6	6.0	6.2	1.2
	11	24	8.4	4.6	6.8	10.6	2.2
	12	9	4.9	3.2	4.9	3.8	1.3
	13	56	3.8	3.3	3.5	2.5	0.3
RIFFLE INDEX	1	33	55.7	44.0	50.5	52.1	9.1
	2	15	86.6	99.0	87.3	27.4	7.1
	3	24	48.4	36.0	46.9	43.2	8.8
	4	54	100.3	91.8	97.4	56.0	7.6
	5	25	94.8	84.0	88.7	69.0	13.8
	6	13	51.5	37.2	48.5	48.8	13.5
	7	34	88.4	76.5	84.4	42.8	7.4
	8	56	37.0	30.1	31.6	39.9	5.3
	9	44	64.4	58.6	60.5	47.5	7.2
	10	29	56.2	41.0	49.4	57.5	10.7
	11	28	60.5	50.3	57.9	46.4	8.8
	12	10	13.5	0.0	3.1	34.2	10.8
	13	69	10.7	0.0	8.0	18.4	2.2
SINUOSITY	1	33	1.2	1.1	1.2	0.2	0.0
	2	15	1.1	1.1	1.1	0.0	0.0
	3	24	1.1	1.1	1.1	0.1	0.0
	4	54	1.2	1.2	1.2	0.2	0.0
	5	25	1.2	1.1	1.2	0.3	0.1
	6	13	1.2	1.1	1.1	0.2	0.1
	7	34	1.2	1.2	1.2	0.1	0.0
	8	56	1.3	1.1	1.2	0.4	0.1
	9	44	1.2	1.1	1.2	0.3	0.0
	10	29	1.2	1.1	1.2	0.4	0.1
	11	28	1.2	1.2	1.2	0.1	0.0
	12	10	1.5	1.2	1.4	0.7	0.2
	13	69	1.2	1.2	1.2	0.2	0.0
POINT BARS (#) (ACTUAL COUNT)	1	33	1.0	0.0	0.7	1.9	0.3
	2	15	1.3	0.0	1.2	1.7	0.4
	3	24	1.0	0.0	0.6	2.5	0.5
	4	54	2.1	2.0	1.9	1.9	0.3
	5	25	2.9	3.0	2.7	3.2	0.6
	6	13	3.0	1.0	2.2	4.5	1.3
	7	34	6.3	5.0	5.4	6.0	1.0
	8	56	2.0	1.0	1.8	2.5	0.3
	9	44	3.0	1.0	2.2	5.4	0.8

	10	29	3.5	2.0	2.7	5.6	1.0
	11	28	4.1	3.0	3.4	5.7	1.1
	12	10	4.0	2.0	1.9	7.6	2.4
	13	69	0.6	0.0	0.4	1.2	0.1
SIDE BARS SPOT CHECKS	1	33	1.3	1.0	1.0	1.7	0.3
	2	15	5.1	5.0	5.0	1.3	0.3
	3	24	1.7	1.0	1.5	1.8	0.4
	4	54	3.2	3.0	3.0	2.4	0.3
	5	25	1.8	1.0	1.6	2.1	0.4
	6	13	1.2	0.0	0.9	1.6	0.4
	7	34	2.4	2.0	2.0	2.8	0.5
	8	56	1.0	0.0	0.7	2.0	0.3
	9	44	1.9	1.0	1.8	2.0	0.3
	10	29	2.1	1.0	1.9	2.4	0.4
	11	28	0.8	0.0	0.7	1.3	0.3
	12	10	2.3	2.5	2.4	1.7	0.5
	13	69	0.2	0.0	0.2	0.6	0.1
MID-CHANNEL BARS SPOT CHECKS	1	33	0.3	0.0	0.1	0.7	0.1
	2	15	0.7	0.0	0.6	0.8	0.2
	3	24	0.3	0.0	0.2	0.5	0.1
	4	54	0.5	0.0	0.4	0.8	0.1
	5	25	0.4	0.0	0.3	0.6	0.1
	6	13	0.5	0.0	0.3	0.9	0.2
	7	34	0.7	1.0	0.7	0.7	0.1
	8	56	0.0	0.0	0.0	0.2	0.0
	9	44	0.3	0.0	0.3	0.6	0.1
	10	29	0.5	0.0	0.4	0.6	0.1
	11	28	0.1	0.0	0.0	0.4	0.1
	12	10	0.4	0.0	0.4	0.5	0.2
	13	69	0.1	0.0	0.1	0.4	0.0
ERODING CLIFFS SPOT CHECKS	1	33	1.0	0.0	0.3	3.5	0.6
	2	15	2.3	2.0	2.0	2.6	0.7
	3	24	1.1	0.0	0.8	2.2	0.5
	4	54	1.7	1.0	1.5	1.9	0.3
	5	25	1.1	1.0	1.0	1.1	0.2
	6	13	0.3	0.0	0.2	0.6	0.2
	7	34	3.4	3.0	3.2	3.1	0.5
	8	56	0.9	0.0	0.6	1.8	0.2
	9	44	1.5	1.0	1.2	2.1	0.3
	10	29	1.0	0.0	0.9	1.6	0.3
	11	28	1.4	0.0	1.2	2.1	0.4
	12	10	2.1	0.5	1.4	3.4	1.1
	13	69	0.6	0.0	0.3	1.4	0.2
SILT SPOT CHECKS	1	33	0.3	0.0	0.0	1.4	0.2
	2	15	0.0	0.0	0.0	0.0	0.0
	3	24	0.0	0.0	0.0	0.0	0.0
	4	54	0.0	0.0	0.0	0.3	0.0

	5	25	0.1	0.0	0.0	0.4	0.1
	6	13	0.3	0.0	0.2	0.8	0.2
	7	34	0.0	0.0	0.0	0.0	0.0
	8	56	0.0	0.0	0.0	0.2	0.0
	9	44	0.3	0.0	0.2	0.7	0.1
	10	29	2.0	2.0	2.0	1.2	0.2
	11	28	0.4	0.0	0.3	0.7	0.1
	12	10	0.1	0.0	0.0	0.3	0.1
	13	69	6.4	7.0	6.5	3.1	0.4
CLAY SPOT CHECKS	1	33	0.0	0.0	0.0	0.0	0.0
	2	15	0.0	0.0	0.0	0.0	0.0
	3	24	0.0	0.0	0.0	0.0	0.0
	4	54	0.0	0.0	0.0	0.0	0.0
	5	25	0.1	0.0	0.0	0.4	0.1
	6	13	0.0	0.0	0.0	0.0	0.0
	7	34	0.0	0.0	0.0	0.0	0.0
	8	56	0.4	0.0	0.2	1.1	0.1
	9	44	0.0	0.0	0.0	0.2	0.0
	10	29	0.1	0.0	0.1	0.4	0.1
	11	28	0.1	0.0	0.0	0.3	0.0
	12	10	0.0	0.0	0.0	0.0	0.0
	13	69	0.8	0.0	0.5	1.9	0.2
SAND SPOT CHECKS	1	33	0.0	0.0	0.0	0.0	0.0
	2	15	0.5	0.0	0.0	2.1	0.5
	3	24	0.0	0.0	0.0	0.2	0.0
	4	54	0.1	0.0	0.0	0.2	0.0
	5	25	0.2	0.0	0.0	0.6	0.1
	6	13	0.0	0.0	0.0	0.0	0.0
	7	34	0.0	0.0	0.0	0.0	0.0
	8	56	0.0	0.0	0.0	0.0	0.0
	9	44	0.0	0.0	0.0	0.2	0.0
	10	29	0.1	0.0	0.0	0.4	0.1
	11	28	2.7	2.0	2.6	1.7	0.3
	12	10	7.1	8.0	7.3	2.3	0.7
	13	69	0.2	0.0	0.1	0.7	0.1
GRAVEL/PEBBLE SPOT CHECKS	1	33	0.1	0.0	0.0	0.4	0.1
	2	15	0.3	0.0	0.2	0.8	0.2
	3	24	2.2	2.0	2.1	1.9	0.4
	4	54	1.7	1.0	1.5	1.7	0.2
	5	25	3.3	3.0	3.3	2.4	0.5
	6	13	4.8	5.0	4.9	2.1	0.6
	7	34	8.7	10.0	9.1	2.2	0.4
	8	56	8.7	10.0	9.0	2.4	0.3
	9	44	7.2	7.5	7.2	1.6	0.2
	10	29	7.3	8.0	7.4	1.5	0.3
	11	28	6.2	6.0	6.2	2.0	0.4
	12	10	1.7	1.5	1.3	2.2	0.7
	13	69	2.0	2.0	1.8	2.3	0.3

COBBLES SPOT CHECKS	1	33	2.6	2.0	2.4	2.4	0.4
	2	15	4.1	4.0	4.1	2.1	0.5
	3	24	1.0	1.0	0.9	0.9	0.2
	4	54	7.3	7.0	7.4	1.9	0.3
	5	25	4.4	4.0	4.4	2.1	0.4
	6	13	2.9	2.0	2.7	2.5	0.7
	7	34	0.0	0.0	0.0	0.0	0.0
	8	56	0.0	0.0	0.0	0.0	0.0
	9	44	2.0	2.0	2.0	1.2	0.2
	10	29	0.0	0.0	0.0	0.0	0.0
	11	28	0.4	0.0	0.3	0.6	0.1
	12	10	0.1	0.0	0.0	0.3	0.1
	13	69	0.1	0.0	0.0	0.3	0.0
BOULDERS SPOT CHECKS	1	33	4.9	4.0	4.9	2.7	0.5
	2	15	3.1	3.0	3.0	2.0	0.5
	3	24	1.6	1.0	1.5	1.9	0.4
	4	54	0.6	0.0	0.5	1.1	0.1
	5	25	0.2	0.0	0.1	0.4	0.1
	6	13	1.5	1.0	1.5	1.2	0.3
	7	34	0.0	0.0	0.0	0.0	0.0
	8	56	0.0	0.0	0.0	0.0	0.0
	9	44	0.0	0.0	0.0	0.2	0.0
	10	29	0.0	0.0	0.0	0.2	0.0
	11	28	0.0	0.0	0.0	0.0	0.0
	12	10	0.0	0.0	0.0	0.0	0.0
	13	69	0.0	0.0	0.0	0.0	0.0
BEDROCK SPOT CHECKS	1	33	2.0	1.0	1.8	2.0	0.4
	2	15	1.9	2.0	1.9	1.5	0.4
	3	24	5.0	5.5	5.0	2.9	0.6
	4	54	0.1	0.0	0.0	0.3	0.0
	5	25	1.7	1.0	1.7	1.5	0.3
	6	13	0.2	0.0	0.1	0.4	0.1
	7	34	0.1	0.0	0.0	0.4	0.1
	8	56	0.0	0.0	0.0	0.0	0.0
	9	44	0.0	0.0	0.0	0.2	0.0
	10	29	0.1	0.0	0.0	0.6	0.1
	11	28	0.0	0.0	0.0	0.0	0.0
	12	10	0.0	0.0	0.0	0.0	0.0
	13	69	0.0	0.0	0.0	0.0	0.0
BANKFULL WIDTH (m)	1	33	10.9	6.6	8.8	11.9	2.1
	2	15	7.9	9.0	7.9	3.2	0.8
	3	24	8.5	6.3	7.4	8.1	1.7
	4	54	16.4	12.9	15.3	11.3	1.5
	5	25	10.2	8.0	9.8	7.2	1.4
	6	13	3.7	3.1	3.7	2.4	0.7
	7	34	11.8	7.0	9.5	13.0	2.2
	8	56	8.7	6.4	7.6	8.1	1.1

	9	44	12.4	8.3	11.0	11.9	1.8
	10	29	9.2	5.0	8.8	8.6	1.6
	11	28	7.1	6.4	6.8	5.0	0.9
	12	10	8.9	8.3	8.3	4.7	1.5
	13	69	7.0	6.0	6.4	5.6	0.7
ALTITUDE (m)	1	33	204.5	210.0	199.7	112.7	19.6
	2	15	279.3	245.0	274.2	122.3	31.6
	3	24	223.2	210.0	221.1	118.3	24.1
	4	54	144.3	142.5	138.7	89.4	12.2
	5	25	136.0	115.0	132.2	85.0	17.0
	6	13	184.2	160.0	184.1	102.2	28.3
	7	34	108.5	90.0	102.7	77.8	13.3
	8	56	71.9	60.0	65.4	58.0	7.8
	9	44	97.5	77.5	89.9	75.3	11.4
	10	29	60.2	50.0	59.5	32.0	5.9
	11	28	69.8	70.0	67.9	49.9	9.4
	12	10	40.9	32.5	40.3	31.5	10.0
	13	69	61.3	60.0	59.3	36.1	4.4

Summary statistics for all sites used in TWINSPAN classification

Variable	N	Mean	Median	TrMean	StDev	SEMean
RIFFLE INDEX	434	57.3	46.4	52.2	53.9	2.6
SINUOSITY	434	1.2	1.1	1.2	0.3	0.0
POINT BAR (#)	434	2.4	1.0	1.8	4.1	0.2
SIDE BARS	434	1.7	1.0	1.4	2.2	0.1
MID-CHANNEL BARS	434	0.3	0.0	0.2	0.6	0.0
ERODING CLIFFS	434	1.3	0.0	1.0	2.2	0.1
SILT	434	1.3	0.0	0.9	2.7	0.1
CLAY	434	0.2	0.0	0.0	0.9	0.0
SAND	434	0.4	0.0	0.1	1.4	0.1
GRAVEL/PEBBLE	434	4.5	4.0	4.4	3.7	0.2
COBBLES	434	1.9	0.0	1.6	2.8	0.1
BOULDERS	434	0.7	0.0	0.4	1.7	0.1
BEDROCK	434	0.6	0.0	0.3	1.6	0.1
BANKFULL WIDTH	434	10.0	7.1	8.8	9.5	0.5
ALTITUDE	434	115.7	85.0	106.6	96.9	4.7
SPECIFIC POWER	370	11.7	7.1	9.7	14.2	0.7
AREA	436	89.9	20.3	49.8	217.4	10.4
GRADIENT	436	14.3	5.8	8.9	61.7	3.0
STREAM ORDER	436	1.3	1.0	1.3	1.0	0.0

Appendix 4

Discharge calculated by the Wharton (1992) method

Site no	Q1.5
1	0.000
7	3.910
11	4.877
12	5.839
14	26.849
15	2.203
17	0.000
18	93.294
20	9.940
22	7.009
23	0.000
24	34.325
25	0.000
26	2.359
29	1.240
31	100.903
32	2.331
34	0.000
35	38.326
37	3.825
39	22.486
42	4.039
43	0.000
44	5.268
48	62.916
59	109.985
61	22.106
63	27.823
64	38.191
65	12.591
66	6.775
68	3.830
72	7.266
73	20.011
74	32.278
75	33.434
77	0.000
79	0.000
80	21.615
83	3.306
85	41.770
87	0.000
88	1.891
89	0.000
90	2.169
92	5.103
94	143.785
99	15.952
101	24.320
102	6.807
103	15.420
104	0.000
105	12.537
106	0.000
109	0.000
110	7.982
115	26.769
116	34.325
119	12.984
120	7.766
122	69.742
123	14.478
124	5.368
125	247.981
126	0.000
129	0.000
132	4.410
133	3.195
136	8.298
137	96.927
140	15.952
141	0.000
142	11.550
143	3.979
144	6.641
145	2.625
146	0.000
150	1.217
151	5.851
152	41.770
154	0.000
155	2.522
159	11.405
160	5.053
161	2.446
169	4.343
172	4.343
178	4.509
179	0.000
180	5.368
187	3.116
188	2.632
189	38.715
190	4.509
198	4.728
199	62.601
200	1.267
201	0.000
213	0.000
214	12.728
215	3.825
216	2.018
218	37.782
239	0.000
240	171.370
244	4.501
250	10.273
251	127.222
253	2.153
270	308.593
271	9.715
273	0.673
283	1.930
289	29.243
295	0.000
316	2.113
319	17.558
327	2.239
329	0.000
344	11.405

355	540.754
356	3.413
370	16.282
378	13.172
381	34.740
382	4.377
385	3.685
392	8.137
395	1.300
398	11.516
400	8.948
401	47.250
402	3.576
408	5.616
410	1.172
415	5.153
417	158.473
418	3.591
424	0.734
428	42.683
432	10.829
433	9.586
434	7.115
443	1.662
445	244.318
446	0.000
450	27.337
463	45.406
466	9.306
471	2.434
472	1.172
473	2.113
474	9.742
478	0.000
480	1.777
491	0.000
495	28.829
498	195.727
499	170.251
500	87.311
501	18.529
504	0.000
506	1.348
511	19.655
526	7.766
527	13.399

529	3.195
531	22.186
532	16.711
534	6.074
541	0.000
549	8.329
561	2.434
564	3.615
566	146.738
567	100.471
570	21.101
573	5.773
574	63.111
579	3.516
581	1.579
582	4.577
602	15.149
603	15.892
604	68.660
605	163.027
613	33.345
614	0.000
615	2.434
619	2.719
640	45.009
641	0.000
642	3.811
645	0.000
647	1.105
650	1.842
652	1.172
659	5.788
680	10.980
681	57.337
682	0.000
683	0.000
684	13.629
685	0.000
689	1.722
695	34.320
699	13.012
717	7.183
718	4.479
719	1.984
721	341.430
722	10.936

723	20.816
724	2.610
726	6.135
729	37.783
730	0.000
733	47.865
735	10.341
736	15.927
739	12.038
740	4.818
756	81.523
757	0.000
758	2.683
759	43.817
761	0.000
762	19.894
763	7.516
766	0.000
767	11.516
770	15.366
771	5.851
774	31.561
775	7.402
777	2.164
778	36.688
779	45.146
796	4.661
797	8.789
798	18.965
800	11.550
802	4.030
804	27.224
805	132.938
806	490.058
808	5.910
811	34.320
812	1.707
814	0.719
835	1.448
836	40.136
837	28.639
839	2.797
840	9.222
841	5.068
844	5.554
845	0.000

847	1.842
849	134.060
851	18.817
852	2.873
854	0.000
855	2.874
866	43.704
867	8.574
869	5.832
870	9.199
872	25.276
877	1.902
878	141.868
881	155.016
883	8.184
884	1.505
885	119.235
887	5.103
891	1.778
892	6.290
897	3.107
902	6.642
903	18.292
915	4.091
916	14.501
918	1.175
919	0.000
921	4.509
922	11.302
925	6.034
926	17.610
927	88.818
929	0.000
930	19.071
932	18.399
933	4.818
938	21.615
941	0.000
942	18.529
944	0.000
945	0.921
947	9.019
948	50.901
951	5.832
960	0.000
962	2.153
963	0.000
968	3.413
969	11.680
970	29.218
971	90.051
972	132.222
973	200.239
974	17.758
975	12.650
976	1.937
977	13.049
978	1.648
979	11.840
980	76.726
981	147.311
984	4.835
987	1.780
993	0.000
1002	1.001
1003	12.694
1005	0.000
1007	2.875
1012	0.000
1014	46.281
1015	20.409
1016	29.219
1017	129.711
1018	48.304
1020	17.695
1023	410.813
1040	0.000
1046	3.768
1047	15.164
1049	0.000
1051	1.835
1057	29.782
1058	27.829
1066	0.000
1076	39.465
1079	33.558
1084	6.292
1086	120.919
1087	7.091
1088	15.745
1102	416.724
1103	1.648
1120	0.000
1121	4.146
1127	1.078
1130	4.964
1133	60.637
1140	36.218
1141	10.446
1146	0.000
1152	20.499
1161	37.704
1166	0.000
1168	131.406
1175	1.662
1190	9.245
1198	3.077
1202	1.065
1220	1.734
1221	3.195
1222	17.677
1234	0.921
1245	37.782
1246	24.057
1250	4.667
1251	2.387
1257	6.672
1269	6.108
1271	0.000
1272	0.000
1275	1.890
1280	0.000
1289	2.067
1293	1.563
1294	1.101
1298	10.980
1302	29.782
1303	21.490
1312	2.823
1314	1.707
1315	1.842
1316	6.239
1317	1.948
1318	5.986
1320	0.000
1326	4.455
1327	13.529
1331	9.215

1337	4.964
1340	6.061
1341	11.336
1349	6.686
1350	12.591
1351	0.000
1353	3.527
1356	6.074
1357	5.244
1362	1.399
1363	18.416
1364	0.000
1366	7.516
1367	14.985
1369	212.349
1371	3.839
1375	0.000
1376	10.611
1377	41.501
1378	16.234
1382	0.000
1389	33.386
1391	1.202
1395	1.050
1397	0.000
1400	1.478
1401	57.523
1402	92.520
1403	0.000
1404	13.840
1405	9.376
1406	88.892
1409	10.463
1410	27.120
1416	9.245
1419	3.397
1420	8.948
1421	0.000
1434	1.496
1435	4.737
1436	2.197
1437	3.630
1438	0.000
1439	16.456
1440	0.903
1442	220.945
1444	2.313
1445	17.558
1446	13.578
1448	8.583
1449	43.884
1451	11.569
1452	5.851
1455	1.172
1462	0.000
1465	3.753
1468	4.599
1469	60.222
1473	0.000
1477	0.000
1478	4.059
1479	4.113
1480	20.588
1483	10.194
1484	39.500
1485	2.371
1486	107.364
1488	6.849
1489	0.000
1490	3.029
1493	19.055
1494	1.943
1495	0.000
1497	97.709
1500	0.000
1501	4.022
1502	7.803
1505	4.214
1509	56.434
1513	0.000
1514	0.000
1521	0.000

Appendix 5

Calculation of Stability Index

Site no	River	Gradient (m m -1)	Discharge (m3 s -1)	Unit stream power (W m -2)	Dominant substrate	Stability index
1	Dean Burn	0.0130	x	x	I	0
7	Cavey Burn	0.0216	3.910	142.84		0
11	Coquet	0.0070	4.877	55.44	C	0
12	Breamish	0.0296	5.839	256.90		5
14	Aln	0.0250	26.849	494.59	G	2
15	Unknown	0.0061	2.203	35.60	G	2
17	Southhope Burn	0.0660	x	x	C	0
18	Coquet	0.0039	93.294	142.26	C	14
20	Swarland Burn	0.0075	9.940	102.63	C	2
22	Ridge End Burn	0.0000	x	x	C	2
23	Tarset Burn	0.0146	1.055	51.87	C	2
24	Rede	0.0041	34.325	92.62	C	14
25	Grasslees Burn	0.0149	x	x		0
26	Forest Burn	0.0333	2.359	174.98		5
29	Routledge Burn	0.1000	1.240	434.11	G	0
31	North Tyne	0.0022	100.903	72.85	C	2
32	Hareshaw Burn	0.0213	2.331	118.59		5
34	Middleton Burn	0.0111	1.012	39.36	G	6
35	Wansbeck	0.0037	38.326	97.92	C	6
37	Raeburn	0.0156	3.825	106.53	G	7
39	Butter Burn	0.0055	22.486	96.78	C	7
42	Barrasford Burn	0.0111	4.039	74.53	C	0
43	Blackheddon Burn	0.0676	x	x	G	0
44	Coldcoates Burn	0.0156	5.268	139.12	B	6
48	Irthing	0.0014	62.916	44.90	C	7
59	Eden	0.0010	109.985	48.74	G	0
61	Gelt Beck	0.0135	22.106	243.90		5
63	Westallen	0.0154	27.823	310.64	C	5
64	East Allen	0.0066	38.191	159.91	C	5
66	Stocksfield Burn	0.0065	6.775	57.10	P	5
68	Team	0.0056	3.830	43.13	G	14
72	Chalk Beck	0.0030	7.266	31.00	G	14
73	Petteril	0.0111	20.011	189.46	P	7
74	Croglin Water	0.0133	32.278	248.04	C	7
75	Black Burn	0.0320	33.434	655.31	C	5
77	East Allen	0.0143	x	x		5
79	T. of Derwent	0.0046	x	x	G	0
80	Browney	0.0087	21.615	167.54	C	14
83	Hawthorn Burn	0.0029	3.306	18.53	G	2
85	Derwent	0.0400	41.770	909.67	C	2
87	Carrock Beck	0.0066	x	x		0
88	Lamb Beck	0.0017	1.891	8.95	G	0
89	Eden	0.0533	x	x		0
90	Ardale Beck	0.0133	2.169	70.83		15
92	Langdon Beck	0.0034	5.103	28.25	C	2
94	Wear	0.0000	x	x	C	14
99	Marrron	0.0056	15.952	87.85	C	0
101	Derwent	0.0926	24.320	1765.58	G	7
102	Mosedale Beck	0.0417	6.807	427.66	C	11
103	Dacre Beck	0.0084	15.420	110.64		9

104	Leith	0.0027	x	x	C	7
105	Trout Beck	0.0533	12.537	770.85	G	0
106	T. of Eden	0.0133	x	x	C	0
109	Hindon Beck	0.0046	x	x	G	2
110	Gaunless	0.0052	7.982	57.66	P	14
115	Ehen	0.0357	x	x	C	2
116	Liza	0.0000	x	x	C	5
119	Howes Beck	0.0385	12.984	466.19	C	7
120	Lowther	0.0066	7.766	62.41	C	15
122	Eden	0.0129	69.742	489.82	G	14
123	Belah	0.0041	14.478	60.49		10
124	Deepdale Beck	0.0046	5.368	39.89		2
125	Tees	0.0041	x	x		10
126	Tees	0.0000	x	x		0
129	Bassleton Beck	0.0000	x	x	G	14
132	Roxby Beck	1.2500	4.410	9004.73	G	7
133	Sandsend Beck	0.0000	x	x	P	2
136	T of Gt Langdale	0.0067	8.298	67.80		11
137	Brathay	0.0000	x	x	I	0
140	Lune	0.0140	15.952	219.48	C	14
141	T. of Scandal	0.0320	x	x	C	0
142	Whitsundale Be	0.0105	11.550	132.44		16
143	Great Punchard	0.0118	3.979	91.72		4
144	Moresdale Gill	0.0026	6.641	24.18	C	2
145	Smelt Mill Beck	0.0588	2.625	302.62	G	14
146	Howl Beck	0.0140	x	x	I	0
150	Stockdale Beck	0.0025	1.217	10.05		4
151	Glaisdale Beck	0.1250	5.851	1194.66		16
152	Esk	0.1134	41.770	2578.91	C	2
154	Annas	0.0222	x	x	C	14
155	T. of Lickle	0.0139	2.522	76.28		11
159	Chapel Beck	0.0250	11.405	279.43	C	11
160	Rawthey	0.0500	5.053	380.89		0
161	Fossdale Gill	0.0036	2.446	21.63		0
169	Ouse Gill	0.0250	4.343	177.35		13
172	Lownorth Beck	0.0000	x	x	G	0
178	Barbon Beck	0.0100	4.509	73.64	C	11
179	Dee	0.0222	x	x		5
180	Duerley Beck	0.0051	5.368	44.98	C	2
187	Sledhill Gill	0.0016	3.116	10.99		2
188	Riccal	0.0089	2.632	57.59	P	0
189	Seven	0.0250	38.715	677.52	C	7
190	Dalby Beck	0.0021	4.509	15.69	G	2
198	Fox Up Beck	0.0296	4.728	228.81		3
199	Wharfe	0.0400	62.601	1443.50	G	2
200	Armathwaite Gill	0.0000	x	x		0
201	T. of Agill Beck	0.0139	x	x		13
213	Lune	0.0028	x	x		0
214	Hindburn	0.0222	12.728	326.06		3
215	Kettles Beck	0.0109	3.825	74.09		3
216	Cowside Beck	0.0000	x	x		4
218	Dibb	0.0018	37.782	43.20	C	8
239	Nidd	0.0067	x	x		0
240	Nidd	0.0100	x	x	G	0
244	Millington Bec	0.0015	4.501	10.48	I	0
250	Brock	0.0200	10.273	251.69	C	0
251	Hodder	0.0014	127.222	57.77	C	7
253	T. of Barley W	0.0119	2.153	71.75	C	14

270	Ribble	0.0333	x	x	C	6
271	Sabden Brook	0.0087	9.715	103.54		0
273	Widdop Beck	0.0033	0.673	10.92		0
283	Mires Beck/Mil	0.0058	1.930	25.90	G	0
289	Darwen	0.0455	29.243	986.76	C	0
295	Lady Ann Beck	0.0017	x	x	P	6
316	Bentley Brook	0.0073	2.113	43.01	B	2
319	Went	0.0313	17.558	537.71	G	7
327	Tawd	0.0167	2.239	91.44	I	14
329	Marsh Brook	0.0000	x	x	G	2
344	North Kelsey Brook	0.0111	11.405	124.18	G	7
349	Sankey Brook	x	x	x	I	0
355	Alport	0.0022	x	x	C	6
356	Hobson Moss Di	0.0061	3.413	40.54		4
359	Paper Mill Dik					7
362	Laughton Drain					0
370	Alaw	0.0080	16.282	141.84	G	0
378	Dean	0.0000	x	x	I	14
381	Noe	0.0030	34.740	81.71	P	7
382	Rivelin	0.0036	4.377	26.40		0
385	Anston Brook	0.0050	3.685	32.83	G	14
392	Bain	0.0833	8.137	810.36	G	6
395	Unknown	0.0267	1.300	113.25	G	14
398	Gyrach	0.0027	11.516	38.09		11
400	Dulas	0.0066	8.948	82.18	P	14
401	Clwyd	0.0040	47.250	114.61	B	2
402	T of Wheeler/C	0.0000	x	x	G	6
408	Peover Eye	0.0045	5.616	41.28	I	14
410	Dean	0.0037	1.172	14.16	C	7
415	Doe Lea	0.0048	5.153	41.44	G	6
417	Poulter	0.0000	x	x	G	0
418	T. of Tuxford	0.0041	3.591	36.07	G	14
424	Seiont	0.0074	0.734	26.64		
428		0.0191	42.683	498.04	G	6
432	Aled	0.0364	10.829	482.34	P	14
433	Ystrad	0.0111	9.586	139.15	G	14
434	Alyn	0.0008	7.115	7.25	C	14
443	T. of Manifold	0.0364	1.662	148.04	C	5
445	Derwent	0.0038	x	x	G	0
446	Smithy Brook	0.0183	x	x		8
450	The Beck	0.0026	27.337	70.46	G	2
463	Conwy	0.0183	45.406	541.39		4
466	Clwyd	0.0110	9.306	118.13	G	2
471	Rookery Brook	0.0000	x	x	S	7
472	Valley Brook	0.0058	1.172	22.32	S	2
473	Wheelock	0.0000	x	x	B	14
474	Horrton Brook	0.0052	9.742	65.69	B	6
478	Derwent	0.0042	x	x		0
480	Rainworth Wate	0.0103	1.777	49.88	I	0
482	Greet	x	x	x	I	7
491	Wen	0.0042	x	x	P	0
495	Conwy	0.0013	28.829	28.69	P	16
498	Dee	0.0012	195.727	63.76	P	14
499	Dee	0.0035	170.251	167.80	C	14
500	Dee	0.0400	87.311	1140.87	G	0
501	Worthenbury Br	0.1000	18.529	1815.82	S	7
504	Checkley Brook	0.0049	x	x	G	14
506	Causeley Brook	0.0022	1.348	9.17	C	2

511	Erewash	0.0267	19.655	513.71		8
514	Car Dike				I	0
526	Erch	0.0333	7.766	317.08	G	14
527	Prysor	0.0125	13.399	164.14		3
529	Llafar	0.0118	3.195	73.88	P	3
531	Ceidiog	0.0039	22.186	76.10	C	11
532	Ceiriog	0.0080	16.711	109.18	C	2
534	Perry	0.0024	6.074	23.61	I	0
541	Hockley Brook	0.0091	x	x	G	0
549	Devon	0.0000	x	x	I	0
561	Cwmnantcol	0.0036	2.434	21.71	P	0
564	Eiddew	0.0029	3.615	20.27		16
566	Tannat	0.0020	146.738	85.85	C	2
567	Tannat	0.0015	100.471	58.76	P	7
570	Rodden	0.0005	21.101	10.55		0
573	Sow	0.0074	5.773	64.50	G	6
574	Sow	0.0089	63.111	290.69	S	6
579	West Meadow Brook	0.0032	3.516	27.40	I	0
581	Dalby Brook	0.0042	1.579	21.51	I	14
582	T. of Eye	0.0105	4.577	104.96	I	10
602	Cerist	0.0167	15.149	224.98	P	6
603	Twrch	0.0011	15.892	16.69		10
604	Vyrnwy	0.0013	68.660	50.09		4
605	Vyrnwy	0.0013	x	x		16
613	Penk	0.0000	x	x	G	6
614	Trent	0.0178	x	x	G	0
615	Pyford Brook	0.0100	2.434	59.63	G	0
617	T. of Mease	x	x	x	I	0
619	Unknown	0.0033	2.719	21.85	G	7
640	Dulas (North)	0.0034	45.009	87.96		11
641	Dovey	0.0005	x	x	C	6
642	Gam	0.0076	3.811	53.69	C	6
645	Severn	0.0204	x	x		16
647	T. of Cound Br	0.0147	1.105	56.90	G	2
650	Wesley Brook	0.0000	x	x	S	2
652	T. of Penk	0.0154	1.172	58.87	G	2
659	Willow Brook	0.0000	x	x	B	0
680	Twymyn	0.0000	x	x	G	2
681	Garno	0.0013	57.337	39.33	C	2
682	Severn	0.0086	x	x	G	2
683	Severn	0.0047	x	x		0
684	Camlad	0.0012	13.629	19.33	G	2
685	West Onny	0.0007	x	x	G	6
689	Worfe	0.0014	1.722	9.65	I	0
695	Anker	0.0100	x	x	I	7
699	Welland	0.0200	13.012	296.55	G	0
717	Clarach	0.0123	7.183	123.79	G	2
718	Rheidol	0.0028	4.479	17.31		8
719	Bidno	0.0000	x	x	P	2
721	Severn	0.0053	341.430	325.93	G	2
722	The Mole	0.0013	10.936	17.28	C	2
723	Clun	0.0023	20.816	38.59	P	2
724	Kemp	0.0013	2.610	8.25	G	0
726	Corve	0.0160	6.135	174.90	G	9
729	Stour	0.0009	37.783	27.46	I	0
730	Stour	0.0017	x	x	I	0
733	Blythe	0.0027	47.865	75.60	G	0
735	Smite Brook	0.0032	10.341	46.90	G	0

736	Swift	0.0023	15.927	39.89		7
739	Ise	0.0033	12.038	44.07		8
740	Harpers Brook	0.0077	4.818	60.51	G	2
756	Ystwyth	0.0084	81.523	269.08	P	7
757	Mynach Myherin	0.0039	0.941	11.86		8
758	Elan	0.0213	2.683	111.92	G	2
759	Wye	0.0046	43.817	109.02		14
761	Aran	0.0047	x	x	G	6
762	Teme	0.0106	19.894	172.87	C	2
763	Redlake	0.0048	7.516	50.09	G	2
766	T. of Mill Bro	0.0035	0.351	7.91	G	0
767	Dowles Brook	0.0050	11.516	70.54		2
770	Arrow	0.0008	15.366	12.20	G	7
771	T. of Blythe	0.0035	5.851	32.97	I	0
774	Avon	0.0067	31.561	165.04	I	0
775	Clifton Brook	0.0017	7.402	20.67	I	0
777	T. of Brampton	0.0098	2.164	50.68	G	0
778	Ise	0.0118	36.688	315.54		0
779	Nene	0.0076	45.146	234.52		0
796	Camddwr	0.0115	4.661	95.50	C	6
797	Glasffrwd	0.0056	8.789	59.86	C	2
798	Claerwen	0.0035	18.965	54.80	C	2
800	Dulas	0.0018	11.550	23.02	G	2
802	Cascob Brook	0.0007	4.030	4.59	G	2
804	Lugg	0.0046	27.224	80.93	G	0
805	Teme	0.0029	132.938	134.47	P	6
806	Teme	0.0111	x	x		0
808	Hadley Brook	0.0075	5.910	78.55	I	0
811	Alne	0.0000	x	x	G	7
812	T. of Avon	0.0156	1.707	87.18	G	0
814	Stockton Brook	0.0021	0.719	7.33	I	0
835	Unknown	0.0087	1.448	41.16	P	5
836	Mydyr	0.0095	40.136	234.03	P	0
837	Aeron	0.0182	28.639	425.21	G	6
839	Camddwr	0.0038	2.797	23.09	P	2
840	Irfon	0.0096	9.222	111.46		6
841	Garth Dulas	0.0089	5.068	63.08	G	2
844	Gladestry Broo	0.0009	5.554	7.15	G	2
845	Curl Brook	0.0028	0.826	9.27	G	0
847	Holly Brook	0.0069	1.842	35.80	B	14
849	Teme	0.0009	x	x		7
851	Piddle Brook	0.0040	18.817	81.14	I	7
852	Ban Brook	0.0000	x	x	G	14
854	Dene	0.0018	x	x		14
855	Dene	0.0043	2.874	34.44		0
866	Cam	0.0029	43.704	87.49		0
867	Babraham	0.0010	8.574	11.79	G	0
869	Glem	0.0133	5.832	138.52	G	2
870	Glem	0.0005	9.199	6.31	S	6
872	Gipping	0.0006	25.276	14.37	I	0
877	Unknown	0.0095	1.902	46.69	P	2
878	Teifi	0.0250	x	x	G	6
881	Teifi	0.0014	155.016	70.39	G	2
883	Gwenffrwd	0.0056	8.184	59.35	G	14
884	Cledan	0.0014	1.505	5.69	G	2
885	Irfon	0.0022	119.235	103.76	G	14
887	Bach Howey Bro	0.0096	5.103	80.17	G	2
891	Little Lugg	0.0022	1.778	12.66	G	14

892	Frome	0.0014	6.290	13.70		14
897	Gran Brook	0.0027	3.107	20.33		0
902	Tove	0.0014	6.642	15.92		0
903	Tove	0.0023	18.292	40.69	I	0
915	Box	0.0029	4.091	25.08	I	0
916	Brett	0.0111	14.501	192.54	I	0
918	Mill	0.0083	1.175	34.27	I	14
919	Shottisham	0.0063	0.769	19.62	I	0
921	Gwaun	0.0106	4.509	78.36	P	5
922	Nyfer	0.0029	11.302	37.66	G	2
925	Tyweli	0.0042	6.034	35.56	G	2
926	Clydach	0.0061	17.610	116.20		5
927	Cothi	0.0079	88.818	318.61	G	2
929	Gwydderig	0.0455	x	x	P	2
930	Nant Bran	0.0123	19.071	232.39	C	2
932	Llynfi	0.0035	18.399	56.55	C	2
933	Honddu	0.0063	4.818	49.18		2
938	Glynch Brook	0.0096	21.615	185.25	G	14
941	Isbourne	0.0058	x	x		0
942	Knee Brook	0.0036	18.529	65.37	G	0
944	Swere	0.0013	x	x	I	14
945	Bloxham Brook	0.0027	0.921	9.75	B	0
947	Great Ouse	0.0000	x	x	G	0
948	Great Ouse	0.0016	50.901	54.54	I	0
951	Flit	0.0000	5.832	0.00	G	0
960	Stour	0.0000	x	x		0
962	T. of Stour	0.0028	2.153	16.58	I	6
963	Ramsey Brook	0.0032	x	x		0
968	T. of Taff	0.0039	3.413	26.36	P	5
969	Cynin	0.0077	11.680	110.17	P	6
970	Duad	0.0007	29.218	16.23	C	2
971	Gwili	0.0118	90.051	471.73	C	2
972	Cothi	0.0100	132.222	539.90	P	2
973	Tywi	0.0200	200.239	1121.34	G	6
974	Sawdde	0.0013	17.758	19.25		5
975	Hydfer	0.0038	12.650	48.18	C	2
976	T. of Senni	0.0133	1.937	63.27	C	2
977	Nant Cynrig	0.0048	13.049	64.34		11
978	Llynfi	0.0016	1.648	8.03	I	14
979	Grwyne Fawr	0.0024	11.840	28.08	C	14
980	Monnow	0.0094	76.726	351.52	C	2
981	Monnow	0.0068	x	x	P	0
984	Ell Brook	0.0036	4.835	37.91	G	0
987	T. of Windrush	0.0018	x	x	P	0
993	Langford Brook	0.0000	x	x		0
1002	Pincey Brook	0.0023	1.001	8.99		0
1003	Chelmer	0.0135	12.694	202.48	G	0
1005	Blackwater	0.0031	80.513	287.17		0
1007	T. of Colne	0.0016	2.875	11.20	I	0
1012	Cwm Waungron	0.0065	1.099	24.11	P	2
1014	Cywyn	0.0213	46.281	577.40	G	2
1015	Gwendraeth Fac	0.0111	20.409	202.01	G	2
1016	Gwendraeth Faw	0.0320	29.219	688.96	C	2
1017	Amman	0.0023	129.711	105.78	C	5
1018	Twrch	0.0029	48.304	84.62		13
1020	Llia	0.0023	17.695	38.59		0
1023	Usk	0.0012	x	x	P	2
1040	Thame	0.0013	0.384	3.15	I	0

1046	Pincey Brook	0.0110	3.768	90.36	G	0
1047	Chelmer	0.0021	15.164	32.57	G	0
1049	Blackwater	0.0172	x	x		0
1051	Unknown	0.0013	1.835	6.64	I	0
1057	Gwendraeth Faw	0.0046	29.782	110.66	B	14
1058	Morlais	0.0006	27.829	11.69	C	2
1066	Usk	0.0022	x	x	C	0
1076	Windrush	0.0000	x	x	G	0
1079	Thame	0.0053	33.558	137.29	I	0
1084	Ver	0.0020	6.292	16.89	G	0
1086	Small Lee	0.0014	120.919	61.99	G	2
1087	Gypsey Brook	0.0083	7.091	96.48	G	14
1088	Cripsey Brook	0.0250	15.745	428.63	I	0
1102	Usk	0.0026	416.724	258.98		2
1103	Mounton Brook	0.0073	1.648	35.59	G	2
1120	T. of Colne	0.0000	x	x	G	0
1121	Brent	0.0021	4.146	16.82	G	2
1127	Rayleigh Brook	0.0014	1.078	5.32	G	2
1130	Ogwr Fach	0.0029	4.964	25.74	G	2
1133	Rhymney	0.0034	60.637	118.85	G	14
1140	Bristol Avon	0.0018	36.218	47.78	G	8
1141	Brinkworth Bro	0.0013	10.446	18.57		0
1146	T. of Mill Bro	0.0167	x	x	I	0
1152	Brent	0.0007	20.499	14.96	G	14
1161	Ely	0.0018	37.704	50.31	B	2
1166	St Catherines	0.0015	x	x	G	7
1168	Bristol Avon	0.0058	x	x	G	6
1175	Sulnam Brook	0.0106	x	x	I	0
1190	Chew	0.0096	9.245	136.19		0
1198	Enbourne	0.0106	3.077	64.17	G	14
1202	Emm Brook	0.0023	1.065	8.70	I	0
1220	Chew	0.0030	1.734	15.60	G	2
1221	Wellow Brook	0.0018	3.195	13.78	G	2
1222	Wellow Brook	0.0016	17.677	29.49	G	0
1230	Test				G	7
1234	Vokes Trib	0.0175	0.921	63.32	I	0
1245	Great Stour	0.0370	37.782	914.31	G	0
1246	Great Stour	0.0053	24.057	104.72	B	6
1250	Haddon	0.0022	4.667	17.06	G	14
1251	Farley Water	0.0008	2.387	4.03	G	14
1257	Sheppey	0.0020	6.672	20.32	G	14
1269	Wey North	0.0000	x	x	G	0
1271	Wey	0.0154	x	x	I	0
1272	Cranleigh Wate	0.0250	x	x		0
1275	T. of Eden Bro	0.0178	1.890	99.81	I	14
1280	Beult	0.0034	x	x		0
1289	Mole	0.0022	2.067	11.53	G	2
1292	T of Monksilve	x	x	x	G	0
1293	T of Doniford	0.0013	1.563	5.86	G	0
1294	Durleigh Brook	0.0011	1.101	4.57	G	0
1298	Alkham	0.0032	10.980	38.02	G	2
1302	Wylye	0.0075	29.782	181.44	G	0
1303	Avon	0.0020	21.490	41.70	G	0
1312	Cranleigh Wate	0.0032	2.823	17.59	G	7
1314	Mole	0.0025	1.707	13.83	I	7
1315	T of Sunnyside	0.0000	x	x		14
1316	Medway	0.0325	6.239	348.31	G	14
1317	Eridge Stream	0.0036	1.948	21.29	B	2

1318	Bartley Mill S	0.0067	5.986	71.14	G	2
1320	T of Newmill C	0.0045	x	x	B	14
1326	Langham Lake	0.0025	4.455	21.65	G	2
1327	Bray	0.0037	13.529	54.51	G	0
1331	Tone	0.0091	9.215	95.46		14
1337	T. of Cam	0.0012	4.964	10.70	G	0
1340	Nadder	0.0000	x	x	I	6
1341	Ebble	0.0098	11.336	124.62	G	0
1349	Hammer Stream	0.0185	6.686	202.14	S	2
1350	Lod	0.0032	12.591	44.29		10
1351	Kird	0.0926	x	x		0
1353	Cowford Stream	0.0095	3.527	73.27	G	14
1356	Rother	0.0455	6.074	450.94	G	14
1357	Rother	0.0111	5.244	114.19	G	0
1362	Coombevalley S	0.0057	1.399	26.04	G	14
1363	Torridge	0.0030	18.416	57.56	G	2
1364	Mere	0.0084	0.213	17.55	G	0
1366	Mully Brook	0.0012	7.516	12.21	G	2
1367	Little Dart	0.0027	14.985	41.27	G	2
1369	Exe	0.0020	x	x	C	0
1371	Culm	0.0039	3.839	29.65	G	2
1375	Yeo	0.0106	x	x	I	0
1376	Yeo	0.0009	10.611	10.52	G	0
1377	Lydden	0.0021	41.501	65.07	I	6
1378	Fontmell Brook	0.0146	16.234	231.48	S	6
1382	King's Garn Gu	0.0227	x	x	G	2
1389	Rother	0.0061	33.386	165.50	S	6
1391	Honeybridge St	0.0060	1.202	28.03	S	0
1395	Bull River	0.0154	1.050	63.32	I	0
1397	Powdermill Str	0.0027	x	x	G	2
1400	Colesmill Stre	0.0041	1.478	22.00	G	5
1401	Torridge	0.0000	x	x		6
1402	Torridge	0.0053	92.520	238.46	G	2
1403	T. of Taw	0.0035	x	x	G	2
1404	Yeo	0.0083	13.840	141.23	G	2
1405	Creedy	0.0035	9.376	41.17		2
1406	Exe	0.0015	88.892	60.57	G	6
1409	Yarty	0.0000	x	x		0
1410	Axe	0.0320	27.120	708.74	G	6
1416	Tarrant	0.0137	9.245	155.61	G	7
1419	Black Water	0.0263	3.397	194.73	G	2
1420	Beaulieu	0.0500	8.948	626.33		2
1421	Darkwater	0.1250	x	x	I	15
1434	Crackington St	0.0073	1.496	31.35		2
1435	Caudworthy Water	0.0094	4.737	87.37	B	5
1436	Lana Lake	0.0018	2.197	9.69	G	2
1437	Wolf	0.0160	3.630	121.10	G	0
1438	Thrushel	0.0179	0.705	56.11	G	2
1439	Taw	0.0134	16.456	239.57	C	14
1440	Yeo	0.0077	0.903	28.35	G	2
1442	Exe	0.0056	x	x		6
1444	Sid	0.0039	2.313	24.24	G	2
1445	Umbourne Brook	0.0015	17.558	26.33	G	2
1446	Char	0.0001	13.578	2.00	G	0
1448	Hooke	0.0016	8.583	16.13	G	0
1449	Sydling Water	0.0000	x	x	G	0
1451	Bere Stream	0.0124	11.569	144.70	G	0
1452	Sherford	0.0027	5.851	26.19	S	0

1455	Milton	0.0022	1.172	8.57	G	14
1462	Tamar	0.0135	x	x	G	2
1465	South Teign	0.0038	3.753	27.19		0
1468	Kenn	0.0064	4.599	57.69	G	0
1469	Otter	0.0071	60.222	216.09	G	0
1473	Frome	0.0154	x	x		0
1477	Issy Brook	0.0118	x	x	G	2
1478	Allen	0.0471	4.059	312.02	G	2
1479	Warleggan	0.0028	4.113	20.75	G	9
1480	Lynher	0.0061	20.588	109.89	G	6
1483	Walkham	0.0143	10.194	190.34		9
1484	West Dart	0.0129	39.500	320.10		6
1485	Ashburn Yeo	0.0026	2.371	15.28		11
1486	Teign	0.0000	x	x	G	0
1488	Porth Stream	0.0118	6.849	125.29	G	2
1489	T. of Ruthern	0.0032	x	x	G	0
1490	St. Lawrence S	0.0333	3.029	197.85	G	14
1493	Lynher	0.0167	19.055	273.06	G	2
1494	T. of Tavy	0.0364	1.943	192.33	G	14
1495	Plym	0.0024	x	x	C	0
1497	Dart	0.0047	97.709	189.47		0
1500	Kestle Stream	0.0125	x	x	G	2
1501	Gwindra Stream	0.0077	4.022	50.52	S	11
1502	Par	0.0083	7.803	83.81		5
1505	Seaton	0.0000	x	x	G	0
1509	Avon	0.0000	x	x	G	0
1513	Trevella Strea	0.0000	x	x	G	2
1514	Portholland St	0.0000	x	x	G	0
1521	Porthcuel	0.0000	x	x	G	2