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Australian River Assessment System: Review of Physical River Assessment Methods — A Biological Perspective

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Natural Heritage Trust
Helping Communities Helping Australia
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REVIEW OF PHYSICAL RIVER ASSESSMENT METHODS: A BIOLOGICAL PERSPECTIVE

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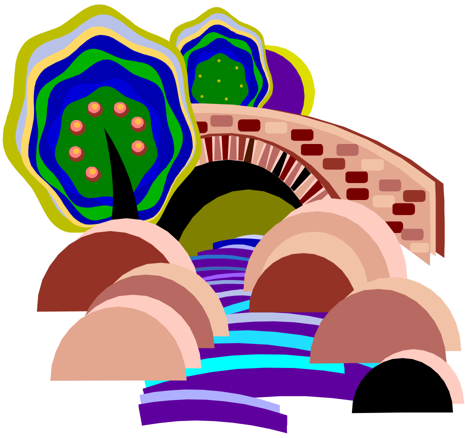

Cooperative Research Centre for Freshwater Ecology

April 2000

A report to Environment Australia for the AUSRIVAS Physical and Chemical Assessment Module

Cooperative Research Centre for Freshwater Ecology

Natural Heritage Trust
Helping Communities
Helping Australia

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Department of the Environment and Heritage

ACKNOWLEDGMENTS

The aim of this document is to review existing stream assessment methods and as such, it draws heavily on published material. In describing the details of each method, it was sometimes difficult to diverge greatly from the existing text. Thus, we would like to acknowledge the creators of each stream assessment method, because this review is merely a summary of their expertise. These authors are:

State of the Rivers Survey	John Anderson
Index of Stream Condition	Lindsay White, Tony Ladson
Habitat Predictive Modelling	Nerida Davies, Richard Norris, Martin Thoms
Geomorphic River Styles	Gary Brierley, Kirstie Fryirs, Tim Cohen
HABSCORE	James Plafkin, Michael Barbour, Kimberley Porter, Sharon Gross, Robert Hughes, Jeroen Gerritson, Blaine Snyder, James Stribling
River Habitat Survey	P. Raven, N. Holmes, F. Dawson, P. Fox, M. Everard, I. Fozzard, K. Rouen, among others
AUSRIVAS	All people involved with the National River Health Program

However, it should be noted that the information supplied in this report is a synthesis and interpretation of published material and any misinterpretations, although unintentional, are the sole responsibility of the authors.

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1 INTRODUCTION

1.1 The physical and chemical assessment module

The Australian River Assessment System (AUSRIVAS) is a nationally standardised approach to biological assessment of stream condition using macroinvertebrates (Coysh *et al.*, 2000). It was developed under the auspices of the National River Health Program (NRHP). Within the AUSRIVAS component of the NRHP, a suite of 'toolbox' projects have been commissioned with the aim of either refining the existing assessment techniques, or developing additional aspects of river health assessment that are complementary to those made by the AUSRIVAS macroinvertebrate predictive models (O'Connor, 1999). One of these projects is the development of a physical and chemical assessment module.

One of the main aims of the physical and chemical assessment module is to develop a standardised protocol for the physical and chemical assessment of stream condition, that will complement the biological assessments of stream condition made using AUSRIVAS. Disregarding the chemical component for now, development of such a protocol requires simultaneous consideration of stream condition from a biological and a physical perspective. While there would seem to be obvious interdependencies between the physical and biological components of streams, merging the two components is, in reality, a complex task because of the different paradigms that exist within the disciplines of stream ecology and fluvial geomorphology. The physical and chemical assessment module represents a first step in bringing together biological and physical or geomorphological approaches to the assessment of stream condition. However, in developing a standardised protocol for physical assessment of stream condition, that is directly relevant to biological assessment of stream condition, several questions become apparent:

- which physical variables are related to the distribution and abundance of biota?;
- how might geomorphological process variables, that describe the formation of habitats, be related to biota?;
- are there any geomorphological process variables that are unrelated to biota but which are useful for describing the condition of a stream from a physical perspective?;

- at which scales are biota related to different habitat components?; and,
- can geomorphological process variables be measured within the 'rapid' biomonitoring philosophy, while still retaining the necessary levels of precision and accuracy?

1.2 Review of stream assessment methods

The common link between assessment of stream condition from a biological and a geomorphological perspective is the expression of stream habitat, or physical structure, as a templet for biological communities. From a biological perspective, the physical habitat is considered as a templet upon which the ecological organisation and dynamics of ecosystems are observed (Townsend and Hildrew, 1994; Montgomery, 1999; Norris and Thoms, 1999). Thus, measurement of biological habitat tends to include the factors that directly influence biotic communities, at scales relevant to the organism of interest (Weins, 1989; Cooper *et al.*, 1998; Sale, 1998) or the disturbance of interest (Rankin, 1995). From a geomorphological perspective, the expression of physical habitat is related to a set of predictable geomorphic processes (Harper and Everard, 1998; Muhar and Jungwirth, 1998; Brierley *et al.*, 1999; Montgomery, 1999). The pattern of stream habitat that forms as a result of these processes provides the templet for biotic communities. Thus, measurement of geomorphological habitat tends to consider fluvial processes as they relate to channel structure, at scales that reflect the hierarchical organisation of stream systems (Schumm; 1977; Frissell *et al.*, 1986; Maddock, 1999). Regardless of how each perspective views habitat, the common ground between geomorphology and biology is that both disciplines consider that a 'healthy' habitat is vital for a 'healthy' biotic community and indeed, for a 'healthy' stream ecosystem (Maddock, 1999; Norris and Thoms, 1999).

Biological monitoring programs are used worldwide to assess stream condition. The use of biota to assess stream condition has numerous advantages, the most prominent being that biotic communities are affected by a multitude of chemical and physical influences (Rosenberg and Resh, 1993). Thus, condition of the biota is a reflection of the overall condition of the stream ecosystem (Reice and Wohlenberg, 1993). However, there are numerous methods that have been developed to assess the physical or geomorphological condition of streams and which have the potential to enhance the interpretation of biological assessments of stream condition, or to provide information on stream condition that is not directly apparent within biological assessment. Any attempt to merge aspects of biological assessment with aspects of physical condition must identify the physical features that are of importance to the biota (Harper *et al.*, 1995; Maddock, 1999), while retaining aspects that may be important to the physical formation of stream habitat.

The aim of this document is to review methods for the assessment of stream condition that are potential candidates for inclusion in a nationally standardised physical and chemical assessment protocol. It is not the aim of this document to make final recommendations for the format of the protocol. Rather, this review forms an initial information base and will be used in conjunction with a habitat assessment workshop to make final recommendations for a physical (and chemical) stream assessment protocol. The focus of this review is on assessment of the physical and geomorphological aspects of stream condition, with consideration of the potential for each method to link physical condition with ecological condition. It will answer four questions about each method:

1. **How did the method come about?**
   Describes the scientific context and river management background of the method.
2. **How does the method work?**
   Provides an overview of the mechanics of the method including the variables collected in the field or laboratory, the methods used to collect the data, and the data analysis.
3. **How does the method assess stream condition?**
   Explains the approach of the method to the assessment of stream condition and considers factors such as predictive ability, definition and use of a reference condition and the philosophies used to determine deviation from this unimpaired reference condition.
4. **How does the method link physical and chemical features with the biota?**
   Examines how the method implicitly or explicitly links the physical assessment of stream condition with biota, or in some cases, biotic condition.

The final section of the review will summarise the advantages and disadvantages of each physical assessment method and evaluate the potential for each method to encompass the physical aspects of river condition that are relevant to stream biota.

2 REVIEW OF RIVER ASSESSMENT METHODS

2.1 Scope and rationale

There are many stream assessment methods that have been developed worldwide. The methods chosen for inclusion in this review represent the suite of approaches currently in use in Australia. The State of the Rivers Survey, Index of Stream Condition and Geomorphic River Styles methods were developed for, and tested in, Australian rivers and streams. Thus, they tend to have an ability to incorporate stream features inherent to Australian conditions such as high flow variability, high turbidity and complex channel morphology. Although based on a method developed in the United Kingdom, the AUSRIVAS and Habitat Predictive Modelling methods have been successfully adapted to Australian conditions. In particular, AUSRIVAS is a nationally standardised and predictive approach to biological assessment that has recently been used to determine the condition of around 6000 river sites across Australia. The United States Environmental Protection Agency's HABSCORE method of stream assessment was used within the AUSRIVAS predictive model and thus, is included in this review. The River Habitat Survey is not currently being applied in Australia. However, it is included in this review because it represents an approach that was applied on a national scale in the United Kingdom, to assess the physical condition of streams and rivers.

There are some additional methods of stream assessment that were not included in the review. The Integrated Habitat Assessment System (IHAS) has been developed in South Africa and is used in conjunction with the country's rapid biological assessment program (McMillan, 1998). The IHAS measures components of the stream habitat relevant to macroinvertebrates, such as substratum, vegetation and physical stream condition. These components are rated and a score representing a continuum of habitat quality is derived. Another method, Pressure-Habitat-Biota (PBH), has been developed for use in small to medium sized rivers and streams in New South Wales (Chessman and Nancarrow, 1999). PBH measures variables representing the pressures on streams (e.g. physical restructuring, water pollution and introduced species), the habitat of streams (e.g. habitat area, habitat diversity and habitat stability) and the biota within streams (e.g. diatoms, riparian vegetation, water plants, macroinvertebrates and fish). These variables are then compared with each other to:

- determine current stream condition;

- identify ecological assets;
- identify ecological problems;
- improve understanding of cause and effect relationships between biota and habitat or pressures; and,
- provide an ecosystem stress classification of stream sub-catchments (Chessman and Nancarrow, 1999).

In addition to the IHAS and PBH methods, the United Kingdom's System for Evaluating Rivers for Conservation (SERCON) was also omitted from this review. SERCON is designed to assess the conservation value of rivers according to criteria of physical diversity, naturalness, representativeness, rarity, species richness and special features (Boon *et al.*, 1998). Field data are collected using an extended version of the River Habitat Survey, and other data are gathered from a range of sources. Rating scores are derived for each variable and these scores are subsequently combined to produce indices for each of the conservation criteria described above (Boon *et al.*, 1998).

Overall, the rationale for omission of IHAS, PBH and SERCON from this review is somewhat subjective and has no relationship to the mechanisms that each method uses to assess stream condition. Rather, the IHAS and PBH methods were omitted because they are still in the development stage and thus, there was a limited amount of literature available. SERCON is a complex system for evaluating conservation potential and thus, it was decided that the inclusion of SERCON's smaller sibling, the River Habitat Survey, would provide an adequate description of the potential for this method to assess physical stream condition.

2.2 AUSRIVAS

2.2.1 How did AUSRIVAS come about?

The Australian River Assessment System (AUSRIVAS) was developed in response to the need for a nationally standardised method to assess the ecological condition of Australia's river systems (Simpson and Norris, 2000). The AUSRIVAS approach is based on the British River InVertebrate Predication and Classification System (RIVPACS, Wright *et al.*, 1984; Moss *et al.*, 1987), which has been successfully used to assess the quality of rivers in the U.K. (Wright *et al.*, 1998). Initially, the adoption of RIVPACS to Australian conditions required modifications to the sampling design and statistical analysis components (Simpson and Norris, 2000). The major advantage of the AUSRIVAS and RIVPACS approaches to river assessment is that the fauna expected to occur at a site can be predicted, forming a 'target' community against which to measure potential ecological impairment.

2.2.2 How does AUSRIVAS work?

AUSRIVAS uses macroinvertebrate information as the basis upon which to assess the ecological condition of river sites (Figure 2.2.1). Macroinvertebrates are collected from reference sites, which are defined as sites representing least impaired conditions. Classification analysis is then used to form reference sites into groups containing similar biota. Physical and chemical data collected at reference sites are then used to discriminate among the biotic groups and the variables with the strongest discriminatory power are chosen as predictor variables for use in the AUSRIVAS predictive model algorithm.

The reference site information forms the templet against which test sites are compared to assess their ecological condition (Figure 2.2.1). A test site is defined as any new site for which an assessment is required. Macroinvertebrates are collected at the test sites, along with a suite of physical and chemical information that includes the predictor variables chosen for use in the AUSRIVAS model. These predictor variables are used to place test sites into the reference site groups formed on the basis of the biota. The model then calculates the probability of occurrence of each taxon at a test site, based on

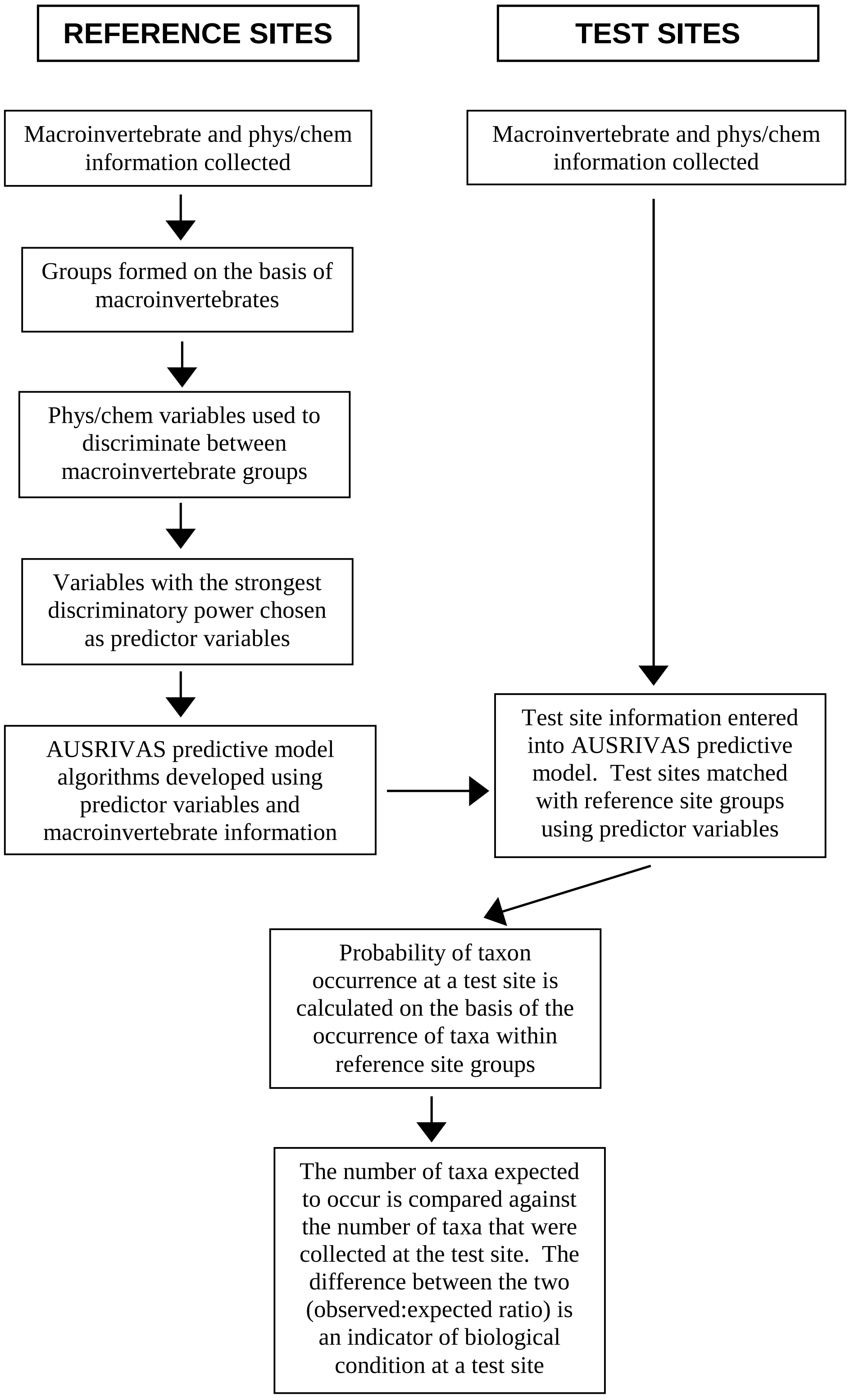


Figure 2.2.1 Schematic representation of AUSRIVAS assessment of site condition.

the occurrence of each taxon within the corresponding reference site groups. The number of taxa predicted to occur at a test site is compared against the number of taxa that were actually collected at the test site, with the difference between the two being an indication of the ecological condition of the site.

2.2.3 How does AUSRIVAS assess stream condition?

Macroinvertebrates are a commonly used group of organisms in the biological monitoring of water quality (Rosenberg and Resh, 1993). From an ecological perspective, the advantages of using macroinvertebrates to assess river condition are that they are common in many different river habitats, they show responses to a wide range of environmental stresses and they act as continuous monitors of the water that they inhabit (Rosenberg and Resh, 1993). Thus, the ecological foundation upon which biological monitoring is based is that the structure of the benthic macroinvertebrate community indicates the state of the entire ecosystem (Reice and Wohlenberg, 1993).

AUSRIVAS assesses site condition by comparing the macroinvertebrates that are predicted to occur at a test site, with the macroinvertebrates that were collected at a test site. The deviation between the number of taxa expected to occur and the number of taxa that were actually observed (observed:expected ratio) is a measure of the ecological condition of a site. If the number, or type, of taxa collected at a test site does not fulfil expectations, then it is likely that water quality or habitat conditions are limiting the biological potential of the site. The observed:expected ratio ranges from 0 to > 1 and represents a continuum of ecological condition. For ease of interpretation, the continuum can be broken into bands that delineate an ecological condition that is impoverished, well below reference, below reference, reference, and richer than reference (Simpson and Norris, 2000).

The robustness of AUSRIVAS assessments of site condition are enhanced through the use of a regional reference condition approach (Reynoldson *et al.*, 1997). Comparison of test sites to groups of reference sites that represent an array of potential regional conditions enables prediction of the taxa likely to occur at sites with given environmental characteristics (Moss *et al.*, 1987; Reynoldson *et al.*, 1997). In predicting the taxa that should occur at a test site, the AUSRIVAS model calculates the weighted probabilities of a test site belonging to each of the reference site groups, which in turn enables natural variation in macroinvertebrate habitat associations to be accounted for before determining site condition. However, there are several limitations of the AUSRIVAS predictive models that currently have the potential to affect assessments of site condition. First, to allow accurate matching of test sites with reference site groups, reference sites must cover a wide range of river types. Secondly, evaluation of whether macroinvertebrate community impairment detected by AUSRIVAS is likely to be caused by water quality degradation, habitat degradation, or a combination of both is highly dependent upon the collection of the appropriate supporting data from each test site.

2.2.4 How does AUSRIVAS link physical and chemical features with the biota?

The fundamental assumption behind AUSRIVAS is that the physical and chemical factors measured at any site are directly related to the macroinvertebrates. This assumption is derived from a multitude of studies that have demonstrated specific physical and chemical influences on macroinvertebrate community structure in streams (Resh and Rosenberg, 1984; Vinson and Hawkins, 1998; Ward, 1992). The empirical evidence linking macroinvertebrates with their environmental requirements provides a strong foundation for the process that AUSRIVAS uses to link physical and chemical variables to taxon occurrence, and the subsequent assessments of ecological condition that are derived from this information.

The physical and chemical variables collected in AUSRIVAS broadly encompass the factors that influence the distribution of macroinvertebrates on a catchment, reach and individual habitat scale. These factors are geographical position, riparian vegetation, channel morphology, water chemistry, habitat composition, habitat characteristics, organic substratum, inorganic substratum and hydrology (Table 2.2.1). Within each factor, a number of different variables are measured to represent specific influences on macroinvertebrate communities (Table 2.2.1). In addition, the US EPA habitat assessment (see Section 2.3) is also performed at each site and a suite of observations that indicate potential human influences are recorded and used to aid interpretation of AUSRIVAS biological outputs (Table 2.2.1). However, there are several shortcomings of the physical and chemical data that may affect the AUSRIVAS assessments of ecological condition. Firstly, AUSRIVAS sampling is conducted by State agencies. As

Table 2.2.1 Physical and chemical variables commonly measured in AUSRIVAS. Broad categories of factors influencing macroinvertebrate distribution are in bold, with the specific variables measured within each factor listed underneath. Compiled from State Agency data sheets.

Geographical position
Altitude
Latitude
Longitude
Catchment area upstream
Distance from source
Channel slope

Riparian vegetation
Width of riparian zone
Cover of riparian zone by trees, shrubs, grasses
Canopy cover of river
Native and exotic vegetation cover
Riparian vegetation density
Continuity of riparian vegetation

Channel morphology
Stream width
Stream depth
Bank width
Bank height

Water chemistry
Temperature
Conductivity
pH
Dissolved oxygen
Turbidity
Alkalinity
Nutrients
Ammonium
Air temperature
Secchi depth

Hydrology
Mean annual discharge
Coefficient of variation of mean annual discharge
Flow pattern
Gauge height

Habitat composition
Percent riffle, edge, pool, macrophytes, run, snags and/or dry bed in sampling area

Reach organic and inorganic substratum
Bedrock
Boulder
Cobble
Pebble
Gravel
Sand
Silt/clay
Substratum heterogeneity
Detritus cover (CPOM and FPOM)
Moss cover
Filamentous algae cover
Macrophyte cover

Riffle/channel/sand bed habitat characteristics
Bedrock
Boulder
Cobble
Pebble
Gravel
Sand
Silt/clay
Detritus cover(CPOM and FPOM)
Periphyton cover
Moss cover
Filamentous algae cover
Macrophyte cover
Water depth
Water velocity
Overhanging vegetation

Edge/backwater/macrophyte habitat characteristics
Bedrock
Boulder
Cobble
Pebble
Gravel
Sand
Silt/clay
Detritus cover (CPOM and FPOM)
Periphyton cover
Moss cover
Filamentous algae cover
Macrophyte cover
Water depth
Water velocity
Trailing bank vegetation
Macrophyte taxa composition

Habitat quality assessment (US EPA)
Bottom substrate / available cover
Embeddedness
Velocity / depth category
Channel alteration
Bottom scouring and deposition
Pool/riffle, run/bend ratio
Bank stability
Bank vegetative stability
Streamside cover
Total habitat score

Site observations
Water and sediment odours and oils
Flow level and restrictions
Local bank and catchment erosion
Landuse
Valley topography
Kicknetting plume
River braiding and bars
Local point source and non point source pollution

such, the specific variables measured in each State vary slightly according to both geographical and administrative need, although the major factors influencing macroinvertebrate distribution are generally encompassed by each State. Secondly, AUSRIVAS assumes a deterministic link between physical and chemical factors and macroinvertebrates, and thus, the predictive capability of the model depends on the ability to capture the variables that most strongly influence macroinvertebrate distribution. While the choice of variables included in the models has a strong empirical basis, it is not clear whether these variables encompass all the potential influences on macroinvertebrate communities. In particular, variables that represent habitat forming geomorphological processes, such as stream power and channel dimension, are omitted from AUSRIVAS. However, the relationship between the habitats that these geomorphological processes form, and the habitat requirements of macroinvertebrates is a contentious issue that has only recently come to the fore of research agendas.

2.3 HABSCORE (USEPA Rapid Bioassessment Protocols)

The United States Environmental Protection Agency (USEPA) has developed Rapid Bioassessment Protocols (RBP) that use fish, macroinvertebrates or periphyton to assess stream condition. Metrics representing structural, functional and process elements of the biotic community are calculated for each site, and aggregated into an index. This multimetric index represents the biological condition of a site (Barbour *et al.*, 1999). Physical and chemical data are also measured at each site, and are used to aid the interpretation and calibration of the index, and also to define the reference condition. It is beyond the scope of this document to consider the process of biological metric calculation and calibration. Rather, the focus will be on the suite of physical and chemical measurements that are collected alongside the biota. In particular, the RBP includes a rapid habitat assessment method that uses a scoring system to rate habitat condition, and which will henceforth be referred to as HABSCORE. HABSCORE has utility outside the Rapid Bioassessment Protocols and has been used as a measure of habitat condition in the AUSRIVAS predictive models (see Section 2.2) and in the Habitat Predictive Modelling approach (see Section 2.7). HABSCORE was originally adopted by Plafkin *et al.* (1989) from work conducted on fish habitat, but has subsequently been updated and modified slightly by Barbour *et al.* (1999). The following discussion refers to the updated version of HABSCORE.

2.3.1 How did HABSCORE come about?

The USEPA Rapid Bioassessment Protocols were developed in response to a need for cost effective survey techniques to assess stream condition (Barbour *et al.*, 1999). The principal requirements underpinning the protocols were:

- cost effective, yet scientifically valid, procedures for biological surveys;
- provisions for multiple site investigations in a field season;
- quick turn around of results for management decisions;
- scientific reports easily translated to management and the public; and,
- environmentally benign procedures (Barbour *et al.*, 1999).

The HABSCORE component of the Rapid Bioassessment Protocols is commensurate with these requirements.

2.3.2 How does HABSCORE work?

HABSCORE is a visually based habitat assessment that evaluates 'the structure of the surrounding physical habitat that influences the quality of the water resource and the condition of the resident aquatic community' (Barbour *et al.*, 1999, p5-5). It includes factors that characterise stream habitat on a micro-scale (e.g. embeddedness) and a macro-scale (e.g. channel morphology), as well as factors such as riparian and bank structure which influence the micro and macro-scale features (Barbour, 1991; Barbour *et al.*, 1999). HABSCORE is composed of ten habitat parameters (Figure 2.3.1). To reflect the difference in habitat types between upland and lowland streams, separate assessments have been developed for high and low gradient conditions (Barbour *et al.*, 1999). At each site, individual parameters are assessed and rated according to a continuum of scores that represent optimal, sub-optimal, marginal or poor condition (Figure 2.3.1). A total score is obtained for each site, and is subsequently used to determine the percent comparability to reference conditions (Plafkin *et al.*, 1989). However, the individual parameter scores and the total assessment score also provide an overall assessment of habitat condition at the sampling site.

HABITAT ASSESSMENT FIELD DATA SHEET Page 1 of 2

HIGH GRADIENT STREAMS

Date: ______________________ Recorders Name: ____

Site No.: ____________________ River and Location: ____________________________________

Habitat parameter	**Condition category**																			
	Excellent					**Good**					**Fair**					**Poor**				
1. Epifaunal (bottom) substrate / available cover	Greater than 70% of substrate favourable for epifaunal colonisation and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonisation potential (i.e. logs/snags that are not new fall and not transient).					40-70% mix of stable habitat; well-suited for full colonisation potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonisation (may rate at high end of scale).					20-40% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.					Less than 20% stable habitat; lack of habitat is obvious; substrate unstable or lacking.				
SCORE	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
2. Embeddedness	Gravel, cobble and boulder particles are 0-25% surrounded by fine sediment. Layering of cobble provides diversity of niche space.					Gravel, cobble and boulder particles are 25-50% surrounded by fine sediment.					Gravel, cobble and boulder particles are 50-75% surrounded by fine sediment.					Gravel, cobble and boulder particles are more than 75% surrounded by fine sediment.				
SCORE	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
3. Velocity / depth regime	All four velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). Slow is <0.3m/s, deep is >0.5m).					Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).					Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score low).					Dominated by 1 velocity/depth regime (usually slow-deep).				
SCORE	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
4. Sediment deposition	Little or no enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition.					Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% of the bottom affected; slight deposition in pools.					Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% of the bottom affected; sediment deposits at obstructions, constrictions and bends; moderate deposition in pools prevalent.					Heavy deposits of fine material, increased bar development; more than 50% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.				
SCORE	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
5. Channel flow status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.					Water fills >75% of the available channel; or <25% of channel substrate is exposed.					Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.					Very little water in channel and mostly present as standing pools.				
SCORE	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
6. Channel alteration	Channelization or dredging absent or minimal; stream with normal pattern.					Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e. dredging (greater than 20 yr) may be present, but recent channelization is not present.					Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.					Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.				
SCORE	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Figure 2.3.1 Habitat assessment data sheet for high gradient streams, showing habitat parameters assessed for HABSCORE. Each parameter is scored on a continuum of conditions representing optimal, sub-optimal, marginal and poor conditions. The score is totalled and to form the overall assessment of habitat quality. After Barbour *et al.* (1999).

HABITAT ASSESSMENT FIELD DATA SHEET Page 2 of 2

HIGH GRADIENT STREAMS

Date: ________________________ Recorders Name: ____

Site No.: _____________________ River and Location: ____

Habitat parameter	**Condition category**			
	Excellent	**Good**	**Fair**	**Poor**
7. Frequency of riffles (or bends)	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank stability (score each bank)	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; 'raw' areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
SCORE	Left bank 10 9	8 7 6	5 4 3	2 1 0
SCORE	Right bank 10 9	8 7 6	5 4 3	2 1 0
9. Vegetative protection (score each bank)	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understorey shrubs, or non woody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimetres or less in average stubble height.
SCORE	Left bank 10 9	8 7 6	5 4 3	2 1 0
SCORE	Right bank 10 9	8 7 6	5 4 3	2 1 0
10. Riparian zone score (score each bank)	Width of riparian zone >18 metres; human activities (i.e. roads, lawns, crops etc.) have not impacted the riparian zone.	Width of riparian zone 12-18 metres; human activities have impacted riparian zone only minimally.	Width of riparian zone 6-12 metres; human activities have impacted zone a great deal.	Width of riparian zone <6 metres; little or no riparian vegetation is present because of human activities.
SCORE	Left bank 10 9	8 7 6	5 4 3	2 1 0
SCORE	Right bank 10 9	8 7 6	5 4 3	2 1 0

TOTAL HABITAT SCORE _________________

Figure 2.3.1 (cont.)

In addition to the HABSCORE assessment of site condition, a suite of variables that represent factors integrated within HABSCORE are also collected at each site. These factors characterise stream type, watershed features, riparian vegetation, instream features, large woody debris, aquatic vegetation, water quality, inorganic substrate and organic substrate (Table 2.3.1). These factors can be included in determinations of reference condition, but are mostly used as an interpretative aid to the assessments of stream condition, made using the multimetric indices. These variables are also collected in AUSRIVAS (see Section 2.2) but are used mainly to aid interpretation of site condition, rather than as predictor variables.

Table 2.3.1 Physical and chemical observations measured alongside the HABSCORE assessment. After Barbour *et al.* (1999).

Watershed features	**Aquatic vegetation**
Predominant surrounding landuse	Dominant vegetation type
Local watershed non-point source pollution	Species present
Local watershed erosion	Proportion of the reach with aquatic vegetation
Riparian Vegetation	**Water quality**
Dominant vegetation type	Temperature
Species present	Conductivity
	Dissolved Oxygen
Instream features	pH
Estimated reach length	Turbidity
Estimated stream width	Water odours
Sampling reach area	Water surface oils
Estimated stream depth	Water clarity
Surface velocity	
Canopy cover of river	**Inorganic sediment/substrate**
High water mark	Sediment odours
Proportion of reach represented by riffle, pool and run stream morphology types	Sediment deposits Sediment oils
Stream channelization	Presence of black undersides on stones
Presence of dams	Substrate composition
Large woody debris	**Organic substrate**
Cover of large woody debris	Detritus (as CPOM)
	Muck-mud (as FPOM)
	Marl (grey, shell fragments)

2.3.3 How does HABSCORE assess stream condition?

As a stand-alone method, HABSCORE provides an ability to assess the quality of instream and riparian habitat at a sampling site. However, a more important function of HABSCORE is that it is used to determine the ability of the habitat to support the optimal biological condition of the region (Barbour *et al.*, 1999). Assuming that reference sites represent optimal condition, the comparability of the habitat and the biota to this reference state can be plotted to determine the ability of the habitat to support the biological community (Figure 2.3.2). There are three important aspects of Figure 2.3.2:

- the upper right hand corner represents a situation with good habitat quality and good biological condition;
- the mid-section of the curve represents a situation where habitat quality decreases and the biological community responds with a concomitant decrease; and,
- the lower left hand corner represents a situation where habitat quality is poor and unable to support the biological community (Barbour, 1991).

Apart from the three situations outlined above, comparison of the condition of the biota with the condition of the habitat can also highlight situations of potential water quality degradation, where habitat quality is high but biological condition is poor (Barbour *et al.*, 1999).

Habitat quality is the initial focus of the Rapid Bioassessment Protocols. Habitat quality at the reference sites is compared against habitat quality at the test site and if equivalent, then a direct comparison of the biological condition can be made using the biological metrics (Plafkin *et al.*, 1989). This ensures that assessments of biological condition indicate impairment, rather than inherent natural differences in stream habitat. If habitat quality is lower at a test site than at the reference sites, then the ability of the habitat to support biota is investigated as a first step, before a determination of biological condition is made (Plafkin *et al.*, 1989).

2.3.4 How does HABSCORE link physical and chemical features with the biota?

HABSCORE was designed to complement assessments of biological condition made using the rapid biological assessment protocols. This compatibility is based on the assumption that the quality and quantity of available physical habitat has a direct influence on biotic communities (Maddock 1999; Rankin, 1995). The parameters measured in HABSCORE (Figure 2.3.1) represent aspects of the habitat that are related to aquatic life use and which are a potential source of limitation to the aquatic biota (Barbour, 1991; Barbour *et al.*, 1999). Thus, the empirical links between habitat and the biota are reflected in this relationship. The process used to determine the ability of the habitat to support an optimal biological community (see Section 2.3.3) also captures these empirical links by considering habitat quality to be a templet that influences the types of biotic communities that can potentially be attained under certain conditions.

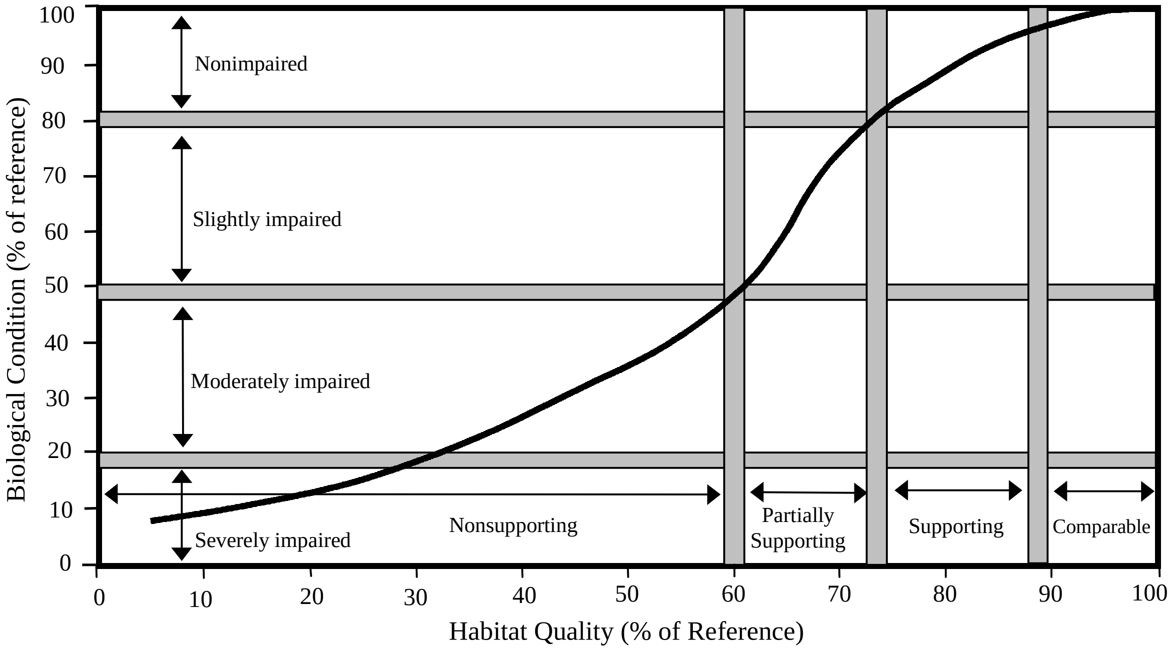


Figure 2.3.2 The relationship between habitat and biological condition. Re-drawn from Barbour (1991).

2.4 Index of Stream Condition

2.4.1 How did the Index of Stream Condition come about?

Australian Governments are increasing their focus on rivers via legislative, research and rehabilitation actions (Ladson *et al.*, 1999). Within this environment, the Victorian Index of Stream Condition (ISC) was developed in response to a managerial need to 'use indicators to track aspects of environmental condition and provide managerially or scientifically useful information' (Ladson *et al.*, 1999, p454).

The ISC evolved in four stages. Stage 1 involved the development of the concept and included a review of stream assessment methods, input from stream scientists and managers, and development of an ISC prototype (Ladson and White, 1999). The desired attributes considered in development of the ISC concept were:

- the indicators are key components of stream condition;
- the methodology is founded in science;
- the results are accessible to managers;
- data collection methods are objective and repeatable;
- natural variability is considered;
- application is cost effective; and,
- indicators are sensitive to management intervention (Ladson and White, 1999).

Stage 1 is analogous to the aims of the current Physical and Chemical Assessment Module. Stages 2 and 3 of the ISC involved trialing and refining the concept and Stage 4 involved application of the ISC across Victoria (Ladson and White, 1999). Future stages will involve assessment and further refinement of the method (Ladson and White, 1999).

2.4.2 How does the Index of Stream Condition work?

The ISC measures stream condition within reaches that are between 10 and 30km in length (Ladson and White, 1999). Reaches are defined as 'contiguous sections of stream chosen so that they are approximately homogeneous in terms of the five components of stream condition' (Ladson *et al.*, 1999 p456). Reaches are delineated mainly from 1:250 000 topographic maps or aerial photographs. Within each reach, measurement sites are selected on the basis of:

- the representativeness of each site to reach characteristics;
- proximity to existing biological, physical and water quality monitoring sites; and,
- accessibility for sampling purposes (DNRE, 1997).

The ISC consists of five sub-indices, which represent key components of stream condition (Table 2.4.1). Each sub-index consists of indicators, which are calculated using data collected in the field or by desk based methods. Each indicator is then assigned a rating score (see Section 2.4.3). Sub-index scores are calculated by summing the component indicator scores, and the overall ISC score is calculated by summing the sub-index scores (Ladson *et al.*, 1999).

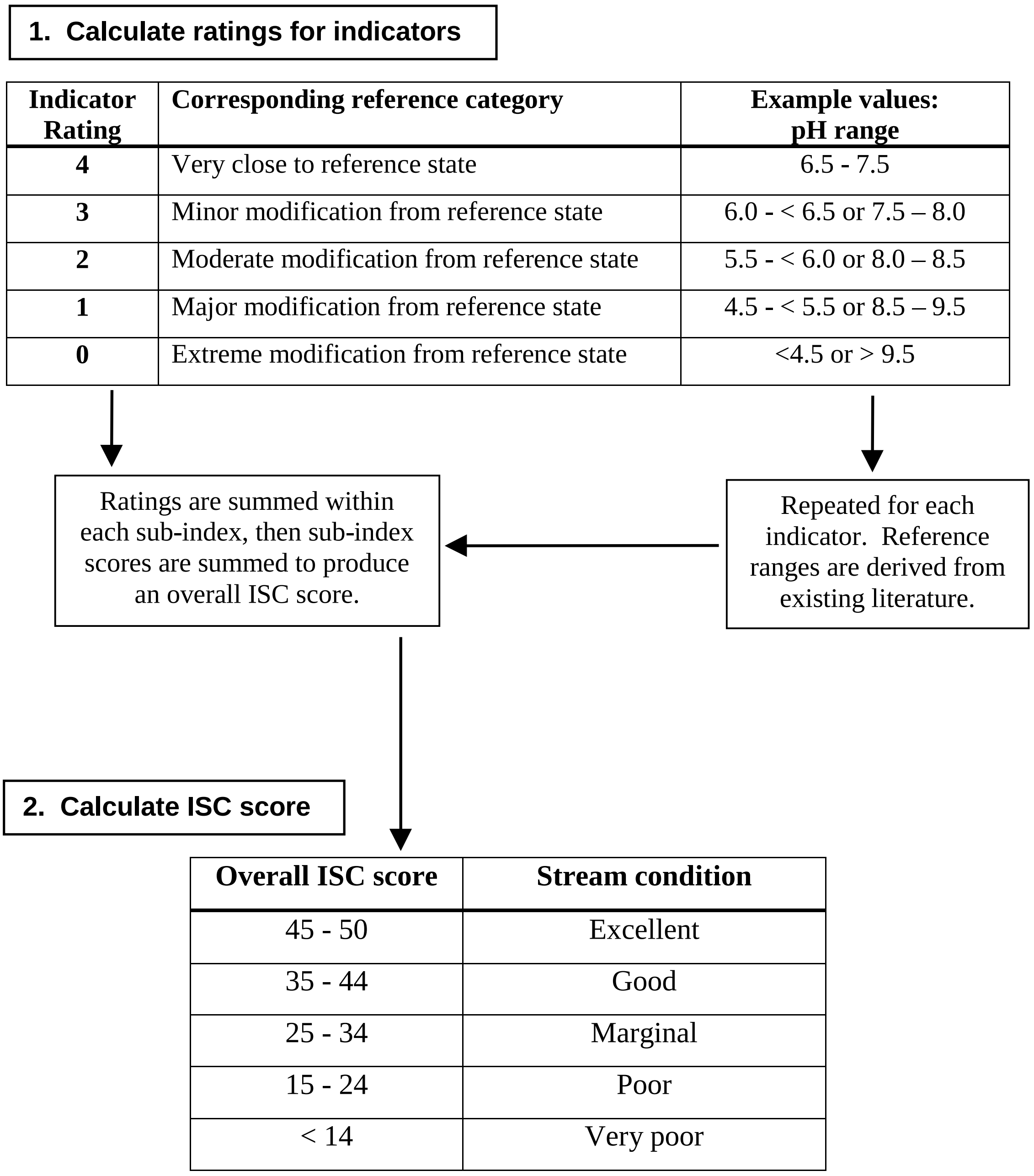
Table 2.4.1 List of indicators used in the Index of Stream Condition. After Ladson and White (1999) and Ladson *et al.* (1999).

Sub-index	**Basis for sub-index value**	**Indicators within sub-index**
Hydrology	Comparison of the current flow regime with the flow regime existing under natural conditions	Amended annual proportional flow deviation Daily flow variation due to change of catchment permeability Daily flow variation due to peaking hydroelectricity stations
Physical Form	Assessment of channel stability and amount of physical habitat	Bank stability Bed stability Impact of artificial barriers on fish migration Instream physical habitat
Streamside Zone	Assessment of quality and quantity of streamside vegetation	Width of streamside zone Longitudinal continuity Structural intactness Cover of exotic vegetation Regeneration of indigenous woody vegetation Billabong condition
Water Quality	Assessment of key water quality parameters	Total phosphorus Turbidity Electrical conductivity Alkalinity / acidity
Aquatic Life	Presence of macroinvertebrate families	SIGNAL AUSRIVAS

2.4.3 How does the Index of Stream Condition assess stream condition?

The ISC uses a rating system to assess stream condition. The use of a rating system is designed to provide as much resolution as possible, within the constraint that there is 'limited knowledge of the relationship between a change in the indicator and environmental effects' (Ladson and White, 1999, p10). Values for each indicator are assigned a rating on the basis of comparison with a reference state (Figure 2.4.1). These ratings are summed to produce an overall score that reflects a continuum of stream conditions from excellent to very poor (Figure 2.4.1). In calculating the overall ISC scores, the scores for each sub-index and for each indicator can be weighted, depending on the perceived importance of each, or the availability of data (Ladson and White, 1999).

The ISC is based on the premise that the hydrology, physical form, streamside zone, water quality and aquatic life components indicate the processes and functions that act to influence stream condition. For example, the hydrology sub-index reflects deviation of the current flow regime from natural conditions, the physical form sub-index reflects channel morphology and the provision of biotic habitat, and the streamside zone sub-index reflects the importance of riparian zone and floodplain processes (Ladson and White, 1999; Ladson *et al.*, 1999). A holistic assessment of stream condition is achieved by integrating these components into a single ISC score. However, it is



1. Calculate ratings for indicators

Indicator Rating	Corresponding reference category	Example values: pH range
4	Very close to reference state	6.5 - 7.5
3	Minor modification from reference state	6.0 - < 6.5 or 7.5 – 8.0
2	Moderate modification from reference state	5.5 - < 6.0 or 8.0 – 8.5
1	Major modification from reference state	4.5 - < 5.5 or 8.5 – 9.5
0	Extreme modification from reference state	<4.5 or > 9.5

Ratings are summed within each sub-index, then sub-index scores are summed to produce an overall ISC score.

Repeated for each indicator. Reference ranges are derived from existing literature.

2. Calculate ISC score

Overall ISC score	Stream condition
45 - 50	Excellent
35 - 44	Good
25 - 34	Marginal
15 - 24	Poor
< 14	Very poor

Figure 2.4.1 Assessment of stream condition using the Index of Stream Condition. Derived from Ladson and White (1999).

recommended that the scores for the component sub-indices are reported alongside the overall ISC score, because the overall score may be composed of sub-indices that vary in condition (Ladson and White, 1999).

The ISC was designed to provide an assessment of long term changes in the environmental condition of rural stream reaches 10-30km in length, with surveys conducted at five year intervals (Ladson and White, 1999). As such, the 'level of detail is only sufficient to signal potential problems, suggest their cause and highlight aspects that may need specific investigations' (Ladson *et al.*, 1999, p455). However, the ISC is a tool for determining the success of environmental intervention policies (Ladson and White, 2000) and can be used in a management context to:

- benchmark stream condition, and for reporting to local, regional, state or Commonwealth agencies;
- aid objective setting by, and provide feedback to, natural resource managers (particularly Catchment Management Authorities) and in particular, to assess trade-offs between utilitarian demands on streams and environmental condition;
- judge the effectiveness of intervention, in the long-term, in managing and rehabilitating stream condition; and,
- review performance against expected outcomes (Ladson and White, 1999).

2.4.4 How does the Index of Stream Condition link physical and chemical features with the biota?

The ISC is designed to be a broad scale and long term assessment. As such, the ISC consists of five sub-indices that reflect different components of stream condition. The aquatic life sub-index is the component that reflects overall biotic condition within the sampling reach (Ladson and White, 1999). Macroinvertebrate indicators are used in the ISC, because this group of organisms provides a continuous assessment of the environment which they inhabit (Rosenberg and Resh, 1993; Ladson and White, 1999). As such, the aquatic life sub-index is inherently related to the hydrology, physical form, streamside zone and water quality sub-indices (Ladson and White, 1999). Inclusion of the aquatic life sub-index provides a somewhat independent measure of stream condition, and can be particularly useful in situations where the biota are degraded but the physical, chemical and hydrological indices are not (Ladson and White, 1999). While there is empirical evidence that broadly links degradation in physical, chemical and hydrological factors with degradation in macroinvertebrate communities, care must be taken when comparing scores for the aquatic life sub-index with scores for the other sub-indices. This is because a scoring system may not be a sensitive reflection of mechanistic relationships between environmental factors and macroinvertebrate community composition.

2.5 Geomorphic River Styles

2.5.1 How did Geomorphic River Styles come about?

River health has traditionally been viewed from a biological perspective, because 'effects on biota are usually the final point of environmental degradation and pollution of rivers' (Norris and Thoms, 1999, p197). However, there is an inherent link between the potential health of biota, and the availability of physical habitat (Brierley *et al.*, 1999). As such, assessment of river health from a biological perspective cannot proceed effectively when analysed in isolation from the factors that determine river structure and function. Geomorphic River Styles aims to address the physical structure and function components of river health. It is framed around 'direct linkage of vegetative and geomorphic process, providing an assessment of habitat availability along river courses, and hence indirect linkage to river ecology' (Brierley *et al.*, 1996, p2).

Assessment of stream condition from a distinctly geomorphological perspective has many benefits to river managers, including:

- an ability to characterise and explain river behaviour at different positions within catchments;
- provision of a predictive basis to assess future river character and responses to disturbance;
- provision of a basis to determine suitable river structures to support viable habitats along river courses;
- help to develop pro-active, rather than reactive, management strategies, setting realistic target goals in development of River/Catchment Management Plans and more effectively prioritorising allocation to management issues; and,
- an ability to be used in programs to assess and monitor river condition (Brierley *et al.*, 1996).

2.5.2 How does Geomorphic River Styles work?

Geomorphic River Styles is a procedure that provides 'a baseline survey of river character and behaviour, evaluating the physical controls on river structure at differing positions in catchments' (Brierley *et al.*, 1996, p2). The procedure is set within a nested hierarchical framework (Frissell *et al.*, 1986) and as such, it incorporates assessment of river structure at the catchment, reach and geomorphic unit scales (Brierley *et al.*, 1996).

There are five stages in the assessment of river character and behaviour:

1. Data compilation (description and mapping)
2. Data analysis (explanation of river character and behaviour)
3. Prediction of future likely river structure
4. Prioritorisation of catchment management issues
5. Identification of suitable river structures for Rivercare planning (Brierley *et al.*, 1996).

Stage one comprises both pre-field data collection and field data collection (Brierley *et al.*, 1996). During the pre-field data collection component, catchment scale characteristics are measured off maps, or by using GIS capabilities (Table 2.5.1). Consideration is also given to historical and archival information about the catchment. In addition, the pre-field component involves identification of reach boundaries off 1:12000 air photographs and a range of reach scale characteristics is subsequently measured at each reach (Table 2.5.1). The reaches delineated off maps are used as sampling units in the field data collection component (Brierley *et al.*, 1996), although the reaches are ratified in the field prior to data collection. Geomorphic units are identified within each reach and at representative locations, the characteristics of each geomorphic unit are recorded (Table 2.5.1). A detailed sediment analysis is also conducted in each geomorphic unit (Table 2.5.1).

In Stage two, data collected in the pre-field and field components are used to interpret river behaviour. This process involves several steps and follows the hierarchical framework. Firstly, the assemblage of geomorphic units is assessed, to

Table 2.5.1 Catchment, reach and geomorphic unit characteristics measured in the Geomorphic River Styles method. After Brierley *et al.* (1996).

CATCHMENT CHARACTERISTICS

Relief measures
Catchment relief
Catchment relief ratio
Longitudinal profile
Valley side slope length and angle
Areal properties
Catchment area
Drainage pattern
Elongation ratio
Drainage density
Linear measurements
Stream order
Stream length
Other measures
Geology
Average annual rainfall and monthly averages
Landuse
Vegetation distribution and type
Discharge

REACH CHARACTERISTICS

Channel planform
Planform geometry
Radius of channel curvature to mean channel width ratio (rc/w)
Meander wavelength
Type of geomorphic units present
Confinement
Valley width
Degree and character of channel constriction
Terrace character
Vegetation character
Percent coverage

GEOMORPHIC UNIT CHARACTERISTICS

Identification
Within channel units
Channel marginal units and bank character
Floodplain units
Morphology and dimensions of geomorphic units
Shape and size
Channel geometry
Channel bed elevation
Width to depth ratio
Hydraulic parameters
Flow character
Mannings roughness coefficient (n)
Froude number
Vegetation character
Vegetation cover dimensions
Vegetation composition
Assemblage and connectivity of geomorphic units throughout the reach
Spatial character of geomorphic units
Channel – floodplain relationship
Lateral stability of the channel
Degree and character of channel obstruction
Stream power
Bankfull discharge
Sediment attributes
Grain size and distribution
Sorting
Rounding
Facies / sedimentary structures
Sediment mix and degree of packing
Type of grading
Sediment relations
Degree of sediment storage
Sediment yield or sediment delivery ratio (SDR)

provide insight into the formative processes within a reach (Brierley *et al.*, 1996). Examples of some of the links between geomorphic units and formative processes that can be deduced from this stage are:

- lateral and/or downstream migration of a channel is reflected by point bar sedimentation, channel asymmetry, eroding concave banks, ridge and swale floodplain topography, meander cutoffs etc.;
- channel contraction is reflected by bench formation and in-channel sedimentation;
- bedrock confinement is reflected by differing assemblages of geomorphic units, dependent on valley alignment, such as concave bank benches, channel scour or steep levee-flood channel assemblages;
- channel avulsion is recorded by abandoned channels on the floodplain;

- sand sheet deposition on floodplains may record changes in the pattern of sedimentation; and,
- a sediment-choked channel, with dissected bars, may reflect bed aggradation (Brierley *et al.*, 1996).

In the second interpretation step, reaches are amalgamated to form source, transfer, throughput and accumulation zones, based on the assemblage of geomorphic units and associated sediment relations along reaches. These 'process zones' represent the capacity of the stream to temporarily store and accumulate materials (Brierley *et al.*, 1996). Thirdly, the catchment characteristics are used to determine the nature of the controls on river character and behaviour in each process zone (Brierley *et al.*, 1996). The evolution of the river is then assessed in a historical context, and provides an indication of pre-disturbance stream characteristics. Lastly, the 'direct controls on habitat availability are assessed by analysis of changes to channel geometry and planform, the assemblage of geomorphic units within each process zone and the nature of altered associations that each of these geomorphic features have with riparian vegetation' (Brierley *et al.*, 1996, p26).

2.5.3 How does Geomorphic River Styles assess stream condition?

The assessment of stream condition using Geomorphic River Styles is achieved using two approaches: comparison of contemporary stream character and behaviour with the conditions expected in undisturbed conditions; and prediction of future river character and behaviour based on extrapolation from contemporary behaviour, sediment storage, and/or theoretical notions of river behaviour (Brierley *et al.*, 1996; Fryirs *et al.*, 1996). The focus of both approaches is the behaviour of process zones, because each zone type may respond differently to disturbance and result in a particular assemblage of geomorphic units.

In the first approach, comparison of contemporary stream conditions with undisturbed conditions allows analysis of changes in both planform (Figure 2.5.1) and cross sectional (Figure 2.5.2) channel structure within different process zones. For example, in the Wolumla Creek Catchment on the South Coast of New South Wales (figure 2.5.1 and fiure 2.5.2), river channel changes since human settlement of the area can be summarised as follows:

- channel planform and geometry have become better defined;
- the association of geomorphic units is more homogeneous despite a larger range of geomorphic units being present;
- variability in the sedimentary character of geomorphic units has been reduced;
- vegetation associations have decreased in variability and are now more homogeneous;
- longitudinal connectivity has increased throughout the catchment. Lateral channel floodplain connectivity has decreased;
- organic matter and nutrient retention within-catchment has greatly decreased; and,
- hydrological implications have been transformed largely as a result of the calibre and volume of materials stored within the channel (Fryirs *et al.*, 1996).

In the second approach to assessment of stream condition, prediction of likely future behaviour is made by extrapolation from contemporary behaviour, sediment storage (Figure 2.5.3) and relationships with theoretical notions of river behaviour (Figure 2.5.4) (Fryirs *et al.*, 1996). For example, in the Wolumla Catchment, analysis based on sediment storage identified sites which were most sensitive to future sediment release (Figure 2.5.3) (Fryirs *et al.*, 1996). Analysis based on theoretical river behaviour can identify the predictive relationships between variables related to river behaviour and channel geometry (Figure 2.5.4), which in turn, can be used to assist in setting targets for stream restoration or Rivercare programs. However, in the Wolumla Catchment, the classical notions of river behaviour do not apply (Fryirs *et al.*, 1996). In addition, the ability of variables to predict channel geometry was highly variable among sub-catchments, highlighting the need for analysis of predictive relationships at the scale of sub-catchments (Fryirs *et al.*, 1996).

2.5.4 How does Geomorphic River Styles link physical and chemical features with the biota?

Geomorphic River Styles is a geomorphological stream assessment method that relies heavily on sedimentary characteristics. As such, it does not directly measure the biota.

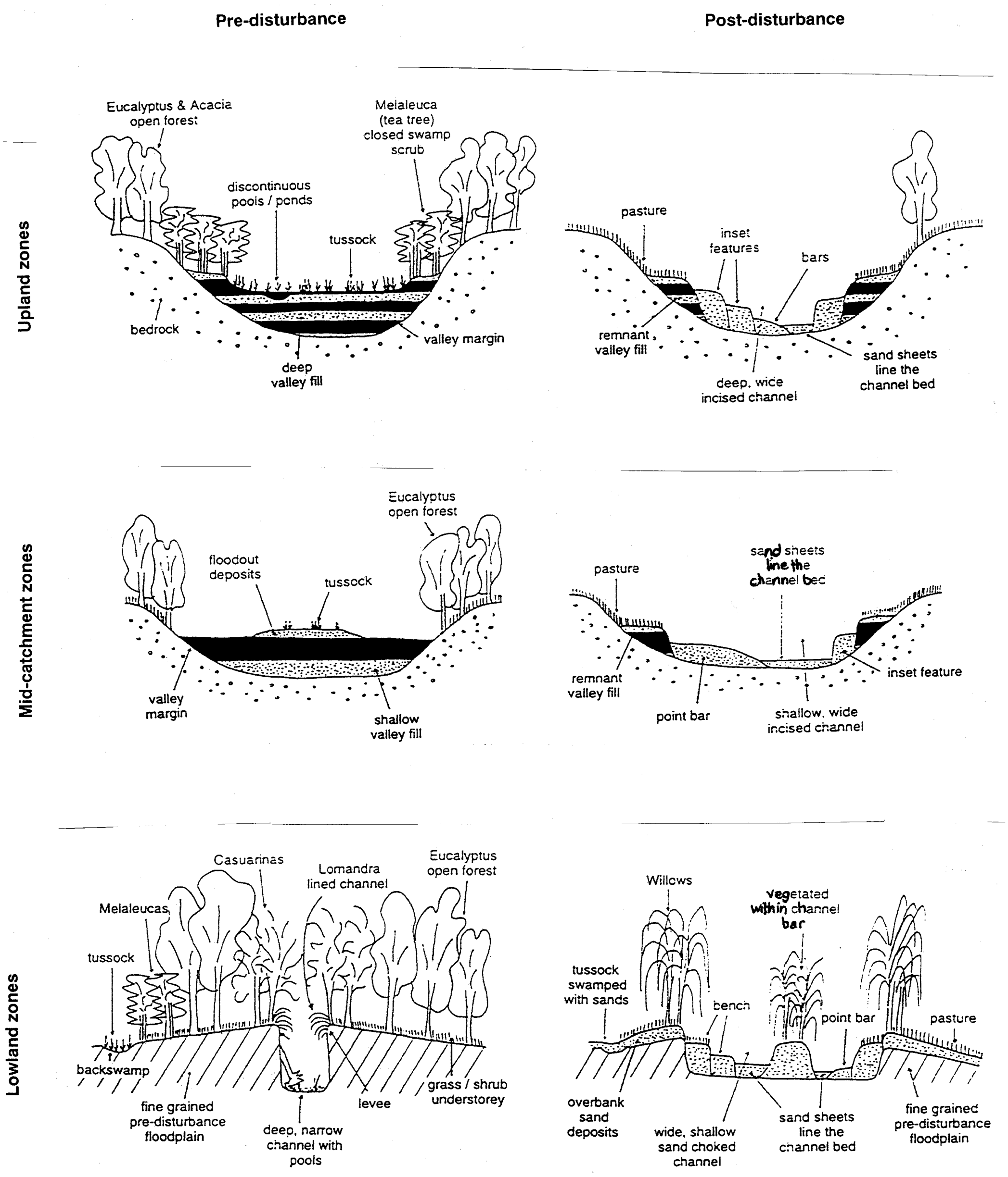


Figure 2.5.1 Planform view of pre-disturbance (left) and post-disturbance (right) channel character within upland, mid-catchment and lowland zones of the Wolumla Creek catchment. After Fryirs *et al.* (1996).

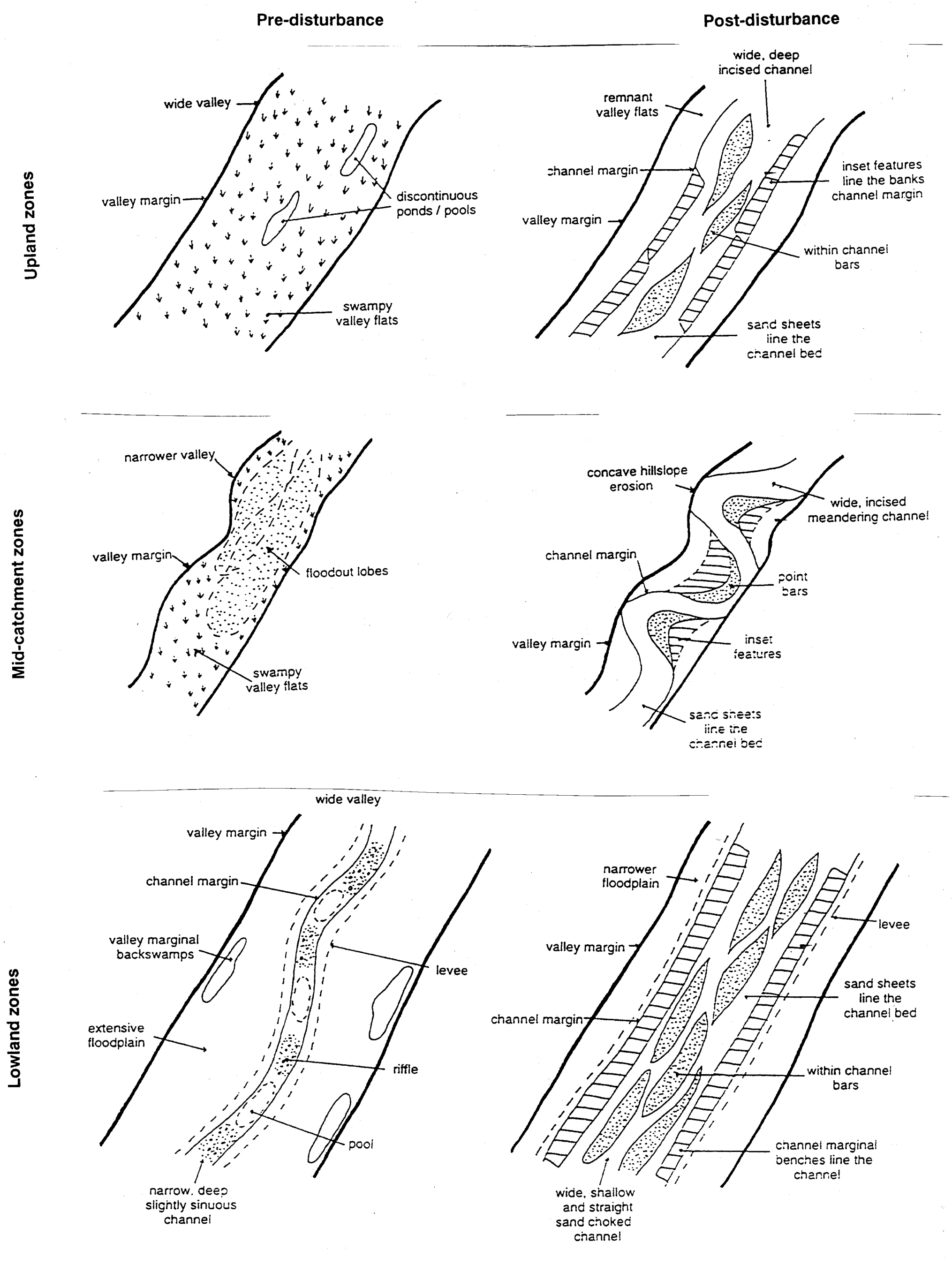


Figure 2.5.2 Cross-sectional view of pre-disturbance (left) and post-disturbance (right) channel character within upland, mid-catchment and lowland zones of the Wolumla Creek catchment. After Fryirs *et al.* (1996).

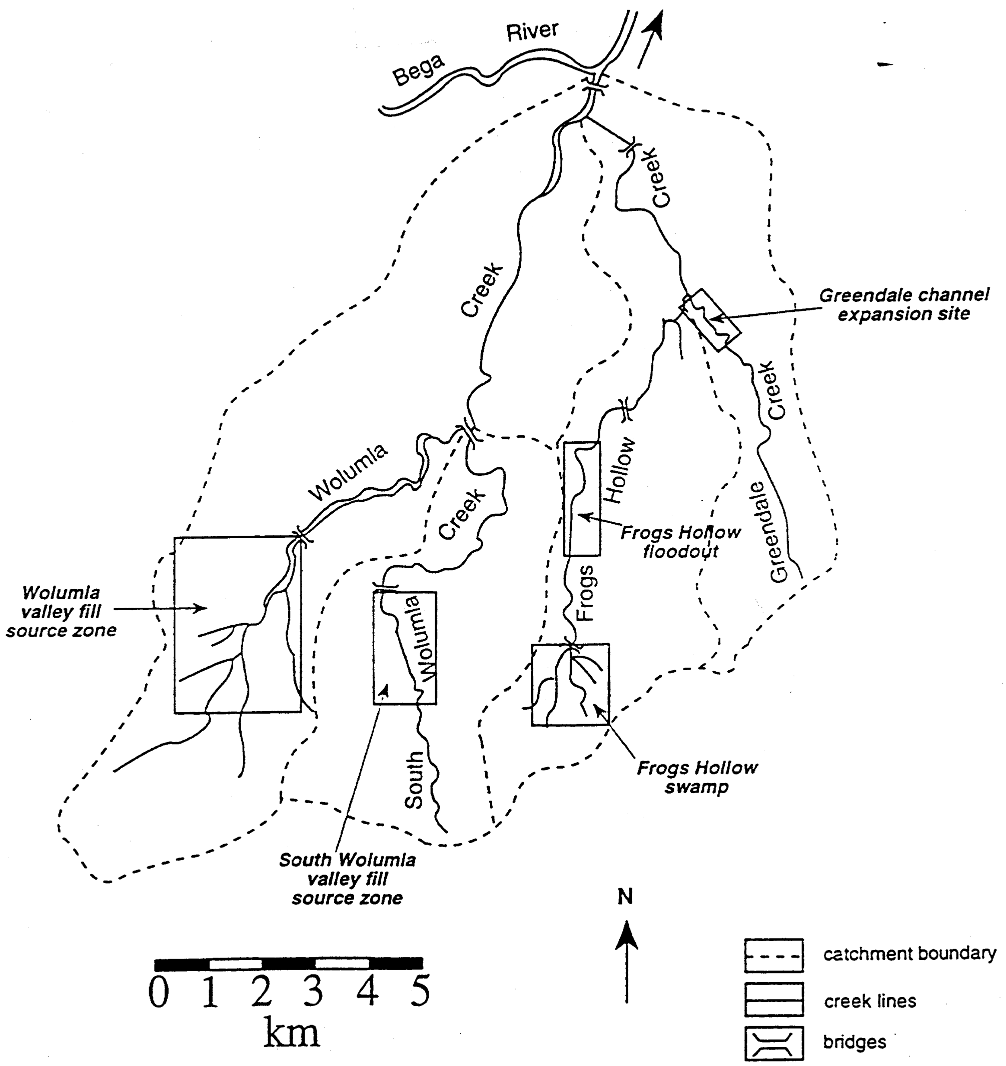


Figure 2.5.3 Identification of sensitive sites in the Wolumla Catchment, based on sediment storage. Frogs Hollow Swamp and Frogs Hollow floodout are intact features which if incised could supply significant volumes of material. Wolumla and South Wolumla valley fill source zones have had the majority of their fills removed, but a significant volume of material still remains stored within these zones. Greendale channel expansion site is an actively eroding transfer zone which is still supplying significant volumes of sediment to Frogs Hollow Creek and is the most sensitive site in the catchment. After Fryirs *et al.* (1996).

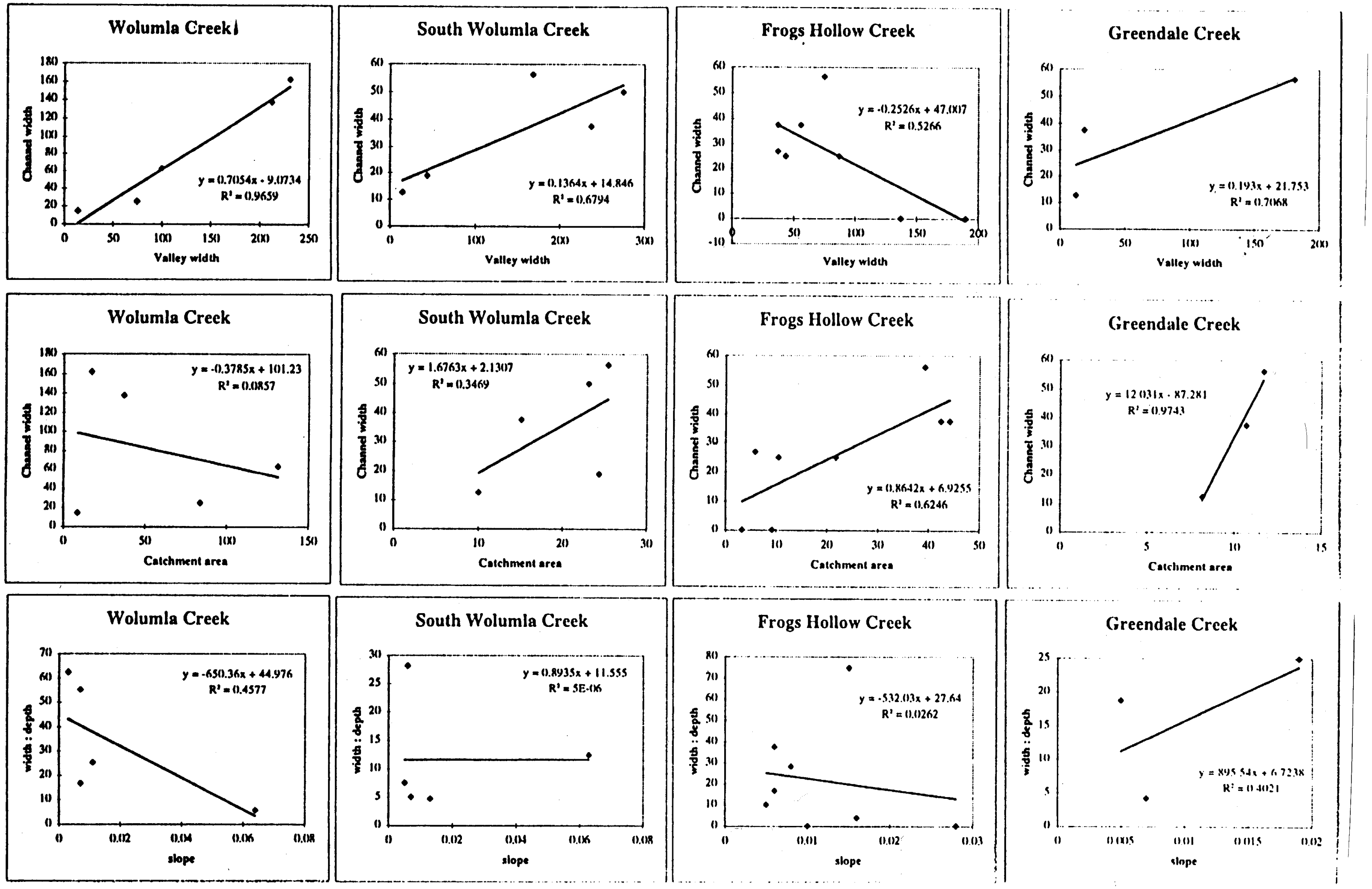


Figure 2.5.4 Predictive relationships between stream characteristics in sub-catchments of the Wolumla Catchment. After Fryirs *et al.* (1996).

However, the process of deducing and predicting geomorphic stream characteristics and behaviour is essentially equivalent to deducing and predicting habitat availability because 'geomorphic processes determine the structure, or physical template, of a river system' (Brierley *et al.*, 1999, p840; see also Cohen *et al.*, 1996). In turn, this template provides the 'framework upon which a wide range of biophysical processes interact' (Brierley *et al.*, 1999, p840; see also Resh *et al.*, 1994; Townsend and Hildrew, 1994). Thus, Geomorphic River Styles may have the potential to merge geomorphology and ecology together under the common banner of a physical habitat template.

The implications of geomorphic channel changes for riverine ecology are evaluated by considering lateral and longitudinal connectivity of the river system, the hydrological regime, and the processing and storage of nutrients and organic matter (Brierley *et al.*, 1996). In the Wolumla Catchment, some of the effects of channel behaviour on riverine ecology are reported as:

- changes in sediment character in the lowland and mid-catchment reaches has resulted in a reduction in the variability of substrate distribution throughout the reaches;
- there has been alteration to the longitudinal connectivity through a significant reduction in riparian vegetation. This has important implications for detritus inputs to stream ecosystems, nutrient retention and the micro-climate of streams, as well as having a possible impact on detritivores;
- reduction in riparian vegetation has resulted in the dominance of exotic species;
- the change in geomorphic character of process zones have altered the relationship between sources of organic matter, retention and redistribution of this material;
- the changes in channel form of process zones associated with large scale bed aggradation could also have significant impacts on the hyporheic zone; and,
- changes to longitudinal relationships of stream ecosystems may result in disjointed migration pathways and reduced habitats for certain fish species (Cohen *et al.*, 1996).

Despite the potential for Geomorphic River Styles to assess biotic habitat, there has been no direct testing of the relationships between different types of biota and different geomorphic units, or process zones. The view of what constitutes a functional habitat may differ significantly between the geomorphological and the biological perspective.

For instance, is the distribution of macroinvertebrate communities within a catchment related to the distribution of source, input, throughput and accumulation zones within a catchment? If certain assemblages of geomorphic units are characteristic of process zones, do macroinvertebrate communities recognise and differentiate between these geomorphic units? Determination of these relationships through future research would provide a strong foundation for linking biotic condition with habitat condition, within a geomorphic process framework.

2.6 State of the Rivers Survey

2.6.1 How did the State of the Rivers Survey come about?

The State of the Rivers Survey was developed in Queensland, in response to a need for detailed information on the physical and environmental condition of streams and rivers (Anderson, 1993a). This information would then be available to the Queensland Department of Primary Industries (DPI) for use in the Integrated Catchment Management process (Anderson, 1993a). The State of the Rivers Survey is not designed to establish the trend or rate of change of stream condition, but rather, it provides a 'snapshot' of the physical and environmental condition of streams. These data can then be used to:

- provide an objective and comprehensive benchmark against which future trends and rates of change of conditions can be assessed by conducting follow-up surveys;
- provide the fundamental information required to classify rivers and streams; and,
- provides an overview to help identify resource management and utilisation practices contributing to the deterioration in physical and ecological condition of rivers (Anderson, 1993a).

The State of the Rivers Survey was developed in two stages. The first stage involved development (Anderson, 1993a; Anderson, 1993b) and testing (Anderson, 1993c) of the method. The State of the Rivers Survey has subsequently been applied to assess stream condition in 26 catchments in New South Wales and Queensland (Anderson, 1999).

2.6.2 How does the State of the Rivers Survey work?

The State of the Rivers Survey methodology aims to assess the condition of homogenous stream sections within catchments (Anderson, 1993a). The use of homogeneous stream sections facilitates comparison of similar stream types among catchments or sub-catchments, and provides an ability to distinguish inherent natural variability from the effects of human impacts. Division of the catchment into homogeneous stream sections is a hierarchical process that involves the following steps:

- a map exercise to subdivide streams into homogeneous stream sections on the basis of available data such as geology, soils, sub-catchment structure, stream order, natural and artificial barriers, altitude, catchment slope, stream gradient and vegetation type and cover;
- visual reconnaissance of the catchment to test the initial homogeneity and to further subdivide the rivers and streams at appropriate boundaries;
- further sub-sectioning is made in the course of conducting the instream surveys;
- analysis of the instream site data and testing of homogeneity between sites in the same section may lead to further sub-divisions;
- compilation of relevant catchment data, with further possible revision of sections; and,
- final classification of stream sections using different combinations of the attributes for different purposes (Anderson, 1993a; Anderson, 1993b).

Within each stream segment, a representative sampling reach is chosen on the basis of the following criteria:

- the reach should be representative of the types of habitat, morphology and physical and ecological condition of the stream segment;
- to represent habitat diversity, the reach should preferably contain at least two complete pools and riffle/run habitats;
- the whole length of the reach should be visible at one location; and,
- the reach should contain at least one pool, which should be the largest and deepest in the area (Anderson, 1993a).

The number of reaches sampled within each catchment varies according to the size of the catchment and the required resolution of the survey (Anderson, 1993a).

Table 2.6.1 Data components and types of variables measured in the State of the Rivers Survey. Compiled from the detailed survey data sheets provided in Anderson (1993b).

Sub-section elements[1]
- Section boundaries
- Sub-catchment centroid
- Elevation information

Hydrology[2]
- Water flow
- Time since last runoff
- General local conditions
- Instream water quality measurements[3]

Site description
- Grid reference
- Latitude
- Longitude
- Catchment area
- Altitude
- Map details
- Site access details
- Photograph details

Reach environs – temporal and spatial
- Water level at sampling time
- Channel pattern
- Local land use
- Local disturbance
- Local vegetation types
- Floodplain features
- Local land tenure
- Overall disturbance rating

Channel habitat
- Channel habitat types
- Reach length
- Sketch of reach

Cross-sections[4]
- Depth[5]
- Water velocity[5]
- Bed sediments[5]
- Bank dimensions
- Bank sediments

Bank condition
- Bank stability[6]
- Bank slope[6]
- Bank shape[6]
- Overall bank condition[6]
- Factors affecting stability
- Artificial bank protection measures
- Levee banks

Bed and bar condition
- Bar type and distribution
- Bar size
- Gravel angularity and shape
- Gravel surface characteristics
- Bed compaction
- Factors affecting stability
- Controls stabilising the bed
- Passage for fish and other organisms
- Overall bed stability rating

Vegetation
- Width of riparian zone[6]
- Vegetation cover of plant types[6]
- Percent exotic species in riparian zone[6]
- Local species checklist[6]
- Aquatic vegetation – submerged and floating
- Emergent aquatic vegetation

Aquatic habitat
- Instream debris cover
- Canopy cover[6]
- Vegetation overhang[6]
- Root overhang[6]
- Bank overhang[6]
- Man-made overhang[6]
- Overall site rating for all aquatic life

Scenic, recreational and conservation values
- Recreational opportunity type
- Recreation types suitable for the area
- Scenic value assessment
- Initial conservation value assessment

1. This component is usually completed post-survey, to characterise the final homogeneous stream sections
2. This component is desk based and is designed to establish an interface with hydrological and water quality data through HYDSYS
3. Measurement of depth, water temperature, dissolved oxygen, pH, conductivity, salinity, turbidity, secchi depth and water velocity is optional
4. One cross section is measured in each habitat type present within a reach
5. Measured at up to 15 locations within the cross sectional transect
6. Measured for left and right banks

In addition to the map-based data that are used to delineate the initial stream sections, the State of the Rivers Survey consists of 11 data components (Table 2.6.1) that are collected at each representative sampling reach. Each data component is composed of different types of variables that represent the physical and environmental aspects of the stream channel (Table 2.6.1). Variables are generally measured using visual estimation, but some variables require physical measurement or an interpretive rating of condition.

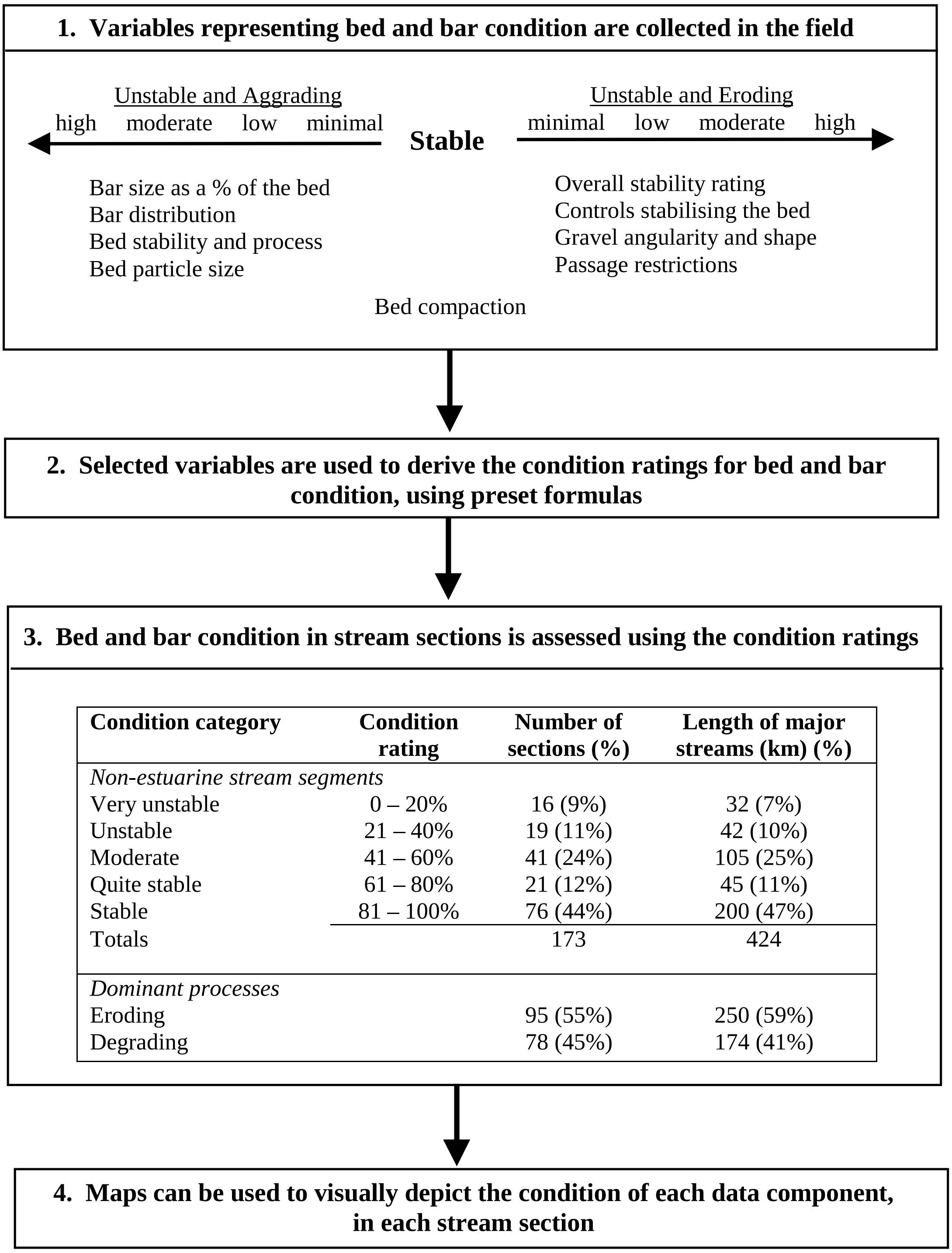
2.6.3 How does the State of the Rivers Survey assess stream condition?

The basis for assessment of stream condition in the State of the Rivers Survey is 'the extent to which the values or perceived function of an attribute has declined from a pristine or undisturbed condition' (Anderson, 1999). A series of condition ratings are produced for each data component. Formulas are used to derive condition ratings, using subsets of variables collected within each component (Anderson 1993b). These condition ratings are based on the extent of degradation from a theoretical maximum of 100%, where 100% percent represents the full value, pristine condition or complete function for the component and 0% represents a complete loss of these (Anderson, 1999). Comparisons with representative sites in good condition are also used to scale the ratings (Anderson, 1999).

Using the condition ratings for each data component, an assessment of condition is derived for each homogeneous stream section (Figure 2.6.1). A final assessment of stream condition within a catchment is achieved by calculating the number of homogeneous stream sections that correspond to each condition rating, for each data component (Figure 2.6.1). The length of stream within each catchment that corresponds to a certain condition can also be calculated (Figure 2.6.1). In addition, an overall condition rating can also be calculated for the whole catchment by resetting the condition ratings for all the data components combined (Anderson, 1993c). Thus, stream condition can be reported on several levels of resolution that can encompass combinations of individual data components or all data components together, as well as individual stream sections or the entire catchment.

2.6.4 How does the State of the Rivers Survey link physical and chemical features with the biota?

The State of the Rivers Survey was designed to 'estimate the ecological condition [of rivers] in terms of the condition of the instream habitat, rather than by conducting flora or faunal surveys' (Anderson, 1993a, p6). As such, the State of the Rivers Survey



1. Variables representing bed and bar condition are collected in the field

Bar size as a % of the bed
Bar distribution
Bed stability and process
Bed particle size

Overall stability rating
Controls stabilising the bed
Gravel angularity and shape
Passage restrictions

Bed compaction

2. Selected variables are used to derive the condition ratings for bed and bar condition, using preset formulas

3. Bed and bar condition in stream sections is assessed using the condition ratings

Condition category	Condition rating	Number of sections (%)	Length of major streams (km) (%)
Non-estuarine stream segments			
Very unstable	0 – 20%	16 (9%)	32 (7%)
Unstable	21 – 40%	19 (11%)	42 (10%)
Moderate	41 – 60%	41 (24%)	105 (25%)
Quite stable	61 – 80%	21 (12%)	45 (11%)
Stable	81 – 100%	76 (44%)	200 (47%)
Totals		173	424
Dominant processes			
Eroding		95 (55%)	250 (59%)
Degrading		78 (45%)	174 (41%)

4. Maps can be used to visually depict the condition of each data component, in each stream section

Figure 2.6.1 Steps in assessing stream condition in the State of the Rivers Survey. The example is derived from an assessment of the Maroochy River Catchment, Queensland (Anderson, 1993c), and shows the bed and bank condition data component only. Variables are collected in each stream segment to represent bed and bar conditions. A condition rating is derived using selected variables and preset formulae. The number of sections that correspond to each condition rating are calculated, to give an overall picture of bed and bar condition in the Maroochy Catchment. Diagram compiled from Anderson (1993c).

primarily makes a detailed assessment of components that describe the physical condition of streams, such as channel habitat, bed condition, bank condition, cross-sectional dimension and riparian vegetation (Table 2.6.1). Anderson (1993a) recognised that habitat attributes of general importance to the biota were encompassed by these components. Many of the variables measured in the State of the Rivers Survey correspond with those measured in AUSRIVAS (see Section 2.2), RHS (see Section 2.8) and Habitat Predictive Modelling (see Section 2.7). Therefore, many of the empirical links between biota and habitat that are encompassed within other methods, are potentially represented by the variables collected in the State of the Rivers Survey.

2.7 Habitat Predictive Modelling

2.7.1 How did Habitat Predictive Modelling come about?

Habitat Predictive Modelling is a new, novel method that adds a predictive capacity to assessment of the physical condition of rivers (Davies *et al.*, 2000). As with AUSRIVAS (see Section 2.2), the major advantage of Habitat Predictive Modelling is that the features expected to occur at a site can be predicted, thus forming a target condition against which to measure habitat impairment. This target condition also has the potential to form the desired state for stream rehabilitation efforts (Davies, 1999). Additionally, in the absence of water quality degradation, physical habitat will have a major influence over biotic assemblages (Davies *et al.*, 2000). As such, Habitat Predictive Modelling complements the AUSRIVAS biological assessments of stream condition by providing information on whether biotic impairment at a site is related to poor habitat quality, or to water quality degradation (Davies *et al.*, 2000).

2.7.2 How does Habitat Predictive Modelling work?

Habitat Predictive Modelling uses a similar approach to AUSRIVAS (see Section 2.2), but uses large-scale catchment features to predict local-scale stream physical habitat features (Davies *et al.*, 2000). Local-scale habitat features are measured at reference sites, which are again defined as sites representing least impaired condition (Figure 2.7.1). Classification analysis is then used to form reference sites into groups containing similar habitat features. Large-scale catchment characteristics, usually

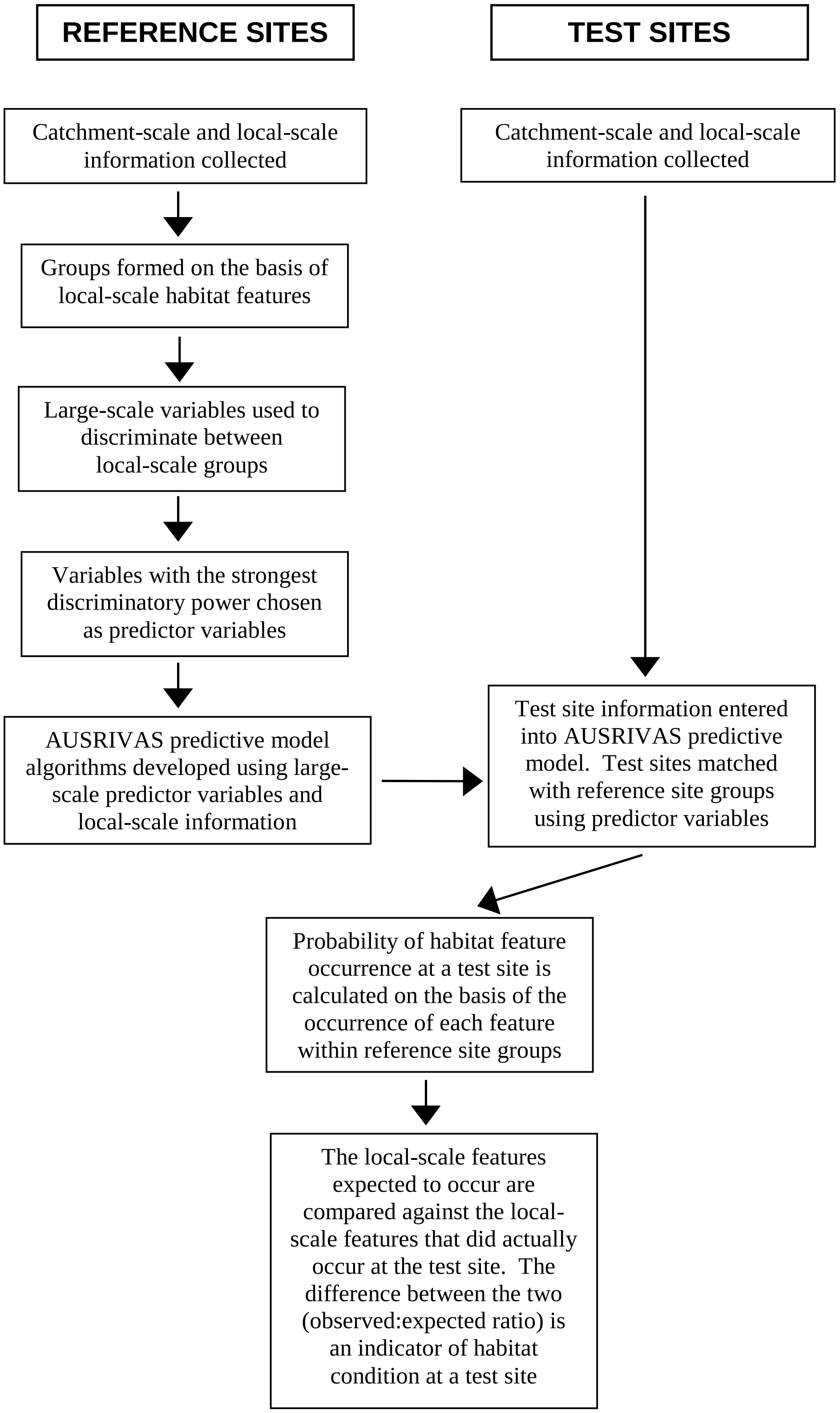


Figure 2.7.1 Schematic representation of Habitat Predictive Modelling and the assessment of habitat condition at a test site.

measured off maps, are then used to discriminate among the local-scale groups and the variables with the strongest discriminatory power are chosen as predictor variables for use in the predictive model algorithm (Figure 2.7.1).

As with AUSRIVAS, the reference site information forms the templet against which test sites are compared to assess habitat condition (Figure 2.7.1). Local-scale habitat features are measured at the test sites, along with a suite of larger scale catchment characteristics that includes the predictor variables. These predictor variables are used to place test sites into the reference site groups that were formed on the basis of local-scale habitat features. The model then calculates the probability of occurrence of each habitat feature at a test site, based on the occurrence of that feature within the corresponding reference site groups. The habitat features predicted to occur at a test site are compared against the habitat features that were actually observed at the test site, with the difference between the two being an indication of habitat condition.

2.7.3 How does Habitat Predictive Modelling assess stream condition?

Habitat Predictive Modelling is based on the observation that stream systems are organised hierarchically (de Boer, 1992) and that there is a top down control on the expression of habitat features. For example, Frissell *et al.* (1986) identified five levels of hierarchical organisation: stream systems, segment systems, reach systems, pool/riffle systems and microhabitat subsystems. The characteristics of each level are constrained by physical processes operating at the next highest level. For example, climate and geology act at the larger stream system scale to constrain the expression of bedrock type, longitudinal profile and slope, which are characteristic of the segment scale. In turn, bedrock, longitudinal profile and slope constrain the development of reach systems (Frissell *et al.*, 1986). Although Habitat Predictive Modelling does not aim to capture the same hierarchical levels as Frissell *et al.* (1986), the prediction of local-scale habitat features from catchment characteristics reflects the constraining relationships between physical processes operating at the large and small levels of the hierarchy. The catchment scale and local-scale variables used in the Habitat Predictive Modelling approach are listed in Table 2.7.1.

Habitat Predictive Modelling assesses stream condition by comparing the local-scale habitat features predicted to occur at a site in the absence of degradation, against the

Table 2.7.1 List of catchment scale and local scale variables used in Habitat Predictive Modelling. Large-scale variables are the predictor variables and local-scale variables are the habitat features predicted. After Davies (1999).

Large scale habitat variables	Local scale habitat variables
Dominant geology in catchment	Riparian width
Percent alluvium in catchment	Percent trees greater than 10m in height
Percent volcanics in catchment	Percent trees less than 10m in height
Percent metasediments in catchment	Percent shrubs and vines
Percent limestone in catchment	Percent grasses, ferns and sedges
Dominant soil type in catchment	Shading of reach
Annual mean rainfall	Stream width
Annual median rainfall	Bank width
Catchment area	Bank height
Maximum catchment length	Percent riffle habitat
Mean catchment slope	Riffle depth
Difference in elevation between source and mouth	Riffle velocity
Relief ratio	Percent edge habitat
Drainage density	Edge depth
Form ratio	Percent boulder in the reach
Elongation ratio	Percent cobble in the reach
Total stream length	Percent pebble in the reach
Valley floor width	Percent gravel in the reach
Valley slope	Percent sand in the reach
Stream order	Percent silt in the reach
Altitude	Percent clay in the reach
Distance from source	Percent bedrock in the riffle
Latitude	Percent boulder in the riffle
Longitude	Percent cobble in the riffle
Alkalinity	Percent pebble in the riffle
Conductivity	Percent gravel in the riffle
pH	Percent sand in the riffle
	Edge bank vegetation
	Percent bedrock in the edge
	Percent boulder in the edge
	Percent cobble in the edge
	Percent pebble in the edge
	Percent gravel in the edge
	Percent sand in the edge
	Percent silt in the edge
	Bottom substrate availability habitat assessment score
	Velocity / depth category habitat assessment score
	Channel alteration habitat assessment score
	Scouring habitat assessment score
	Pool / riffle / run / bend habitat assessment score
	Bank stability habitat assessment score
	Vegetative stability habitat assessment score
	Vegetation cover habitat assessment score
	Total habitat assessment score

features that were actually observed at a site. The deviation between the two measures (observed:expected ratio) is an indication of habitat quality. This is the same process that is used in AUSRIVAS to detect biological impairment (see Section 2.2). However, in adapting a technique designed to detect biological impairment into a method for assessing habitat condition, several limitations have become apparent. Firstly, AUSRIVAS predicts the occurrence of macroinvertebrate taxon at a site, whereas, there is a need with habitat assessment to predict a more continuous type of data. Currently, the habitat predictive model addresses this by converting each local-scale habitat variable into categories, prior to classification. However, the use of categorical data can result in more than one category being predicted to occur at a site, which may result in a distorted observed:expected ratio (Davies *et al.*, 2000). Secondly, the observed:expected ratio may provide a resolution that is too coarse to accurately reflect habitat condition. For example, one site assessed by Davies *et al.* (2000) demonstrated an observed:expected ratio of 0.57, which is indicative of impairment. However, examination of the raw data showed that the site actually contained more trees and shrubs than predicted, which indicates that riparian vegetation is not a contributing factor in the habitat impairment observed at this site. Thus, it is suggested that the habitat features predicted to occur should be checked against the observed habitat features to determine if the deviation between them actually represents damage to the stream habitat (Davies *et al.*, 2000). Despite some analytical limitations of Habitat Predictive Modelling, the technique was successful in predicting small-scale habitat features, and represents a promising step forward for habitat assessment.

2.7.4 How does Habitat Predictive Modelling link physical and chemical features with the biota?

Habitat Predictive Modelling is a habitat based approach and thus, it does not attempt to integrate biological aspects. However, the method has the potential to link physical features with biota, particularly macroinvertebrates, in two ways:

- Habitat Predictive Modelling can predict the occurrence of local-scale habitat features that are important to biota, such as riparian vegetation and substratum. Where specific macroinvertebrate-habitat relationships are known, the absence of habitat features from a site provides information about the ability of the habitat to support biota; and,
- the use of similar methods in AUSRIVAS and Habitat Predictive Modelling provides potential for establishment of empirical relationships between the observed:expected ratios of the habitat and the biota. This is particularly relevant if the same reference sites are used to construct the two different models.

2.8 River Habitat Survey

2.8.1 How did the River Habitat Survey come about?

The River Habitat Survey (RHS) is a river assessment method used in the United Kingdom. The RHS arose from a need to develop a nationally standardised system to measure, classify and report on the physical structure of rivers (Raven *et al.*, 1997). In designing the RHS, consideration was given to seven basic requirements. Thus, the RHS should:

- produce outputs easily understood and used by river and floodplain managers;
- be a tried-and-tested field method, compatible with existing methods such as river corridor surveys, for use in environmental and post-project appraisal;
- be based on a representative sample of river habitat features;
- have a computer database capable of deriving statistically valid systems for classification;
- facilitate the description and comparison of physical structure and habitat quality at catchment, regional and national scales;
- be accepted by external organisations, notably the conservation agencies; and,
- with European Directives in mind, have applicability throughout the UK and beyond (Raven *et al.*, 1998b).

Information derived from the RHS is designed to assist river management decisions and provide an ability to predict the physical features of a stream that would occur under unmodified conditions (Raven *et al.*, 1997). The RHS was conducted in two phases. The first phase involved the design and testing of survey methods as well as sampling of a reference site data base of more than 3000 stream sites across the U.K. (Fox *et al.*, 1998). The second phase is currently under-way and aims to use the RHS in management applications such as catchment management plans, environmental impact assessments, stream rehabilitation plans and wildlife conservation (Raven *et al.*, 1998b).

2.8.2 How does the River Habitat Survey work?

The RHS uses the physical structure of streams to assess the character and quality of rivers (Table 2.8.1). Statistical theory was used to aid the survey design and the

Table 2.8.1 Variables measured in the River Habitat Survey. (sc) denotes variables collected at spot checks. After Fox *et al.* (1998).

Background and map derived data

- Date of survey
- River name
- Catchment name
- Grid reference
- Altitude
- Valley slope
- Solid geology code
- Drift geology code
- Distance from source
- Site planform

Channel data

- Predominant substrate (sc)
  - Bedrock
  - Boulders
  - Cobbles
  - Gravel/pebbles
  - Sand
  - Silt
  - Clay
  - Artificial
  - Not visible
- Deposition features (sc)
- Braiding/side channels
- Vegetation types and extent (sc)
- Shading of channel
- Tree boughs overhanging channel
- Underwater tree roots
- Fallen trees
- Coarse woody debris
- Leafy debris
- Debris dams
- Predominant flow type (sc)
  - Free fall
  - Chute
  - Broken standing water
  - Chaotic
  - Rippled
  - Upwelling
  - Smooth boundary turbulent
  - No perceptible flow
  - No flow (dry)
- Extent of waterfalls, cascades, rapids, riffles, runs, boils, glides, pools, marginal deadwater
- Waterfalls >5m high
- Number of riffles
- Number of pools
- Modifications (sc)
- Artificial features
  - Culverts
  - Weirs
  - Foot bridges
  - Road bridges
  - Outfalls
  - Fords

Bank data (left and right recorded separately)

- Substrate (sc)
- Erosion and deposition features (sc)
- Shape
- Modifications (sc)
- Flood embankments
- Bank face vegetation structure (sc)
- Extent of bankside trees
- Exposed bankside roots
- Number of point bars
- Extent of side bars
- Banktop land use (sc)

Other site data

- Valley shape
- Adjacent land use
  - Broadleaved woodland
  - Coniferous plantation
  - Orchard
  - Moorland/heath
  - Scrub
  - Tall herb/rank vegetation
  - Rough pasture
  - Improved/semi improved grassland
  - Tiled land
  - Wetland
  - Open water
  - Suburban/urban development
- Site dimensions
  - Bank-top height
  - Bank-top width
  - Water Width
  - Water depth
  - Embankment heights
- Special floodplain features
  - Artificial open water
  - Natural open water
  - Water meadow
  - Fen
  - Bog
  - Carr
  - Marsh
  - Flush
- Notable nuisance species
  - Giant hogweed
  - Himalayan balsam
  - Japanese knotweed

selection of sampling sites throughout the U.K. (Jeffers, 1998b, Fox *et al.*, 1998). At each randomly selected site, a 500m length of river is surveyed. At 50m intervals along this length of river, 10 spot checks are performed. A range of features is recorded at each spot check (Table 2.8.1). To ensure that features and modifications not occurring at the spot checks are included, a sweep up checklist is also completed (Raven *et al.*, 1998b). In addition, cross sectional measurements of water and bankfull width, bank height and water depth (Table 2.8.1) are made at one representative location within the 500m sampling site (Raven *et al.*, 1998b). When used in conjunction with the survey data, these measurements provide information about the geomorphological processes acting on the site (Raven *et al.*, 1997). Map variables such as altitude, slope, planform and geology (Table 2.8.1) are measured in the laboratory. Data are entered onto an electronic database and photos of each sampling site are also stored electronically (Raven *et al.*, 1998b).

2.8.3 How does the River Habitat Survey assess stream condition?

The RHS takes the view that 'in rivers, habitat is the result of predictable physical processes and so conveniently sits between the forces which structure rivers and the biota which inhabit them' (Harper and Everard, 1998 p395). Thus, the RHS measures variables that represent the character of stream habitats, with the assumption that these variables reflect the geomorphological processes that are acting to form those habitats (Newson *et al.*, 1998b). While geomorphological theory underlies many of the variables collected, the RHS is not strictly a geomorphological survey and specific measurements of geomorphic processes rates are not considered (Newson *et al.*, 1998b).

In RHS, the basis for assessing habitat quality, using the information collected at individual 500m sampling sites is:

- quality is based on the presence of channel and river corridor features which are known to be of value to wildlife;
- the two main factors which determine habitat quality are the diversity and 'naturalness' of physical structure; and,
- the system is calibrated, wherever possible, using known top quality sites surveyed specifically for this purpose (Raven *et al.*, 1998b).

Habitat quality assessment can be achieved using four main approaches (Figure 2.8.1). In the first approach, habitat quality is assessed by identifying sites that have pristine and modification free channel characteristics and which are located in areas with a semi-natural land use. In the second and third approaches, reference site groups that represent similar river types are derived, and rarity of individual features or combinations of features is determined within these reference site groups. In the fourth approach, a habitat quality assessment (HQA) score is calculated from the presence and extent of habitat features recorded in the survey (Raven *et al.*, 1998a). The extent of artificial modification in the channel can also be expressed as a separate habitat modification score (HMS, Raven *et al.*, 1998b).

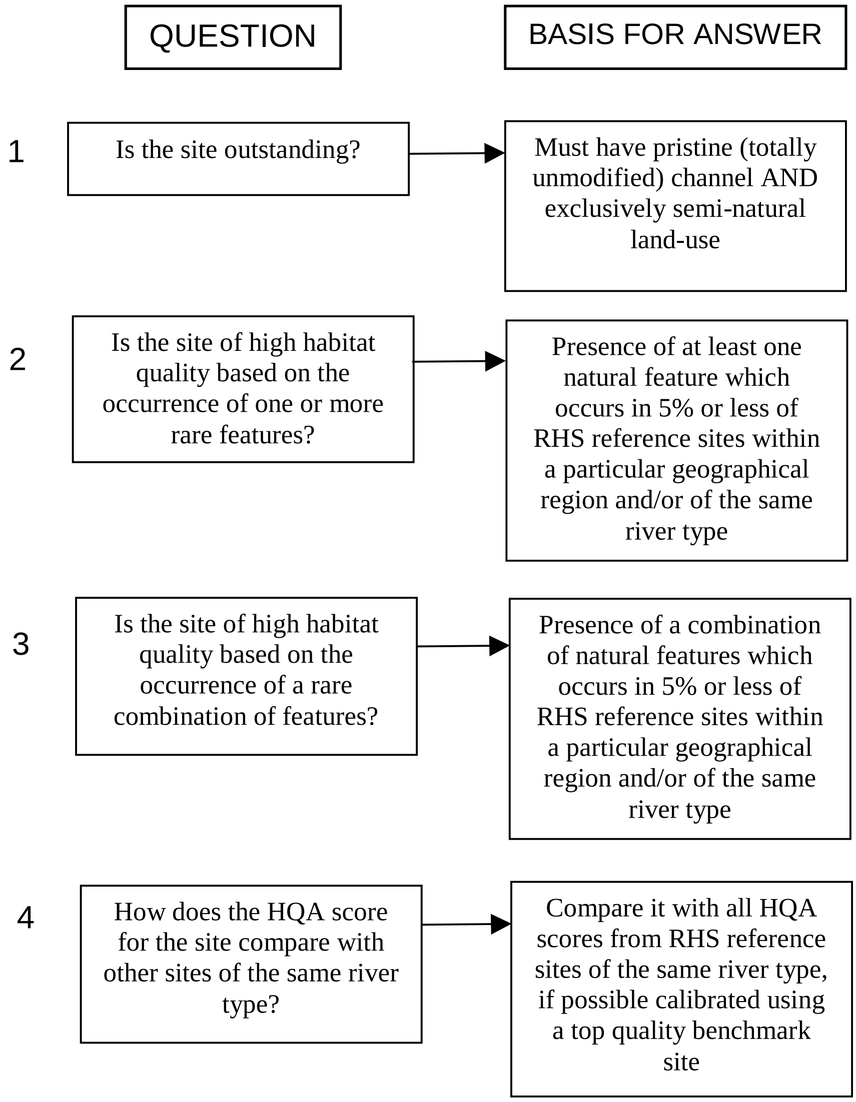


Figure 2.8.1 Four approaches to assessment of habitat quality in the River Habitat Survey. After Raven *et al.* (1998b).

Although still under investigation, one promising outcome of the RHS is an ability to predict the features that are likely to occur in a stretch of river, from map based variables (Jeffers, 1998a). This predictive ability will potentially assist in identifying the effects of channel modification, as well as enabling targets against which rehabilitation efforts can be measured.

2.8.4 How does the River Habitat Survey link physical and chemical features with the biota?

The focus of the RHS on the measurement of habitat quality reflects the underlying assumption that biotic diversity is directly related to habitat diversity (Harper and Everard, 1998). To bridge these two concepts, the RHS uses both a biotope and a functional habitat approach (Newson *et al.*, 1998a). The biotope approach is top down in that the use of habitat units by biota is inferred from a knowledge physical conditions (Newson *et al.*, 1998a). The functional habitat approach is bottom up, in that each habitat is defined from knowledge of the biota that are found in each habitat (Newson *et al.*, 1998a). Thus, it is assumed that by assessing habitat features within this framework the physical influences on biotic composition and the physical influences on habitat formation will both be included.

As mentioned in the previous section, assessment of habitat quality considers the occurrence of habitat features that are of known value to wildlife. The link between these features and wildlife is treated slightly differently in each of the four main approaches. In the first approach, the focus on naturalness reflects the value of this state to wildlife conservation (Raven *et al.*, 1998a). In the second and third approaches, rarity can include features that are of known value to wildlife (Raven *et al.*, 1998a). In the fourth approach, the HQA score considers the presence or absence of features that are of known wildlife interest (Raven *et al.*, 1998a). While there is an empirical basis for the relationships between physical features and biotic structure and process (Resh and Rosenberg, 1984; Harper and Everard, 1998), there is an implicit assumption that the features included in assessments of habitat quality, and in the RHS in general, reflect those relationships. This has not been specifically tested, however, one promising development that may strengthen knowledge in this area is the proposal to link the RHS with the biological assessment program RIVPACS (Wright *et al.*, 1998).

3 SUMMARY AND EVALUATION OF RIVER ASSESSMENT METHODS

3.1 Summary of river assessment methods

The following provides a summary of the advantages and disadvantages of each of the seven river assessment methods examined in detail in the previous section. Each method was developed for a different purpose and thus, the use of the term 'advantages' and 'disadvantages' are not judgements about the relative value of each method as an individual tool for river assessment. Rather, examination of advantages and disadvantages is framed in light of the potential for each method, or components of each method, to fit the requirements of a standardised physical and chemical assessment protocol, within an AUSRIVAS style framework.

3.1.1 AUSRIVAS

Advantages

- Nationally standardised biomonitoring approach
- Uses biota as the endpoint to represent environmental condition
- Comparisons to reference condition establish level of biological impairment
- Capability to predict taxon occurrence at sites
- Incorporates established empirical links between the biota and some of the physical and chemical variables used as predictor variables (e.g. substratum, riparian vegetation, altitude)
- Outputs easily understood by managers, scientists and community groups

Potential disadvantages

- Limited ability to link causal factors (water quality degradation, habitat quality degradation or both) to biological condition
- Assumes that all the major physical, chemical and habitat factors with an empirical link to macroinvertebrate community structure and which can provide an independent way of matching test sites with reference site groups, were included in constructing the predictive models
- Limited ability to predict macroinvertebrate community structure in large river systems

Sampling and data collection issues

- Requires collection of an extensive reference site database to develop models

- Rapid sampling philosophy - approximately 1 hour field work and 1-3 hours laboratory work per site
- Small deviations in methods can limit model capabilities (e.g. live pick and laboratory sort data are not interchangeable)

3.1.2 HABSCORE

Advantages

- Integrates habitat parameters into a score that represents a continuum of conditions for biota. Reference conditions are considered optimal.
- Can be used without modification in other monitoring programs (e.g. AUSRIVAS)
- Habitat parameters are used to determine the ability of the habitat to support biota
- Habitat parameters represent aspects of the habitat that are related to aquatic life use
- Additional site observations aid interpretation of biological condition at a site

Potential disadvantages

- Most criticism is of the multimetric approach to biomonitoring, rather than of the HABSCORE method
- Subject to operator differences in interpretation and scoring of the habitat parameters (Hannaford and Resh, 1995)

Sampling and data collection issues

- Rapid sampling philosophy – approximately 15min per site to assess habitat parameters

3.1.3 Index of Stream Condition

Advantages

- Used for long term assessments of whole stream reaches
- Integrates several key components of stream condition (hydrology, physical form, streamside zone, water quality and aquatic life)
- Management orientated, with a scientific basis. Also useful as a tool for monitoring management interventions

- Indices can be weighted according to their perceived importance, or according to data availability
- The reference state ratings are based on knowledge of levels of stress that cause biological community degradation (e.g. pH, riparian vegetation cover)

Potential disadvantages

- Designed to be repeated every five years, so it has limited suitability for routine monitoring programs
- Reach scale and long term assessment focus means that it may not be detailed or sensitive enough to pick up all perturbations
- Information on the link between a change in index value and a corresponding change in environmental condition is limited
- Determination of reference condition is subjective

Sampling and data collection issues

- Field assessment takes approximately 2 hours at a site. Desk based data collection is also required

3.1.4 Geomorphic River Styles

Advantages

- Foundation in geomorphological theory
- Measures habitats, or physical structure at different scales
- Ability to predict future river character and responses to disturbance, based on geomorphological process theory
- Habitat based links between geomorphology and biota
- Set within a hierarchical framework

Potential disadvantages

- Assumes that the habitat units considered are relevant to biota
- Requires a high level of geomorphological expertise, particularly for interpretation and prediction
- Establishment of the benchmark reference condition is subjective and requires a high level of geomorphological expertise to determine
- Indirect, rather than direct links to river ecology
- Limited testing of the links between geomorphological parameters and biota. For example, is the distribution of geomorphological process zones related to the distribution of the biota?

Sampling and data collection issues

- Air-photos may not be available for some areas, to delineate stream reaches
- Specialised equipment may be required for surveying

3.1.5 State of the Rivers Survey

Advantages

- Comprehensive coverage of stream sections within a catchment
- Assessment of at many levels - whole catchment, individual sections or individual tributaries, using data components individually or together
- Use of homogeneous stream sections allows extrapolation from the sampling scale to larger areas
- Physical measurements indirectly represent geomorphological processes
- Some empirical links between the parameters measured and stream biota (e.g. substratum, riparian vegetation)

Potential disadvantages

- Comparisons to reference condition are subjective
- Links between some measured parameters (e.g. bank condition, bar shape) and biota are not well established
- Links between structure and process are weak

Sampling and data collection issues

- Rapid sampling philosophy - 3/4 to 1 hour per site in the field
- Some desk based data collection also required

3.1.6 Habitat Predictive Modelling

Advantages

- Ability to predict the occurrence of stream habitat features
- Ability to incorporate variables that are directly relevant to biota, as well as variables that are based on geomorphological processes
- Comparisons to reference condition establish habitat impairment
- Use of a method identical to AUSRIVAS may facilitate direct comparison of macroinvertebrate and habitat observed:expected scores
- Set within a hierarchical framework

Potential disadvantages

- Choice of variables may affect predictive ability. Emphasis on biological variables may facilitate links to AUSRIVAS outputs, however, geomorphological process variables may also be important for predicting habitat features
- Currently subject to some analytical limitations (e.g. prediction of categories rather than continuous data)

Sampling and data collection issues

- Can make use of data collected for the existing AUSRIVAS program
- Depending on the choice of variables, rapid sampling philosophies can potentially be applied to data collection

3.1.7 River Habitat Survey

Advantages

- Geomorphological theory underlies many of the variables collected
- Uses the functional habitat and biotope philosophies to link physical habitat with the biota
- Several mechanisms available to determine habitat quality and identify benchmark sites
- Nationally standardised approach
- Potential for linkage with the RIVPACS biological assessment program

Disadvantages

- Links between biota some of the habitat components measured are not well established
- Counts of classes the only feasible data form for most measurements. Thus, the mixture of qualitative and quantitative data, with nominal, ordinal and interval types makes statistical tests difficult

Sampling and data collection issues

- Requires collection of an extensive database to determine initial stream types
- Problems were identified with operator differences - this necessitated the use of occurrence rather than quantitative data, which subsequently reduced the ability for statistical analysis
- Rapid sampling philosophy - approximately 1 hour per site in the field

3.2 Evaluation of river assessment methods

Each of the river assessment methods considered in this review was developed for a specific purpose and thus, the methods reflect a range of management goals and scientific approaches. However, development of a standardised protocol for the physical and chemical assessment of river condition requires consideration of the following specific qualities:

- scale of focus that is commensurate with the AUSRIVAS biological monitoring protocol;
- capacity to measure stream condition against a desirable reference state;
- incorporation of parameters that are relevant to the biota, especially macroinvertebrates;
- representation of important geomorphological processes that influence the formation of stream habitat;
- conformity with a rapid philosophy of data collection and analysis;
- potential for use by non-experts;
- scientific outputs presented in a form that is easily interpreted by managers;
- adaptability and applicability to a wide range of river types across Australia; and,
- ability to predict physical stream characteristics.

The representation of each of these qualities within the seven river assessment methods examined in this review is summarised in Table 3.2.1. Overall, the methods generally use rapid data collection and analysis methods, they have the potential for use by non-experts and their scientific outputs are presented in a form that is easily interpreted by managers (Table 3.2.1). Each of the methods also has some capacity to assess stream condition against a reference state, however, the degree to which this function is utilised in determining site condition varies among the methods. Similarly, the methods vary widely in predictive ability, applicability to a wide range of river types across Australia and scale of focus (Table 3.2.1). Differences between the dominant paradigms of stream ecology and geomorphology are reflected by two criteria: the incorporation of parameters relevant to biota and the representation of important geomorphological processes (Table 3.2.1). Geomorphic River Styles, State of the Rivers Survey and River Habitat Survey were each designed to assess physical or geomorphological aspects of streams and thus, they attempt to incorporate empirical relationships between physical parameters and biota indirectly. Conversely, AUSRIVAS, HABSCORE and Index of Stream Condition have a strong biological component and thus, they fail to fully

Table 3.2.1 Evaluation of seven river assessment methods against the desired qualities of a standardised physical and chemical assessment protocol. The representation of each of the qualities by the methods is designated as yes (Y), no (N), potentially (P) or indirectly (I).

Desired qualities of the physical and chemical assessment protocol	**Potential methods for inclusion in the physical and chemical assessment protocol**						
	AUSRIVAS	HABSCORE	Index of Stream Condition	Geomorphic River Styles	State of the Rivers Survey	Habitat Predictive Modelling	River Habitat Survey
Scale of focus commensurate with the AUSRIVAS biological monitoring protocol	**Y**	**Y**	**N**	**P**	**P**	**Y**	**P**
Capacity to measure stream condition against a desirable reference state	**Y**	**Y**	**Y**	**I**	**Y**	**Y**	**I**
Incorporation of parameters that are relevant to the biota, particularly macroinvertebrates	**Y**	**Y**	**Y**	**P**	**P**	**Y**	**P**
Representation of important geomorphological processes that influence the formation of stream habitat	**N**	**N**	**N**	**Y**	**I**	**P**	**Y**
Conformity with a rapid philosophy of data collection and analysis	**Y**	**Y**	**N**	**N**	**Y**	**Y**	**Y**
Potential for use by non-experts	**Y**	**Y**	**Y**	**N**	**Y**	**Y**	**Y**
Scientific outputs presented in a form that is easily interpreted by managers	**Y**	**Y**	**Y**	**P**	**Y**	**Y**	**Y**
Adaptability and applicability to a wide range of river types across Australia	**Y**	**P**	**P**	**P**	**P**	**Y**	**P**
Ability to predict physical stream characteristics	**Y**	**N**	**N**	**Y**	**N**	**Y**	**P**

consider geomorphological processes. Finding common ground between biologically and geomorphologically relevant parameters would provide a more holistic perspective on the assessment of stream condition.

3.3 Future directions - habitat assessment workshop

As discussed in Section 1.1, development of a protocol for the physical assessment of stream condition that is complementary to AUSRIVAS requires simultaneous consideration of biological and geomorphological methods and approaches. This review is a first step towards merging the two approaches to stream assessment, and provides an information base that that will be built upon at the habitat assessment workshop, scheduled for 2-3 May, 2000. The habitat assessment workshop will bring together geomorphologists, hydrologists and ecologists and will involve the authors of several of the methods covered in this review. The aim of the workshop is to develop a framework for a standardised physical and chemical assessment protocol. One of the main challenges of the workshop will be to determine the physical variables that are relevant to biota, and to determine the most suitable methods for measuring these variables in a cost effective manner, and within a rapid sampling philosophy. Specifically, it is hoped that the questions posed in Section 1.1 will be answered in detail during the course of the workshop to form the basis for a standardised physical and chemical assessment protocol. The outcomes and recommendations from the habitat assessment workshop will be reported in a future document.

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