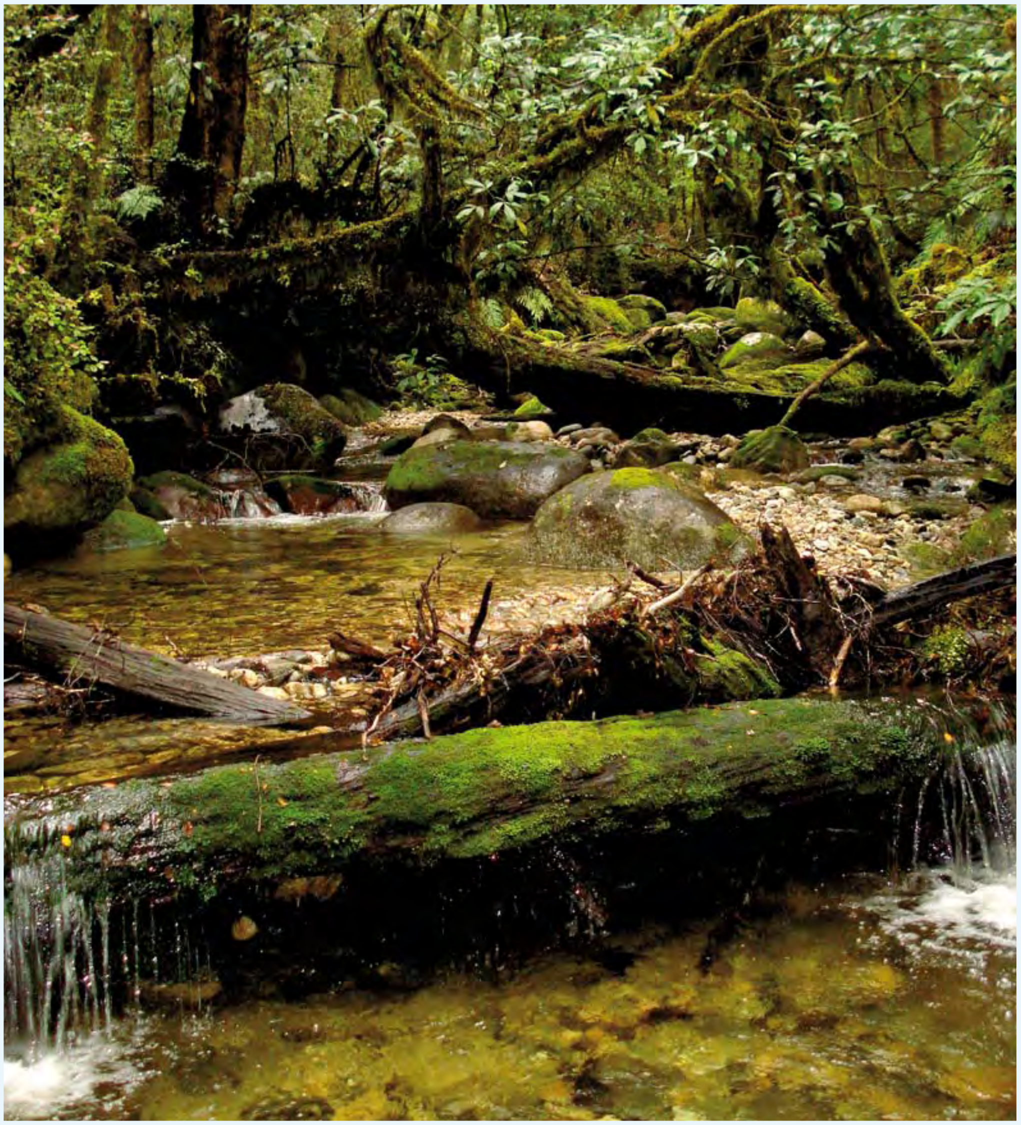
Stream Habitat Assessment Protocols

for wadeable rivers and streams of New Zealand



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Jon S. Harding, School of Biological Sciences, University of Canterbury

Joanne E. Clapcott, Cawthron Institute

John M. Quinn, National Institute of Water and Atmospheric Research

John W. Hayes, Cawthron Institute

Mike K. Joy, Institute of Natural Resources, Massey University

Richard G. Storey, National Institute of Water and Atmospheric Research

Hamish S. Greig, School of Biological Sciences, University of Canterbury

Joe Hay, Cawthron Institute

Trevor James, Tasman District Council

Mary A. Beech, Environment Canterbury

Rachael Ozane, Otago Regional Council

Adrian S. Meredith, Environment Canterbury

Ian K.G. Boothroyd, Golder Associates

Cover image: A tributary of the Inangahua River near Reefton, Westland, with complex physical habitat. The stream includes pool, runs, rapids and cascades and is heavily shaded by native vegetation. The in-stream habitat consists of cobble and boulder substrate with large woody debris obstructing the flow and providing fish cover. Photograph: Hamish Greig.

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Preface

Often when you visit a stream or river for the first time your impression of that stream is based on the visual clues about its surrounding landscape and how the stream looks. These visual impressions are in effect an assessment of the physical condition of the stream. Although we may not think of it in that context, what we are doing is picking up cues about the condition of riparian zone, the presence of human engineering structures, the current and recent of flow conditions and the morphology of the stream bed. Historically, much of the focus of stream assessments have been on measuring water quality and collecting ecological information about algae, invertebrate and fish communities. Frequently, less emphasis has been placed on collecting hydrological, riparian or stream morphology data. Increasing pressures to extract water from our streams and rivers has meant that understanding the relationship between flow levels and stream communities have become more important. Similarly, greater demands for stream restoration and effective riparian management have occurred as our understanding of the importance of riparian and habitat conditions in maintaining the structure and function of healthy streams has increased. As a result, there has been an increasing need for better and more consistent tools to characterize and quantify stream habitat. These protocols are an attempt to fulfill that need.

Acknowledgements

The development of these protocols have been greatly improved by feedback from various colleagues from Regional Councils, Department of Conservation, Consultants, Research Institutes and tertiary Academics. We also thank participants at workshops held at the NZ Freshwater Sciences Conference in Rotorua in 2007 and at New Plymouth in 2008 who suggested numerous significant improvements. These protocols were developed under the Envirolink Tools program funded through the Foundation for Science Research and Technology. Finally we thank Matthew Walters for formatting and arranging publication of the final document and Joanne Ocock for compiling Appendix 2.

Contents

CD
- GIS shape files and Excel tables with REC and FWENZ catchment and reach data
- Electronic field forms for P1, P2, and P3
- Excel spreadsheets with macros to calculate hydrological indices

Part 1 – Introduction

Overview

The physical character of a stream determines the quality and quantity of habitat available to biological organisms and the stream's aesthetic and amenity values. Physical habitat is the living space for all in-stream flora and fauna, it is spatially and temporally dynamic and its condition and characteristics set the background for any assessment of the health of a waterway. As such, physical habitat is regularly measured as part of a wide range of stream research and resource activities in New Zealand and overseas.

In 2006 a survey was conducted of Regional Council and other government freshwater scientists in order to determine the current use and types of physical habitat assessments being undertaken (Appendix 1). The results from this survey indicated that many organisations currently undertook physical habitat assessments as part of regular site assessments, however considerable variability existed among the parameters measured and how this data was subsequently used.

Key issues that were identified from the survey and that have guided the development of these protocols include:

a) A wide diversity and disparity between habitat assessment methodologies being used by Regional Councils, Research Institutes, Government Agencies, Universities and Consultants. Virtually every organisation uses differing protocols.

b) Little or no peer-review has been conducted on the various protocols in use, making comparisons between methods difficult and creating doubts about the reliability and usefulness of data.

c) Many habitat assessment criteria are qualitative and subjective, thereby creating opportunities for error and significant variability in results and conclusions.

d) Little is known about the suitability of some methods compared to others.

e) The need for national consistency and an ability to compare habitat conditions both within and across regional boundaries and over time.

The primary purpose of this book is to provide a set of practical, cost-effective and standardised protocols for the assessment of physical habitat in New Zealand waterways. These protocols were produced in response to a request by Regional Councils to provide guidelines and preferred methods for the assessment of physical habitat conditions within stream and river systems. They have not been designed to include lentic systems such as ponds and lakes. As in the protocols developed for sampling macroinvertebrates (Stark et al. 2001), these guidelines apply to wadeable streams and do not attempt to encompass larger rivers. The assessment of non-wadeable rivers remains difficult and restricted to parameters which can be evaluated from the bank, from a boat or by desktop assessments. Although many of the parameters in these guidelines can be assessed via desktop and stream bank evaluations, a number of features also require the observer to measure in-stream conditions.

During the development of these protocols the authors identified several river systems which although wadeable, might be particularly challenging to adequately assess. In particular, it may be difficult to accurately measure channel and cross-sectional profile parameters of wide braided rivers. In these cases the assessor needs to make a decision about how they will treat these systems and how realistic it is to collect representative quantitative data.

Scope

This book is designed as a self-contained guide to measuring the physical habitat of wadeable streams. It introduces key principles and issues relating to habitat assessment and provides a range of protocols for conducting field and desktop assessments. The practitioner is provided with a choice of protocols and guidance on selecting the most appropriate protocol for their aims. It is intended that the information provided will allow practitioners to measure the current state of stream habitat using accurate and specific variables that allow for the identification of a trend in habitat condition both spatially and temporally.

This document is structured into three parts:

Part 1 - Introduction

- Outlines the many reasons why a habitat assessment might be conducted
- Assesses the relative merits of qualitative and quantitative measurements
- Considers issues of scale and reference condition
- Provides advice on quality assurance and quality control
- Provides guidance on selecting the right protocol

Part 2 - Protocols

- Introduces stream habitat parameters and their ecological relevance
- A choice of three field protocols that require different levels of input (time, training, equipment, and analytical investment) and provide different qualities of data
- Step by step guidelines for the application of each protocol
- Desktop protocol (which is used in conjunction with field protocols)
- Recommendations for quality control

Part 3 – Supporting documentation

- Results of a survey of Regional Councils and agencies used to guide the development of these protocols (Appendix 1)
- Collated information from regional and national applications and international literature to ensure methods are consistent and shaped by the best knowledge available (Appendix 2)
- Physical components that are most likely to have causal linkages with the structure and functioning of biological communities (Appendix 2)
- Fieldsheets for protocols 1, 2 and 3 (Appendix 3)
- Electronic spreadsheets to aid in the management, analysis and reporting of data (attached CD).

Although the key section for many readers will be the recommended ‘Protocols’, we have included a comprehensive appendix which reviews recent New Zealand and international literature on stream habitat assessments. This literature has been synthesized in order to identify the common parameters and conditions frequently assessed in current stream habitat methods and we have attempted to clarify the ecological and functional conditions that these parameters relate to. These protocols also include standard field sheets and a detailed description of how to collect the relevant data for each protocol. Where possible, we have included diagrams and photos to support the appropriate protocols.

However, this document does not provide advice on the development of regional or national stream habitat assessment programs. As multiple protocols have been provided it is essential that during the design phase of any program, the program managers have a very clear idea of what data they need and how they will use them. It is intended that the protocols provided will only be used once the reason for habitat assessment has been decided, although guidance is provided on the choice of protocols for certain applications.

It is essential that each user has a clear vision about what they want from any stream habitat assessment, and that they clearly identify their aims and objectives in advance.

Many habitat protocols used internationally provide a “scoring” system, enabling users to rank sites based on perceived degradation of physical habitat. During the development of these protocols the project team debated this issue. We concluded that we could not provide a robust scoring system unless it had been adequately tested and had been demonstrated to be scientifically defensible. We believe that we do not currently posses sufficient robust science to link scored values to ecologically meaningful results. Furthermore, real challenges are apparent when trying to develop a scoring system which could be applied to the wide range of topographies and geologies occurring throughout New Zealand. For example, natural pumice material in the Volcanic Plateau creates physically unstable stream substrate which is not easily comparable to boulder-dominated streambeds in Fiordland. However, this document does provide an introduction to the concept of reference condition and discusses some tools available for determining reference condition or identifying reference sites, if desired.

These Stream Habitat Assessment Protocols have been developed with the following guiding principles:

a) A focus on physical habitat parameters only. Water quality and biological data are not included although we intend that the physical variables suggested will have direct and indirect associations with stream condition and health. Although some in-stream parameters include assessment or measurement of algae, moss and macrophytes, these parameters are included for their value as habitat or as indicators of waterway condition and disturbance (see ‘Defining stream habitat’ and ‘Aims of physical habitat assessment’).

b) Any physical habitat assessment requires understanding the stream condition at multiple spatial scales. We have identified parameters and methods at three spatial scales; the whole catchment scale, the valley segment scale and the reach scale (see ‘Site selection’ and ‘Scale considerations’).

c) The methods are designed to be applied to all wadeable lotic waterways in New Zealand; however any interpretation of these results needs to be placed in the context of the type of waterway. For example, a spring or lake outlet would be expected to have naturally differing physical conditions from each other. As in any assessment, we consider that findings should be compared over time and with control or reference condition values (see 'Reference sites').

d) Regional Council staff requested that field measurements at any site be conducted within a reasonable timeframe. However, time limitations restrict the quantity and quality of data collected; therefore we have provided three alternative protocols that differ in required levels of investment in training, equipment, field time and analytical time (see 'Quantitative v qualitative data' and 'Selecting the right protocol').

e) Users should be familiar with many of the methods as these protocols have been adapted from methodologies currently in use. Definitions and examples are provided to further clarify how to measure parameters. Where there is already an established habitat assessment protocol in use, we recommend practitioners adopt these new protocols in addition to their existing protocols for at least three sampling seasons. This will allow for the calibration of historic datasets (see 'Transition from existing protocols' and 'Quality assurance and quality control' and 'Glossary').

Guiding principles

Defining stream habitat

Stream habitat is where stream organisms live. It is the water and the physical, chemical and biological environment that the water flows under, over and permeates through. Rivers and streams are open ecosystems that connect and are intimately linked to their surrounding environments by the water cycle, from the atmosphere to the oceans. Like water, many organisms traverse ecosystems and may only spend part of their life in a stream. Besides providing a basic medium for survival, the physical stream habitat may provide shelter, protection from predators, habitat for eggs and oviposition, as well as modifying water chemistry and parameters.

There is extensive literature which demonstrates that the quantity and quality of physical habitat determines the successful colonisation and maintenance of populations (Appendix 2). Hence we can use measures of physical features to describe habitat and the likely responses of biological communities.

The physical characteristics of a stream are determined by the interaction between a range of factors including topography, climate, geology and land-use which directly control the geomorphology and hydrology of the river. These processes interact at a multitude of scales to produce a mosaic of physical features that describe stream habitat. For example, catchment geology interacts with annual stream discharge to influence channel shape, while shear stress interacts with localised water velocities to distribute fine sediments across the streambed. These interactions and resulting physical features are temporally and spatially dynamic and result in changes to physical stream characteristics longitudinally down a river network, laterally across a river flood plain, vertically from the water surface to the hyporheic zone, and over time in response to the natural flow regime.

Parameters that describe the physical characteristics of stream habitat can be categorised hierarchically (Fig. 1). This provides some indication of the scale of the interaction between hydrology and geomorphology that shapes these characteristics (for further discussion see the 'Scale considerations' section).

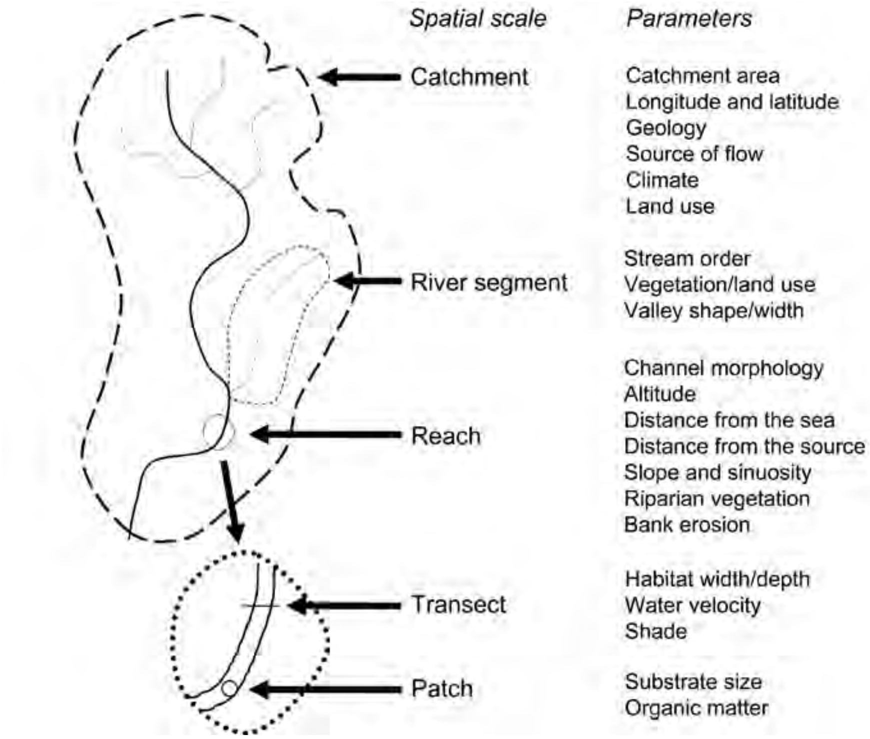

Figure 1. A hierarchical view of the physical characteristics that shape stream habitat.

Aims of physical habitat assessment

The physical stream environment might be assessed for a number of reasons, however, the two most common reasons are probably to:

- categorise streams into typologies that aid in stream management
- provide an assessment of the habitat available to stream life

The former aim has resulted in the development of geographical information system (GIS) layers in New Zealand that have the potential to provide powerful tools for the classification of stream environments, for example, the River Environment Classification (REC) (Snelder et al. 2004) and Freshwater Environments of New Zealand (FWENZ) (Leathwick et al. 2008).

In practise, habitat data is often collected to provide a background assessment of the health of a waterway. Typically these might be as:

- State of the environment reporting (SOE)
- Assessment of environmental effects (AEE)
- Consent and compliance monitoring
- Assessment of restoration efforts

They are also used to provide correlative data to investigate mechanisms to explain the patterns in diversity, distribution and abundance of biological communities. For example:

- fundamental ecological research
- fish and/or macroinvertebrate habitat predictive modelling

As we have already stated, the final decision about what to measure and what not to measure needs to be decided in the context of specific assessment aims.

Quantitative vs qualitative assessment

The approach taken to analyse stream habitat influences the types of factors measured and their intensity of measurement. For example, if stream habitat is going to be categorised using predictive modelling, then the physical data collected needs to be quantitative in nature, whereas other more subjective or qualitative assessment may be acceptable for the characterisation of sites. Differing approaches may require markedly different levels of intensity of data collection. Consequently, the most basic difference between methods of stream habitat assessment is whether data collection is based on quantitative- or qualitative-style measurements; each of which have their benefits and drawbacks.

The **qualitative** method, such as that used in the USEPA's Rapid Bioassessment Protocols (RBPs; Barbour et al. 1999) is characterised by visual observations which are ascribed to categories. This allows for rapid, low cost evaluations which are easy to understand and interpret. Habitat quality is often scored, however, while visual assessments are attractive because of their ease of use in the field and in data reduction, their lack of precision limits their applicability (Kaufmann et al. 1999). The use of qualitative scoring systems in habitat assessment can be improved by comparisons with reference streams that are relatively unimpacted (see 'Reference sites'). Kaufmann et al. (1999) conducted a comprehensive review and analysis of precision in stream physical habitat assessment, and presented a number of suggestions for reducing subjectivity and increasing precision in both quantitative and qualitative measures. Relevant points for qualitative assessment include:

1) Visual estimates are more precise when limited to measurable characters (e.g., cover, % composition), rather than judgments of habitat quality.
2) Assessments should be independent of flow conditions, e.g., measurements can be taken at baseflow or flood.
3) The size of habitat assessed should be kept constant.
4) Precision can be increased by combining metrics into one unit (e.g., use coarse instead of fine Wentworth substrate classifications).
5) Repeated samples of the same stream reach increases precision over time, regardless of the measurement/quantification process used.

In contrast to subjective assessments in qualitative protocols, data obtained using the **quantitative** approach is determined by actual measurements of habitat parameters. This reduces subjectivity and promotes a level of precision, accuracy and repeatability not attainable in qualitative methods. For example, quantitative assessments of stream width and water depth can be measured very accurately and together with substrate composition are often the most precise quantitative assessments. However, estimates of land use, bank vegetation, embeddedness, bankfull width and bank-bank width are often the least precise (Wang et al. 1996). Regardless of their relative precision, measurements that enable the quantitative assessment of habitat parameters can be time consuming and costly, and require more complex data analysis than qualitative approaches.

Therefore, these protocols provide a selection of qualitative, semi-quantitative and quantitative assessments to cover a range of different study objectives that require different levels of output (see also 'Selecting the right protocol').

Scale (time and space) considerations

Any assessment of stream habitat conditions is likely to involve analysis at multiple spatial scales. This is because numerous drivers interact at varying scales to shape the physical stream environment.

Components that are commonly used to characterise stream physical habitat include:

- catchment-scale conditions (e.g., surrounding land use)
- bank and floodplain characteristics (e.g., bank stability and amount of bank undercut)
- riparian zone features (e.g., canopy cover, riparian width and vegetation composition)
- in-stream conditions (e.g., substrate composition and wood)

We have developed a combination of desktop and field assessments to encompass physical features at multiple scales; with landscape level features predominantly recorded during a desktop assessment and smaller scale attributes measured in the field. In addition to spatial aspects, some assessment parameters also characterise the temporal variation of stream habitat. For example, mean annual low flow provides an indication of the flow regime throughout a year. For many parameters, temporal variability can only be assessed by the comparison of multiple measurements taken over time. Because many parameters will be influenced by seasonal variability (e.g., periphyton is most abundant in late summer, or fine sediment distribution may change after spring flood events), we recommend that annual assessments be made at the same time of year when possible. Where possible we have tried to select parameters that are independent of flow conditions, but high flow can restrict assessment of some metrics. We recommend that field assessments be conducted during base flow conditions if possible.

Site selection

Site selection will be strongly influenced by the aims and objectives of a study or monitoring programme. Sometimes a stream habitat assessment will form only one part of an assessment conducted at a site. In which case, the primary focus of the work will determine site selection. When the primary purpose is a stream habitat assessment, site selection will be determined by whether the aim is to provide a fair representation of a defined area or stream type (e.g., to categorise streams or for the purposes of SOE reporting), or to measure a localised change in habitat condition (e.g., assessing restoration efforts, AEE, or consent and compliance monitoring). In the former aim, replicated sites of similar qualities would need to be selected (e.g., a minimum of 3-5 reaches on differing rivers). In the later aim, a single reach might be the focus of assessment, but sites providing control conditions will probably be required for comparison. Random selection of survey sites is essential if the intention is to make inferences about general stream condition at larger scales (e.g., catchment, by land use category, within a whole region).

In both circumstances it may be useful to apply stream classification tools to stratify sampling effort and help select appropriate sites for comparison. There are a number of methodologies available. The Rosgen (1996) classification, which uses geomorphic characteristics to group streams into seven types, is a commonly used example. More recently, geographical information system (GIS) tools have been developed, which group streams based on physical templates. For example, the River Environment Classification (REC; Snelder et al. 2004) groups streams into types based on variables derived from geology, climate, source of flow and position in the river network. Similarly, Freshwater Environment Environments of New Zealand (FWENZ Leathwick et al. 2008) hierarchically groups sites by physical similarity. Together these systems provide a comprehensive classification of New Zealand rivers by segment and we recommend the use of GIS classification for guiding site selection.

Site selection starts as a desktop exercise with the identification of representative sites using a combination of topographic maps, aerial photographs, REC and FWENZ information and local knowledge. Ideally, a list of potential sites are identified from which a sub-set of suitable sites can be found. Sites should then be randomly selected and followed up by a field visit to verify that each site is suitable for the study.

If the aim of an investigation is to monitor temporal changes, fewer sites will need to be selected, but each site will be visited on multiple occasions, perhaps over a considerable time period. In this case, it is important to ensure that sites can be found again, potentially after substantial changes have occurred in the surrounding landscape and assessment personnel. Recording accurate grid references, noting prominent structures near by and making site diagrams will all aid in ensuring that the same reach is re-sampled on subsequent occasions.

If the investigation is monitoring changes in critical sites affected by a specific impact, very few sites may be assessed and a typical before and after, control and impacts (BACI) methodology can be adopted (Fig. 2). Care needs to be taken to ensure that sites are suitably located to be true control/impact sites. This is especially important if the pathways and effects are diffuse, and considerations of both potential upstream and downstream impacts are important. For example, barriers to fish migration may influence fish communities many kilometres into a stream (Eikaas and McIntosh 2006).

When the aim of the investigation is to describe the mean and variance of habitat conditions in a stream or segment, sufficient replicate sites need to be selected to capture spatial variability within the focal stream.

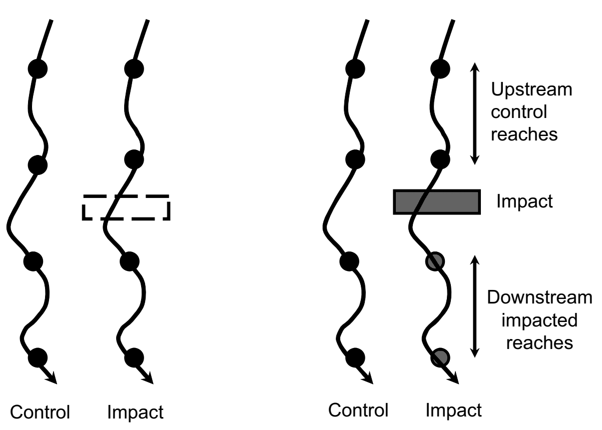

Figure 2. Before-after-control-impact (BACI) design. Solid circles indicate sample reaches. Multiple before and after and upstream and downstream reaches are important to reduce any possible confounding effects of variation between individual sites caused by chance.

Regardless of the aim of the investigation, a few points should always be considered during the site selection stage:

How long should a survey reach be?

For stream habitat assessment a site is defined by a survey reach. The length of the survey reach should incorporate the full variation in habitats (i.e. run, riffle, pools) and this will vary according to stream width. The length of the survey reach should also reflect the aims of the study, for example, a rapid qualitative assessment may only require 10x the wetted width (AUSRIVAS; Parsons et al. 2001) whilst an in-depth quantitative assessment may require 40x the wetted width (USEPA; Kaufmann et al. 1999). We recommend the sampling reach should be 10x the average wetted width at base flow for Protocol 1 (or, as long as you can see upstream and downstream from a vantage point) and 20x the average wetted width for Protocols 2 and 3 respectively, to ensure in-stream variability is appropriately assessed. With very narrow and very wide channels we recommend a minimum reach 50m long and a maximum 500m long regardless of the protocol used.

Is the site affected by structures that may affect habitat?

Bridges, weirs, road crossings, gravel/water abstraction will affect the natural morphology of a stream and they should be avoided if possible, unless of course they are the focus of the assessment.

Can you safely make measurements along the whole reach?

First and foremost with any field sampling is the consideration of personal safety and hazard identification. Stream habitat assessment protocols require the practitioner to walk the length of the sample reach and in more detailed protocols to regularly enter the stream. An assessment can not be completed if there is an unacceptable risk to personal safety. We recommend that assessments are not conducted during above average flows and that caution is taken when sampling systems known to respond rapidly to flow changes.

Access: do you need permission, where will and how will you access sites, does this change seasonally?

It is not very often that data is collected in isolation. At a minimum, a mapped location of the site is necessary to relocate the site (e.g., northing and easting or a grid reference). Where relevant, private land holder details should be recorded and they should be contacted prior to field visits.

Reference sites

Comparison to a reference condition is often used as a framework to 'judge' the health of a waterway (Hawkins et al. 2000, Boothroyd et al. 2002, Stoddard et al. 2006). Study sites are compared to reference sites to determine the departure from natural condition. The similarity between, or ratio of observed (study site) to expected (reference), can be used to score stream condition. This approach has been applied to macroinvertebrates (Joy and Death 2003) and fish (Joy and Death 2002, 2004) in New Zealand. This approach could also be applied to physical habitat assessment.

Identifying appropriate reference sites might use a stream classification (e.g., FWENZ and REC) to ensure a study stream is compared to a reference streams of similar natural characteristics. However, in many regions determining a reference condition can be hampered by the lack of non-impacted sites for some stream types, in which case a management decision must be made on what constitutes best-attainable reference condition. Often this equates to a 'least disturbed' condition. This incorporates a degree of subjectivity in reference site selection which is potentially problematic. For example, Frappier and Eckert (2007) argued that reference streams selected in RBP's are based on highly subjective ideas of what an 'ideal' stream looks like, and that because the scores of similar streams can vary tremendously, there is a reduction in sensitivity at detecting alterations to the stream habitat. Several other workers have also noted problems with validating reference streams (Boothroyd et al. 2002). Comparison to reference condition is further made difficult due to the natural variation within some stream types. This source of potential error can be reduced by multiple study and/or reference sites. Managers should be aware that conclusions based on the use of reference conditions in stream habitat assessment is constrained by assumptions made during their selection.

Transition from existing methods

Numerous methods have been developed worldwide to assess the physical or geomorphological condition of streams (see review in Appendix 2). These methods have the potential to enhance the interpretation of biological assessments of stream condition, or to provide information on stream condition that may not be immediately apparent based on biological assessment alone.

The protocols documented here are based on recurrent parameters in international methods. Stream features and parameters inherent to New Zealand have been incorporated, such as high flow variability and complex channel morphology. Some of the protocols that practitioners may be familiar with (and from which these protocols take guidance) include:

Qualitative

- USEPA Rapid Bioassessment Protocol (RBP) - Barbour et al. 1999 (USA)
- Riparian, Channel and Environmental Inventory (RCE) - Petersen 1992 (Sweden)
- Habitat Condition Index - Oliveira and Cortes 2006 (Portugal)
- HABSCORE – a component of RBP, RHS and AUSRIVAS (NZ and Australia)

Quantitative

- USEPA Wadeable Streams Assessment - Kaufmann et al. 1999 (USA)
- Australian River Assessment System (AUSRIVAS) Physical Assessment Protocol – Parsons et al. 2004 (Australia)
- State of the Rivers Survey, Queensland - Anderson 1993 (Australia)*
- Victorian Index of Stream Condition - Ladson et al. 1999 (Australia)*
- RiverStylesTM - Brierley and Fryis 2000 (Australia)
- CREAS and WIS – McMurtrie and Suren 2006, Suren and McMurtrie 2006 (NZ)*
- River Habitat Survey (RHS) and Habitat Quality Assessment - Fox et al. 1998, Raven et al. 1998 (UK)*

* contains qualitative assessments

There will be similarities between the New Zealand protocols and aspects of some of the methods above (further discussed in Appendix 2). However, the New Zealand protocols provide a nationally consistent method developed to enable a habitat assessment to be made on a number of levels and timeframes.

Where an established habitat assessment protocol is being used, we recommend users adopt these new protocols in addition to their existing protocols for at least three sampling seasons. This may allow for the calibration of past datasets and further aid in the training of users. It will also allow for the comparison of protocols to determine whether data are comparable and which protocol is the most appropriate to adopt long-term.

Quality assurance and quality control

Quality assurance (QA) is used to control and minimise error whilst ensuring a robust and accurate data set, whereas quality control (QC) is used to monitor quality. The first step to good quality assurance in stream habitat assessment is choosing the most appropriate protocol for the given study aims and objectives (see also 'Selecting the right protocol'). The second step is ensuring accurate data collection through user training and equipment calibration. In these protocols we have provided detailed instructions, photographs, diagrams and definitions in order to assist users in collecting consistent data. The final step is implementing quality control procedures such as data checking, cross user-validation and on-going training.

As outlined in the 'Quantitative vs qualitative' section, qualitative assessments are less precise than quantitative assessments because they involve a subjective judgement by the user which will be influenced by their experience and background. Therefore, between-user error is the most likely form of error in stream habitat assessments. This can be minimised by group training and an increased understanding of the terminology involved in assessments. Newcombe et al. (2007) suggest that training can increase precision and repeatability, preventing serious errors in interpretations that result from biased data.

During training, attention needs to be focussed on some parameters where there is proven confusion and ambiguity. For example, Maxted et al. (2002) showed that it is often difficult to distinguish pools from slow runs, mud silt from soft clay, fine and coarse detritus, or native shrubland from mixed shrubland. In contrast, the accuracy of direct visual observations for quantifying substrate composition is reasonable compared to photo-digital techniques (12% difference for any substrate class at worst, but usually less than 5%)(Wang et al. 1996). In general, variation among adequately-trained observers can be relatively low, but quality checks should be maintained, particularly with new observers. These protocols offer further recommendations for quality control in Part 2 on training and data collection, data entry and analysis.

Selecting the right protocol

To aid the user in collecting and collating the appropriate data required for an assessment of physical stream habitat, these protocols provide a desktop protocol and field protocols across three levels of complexity. The desktop protocol can be used in the site selection process and may also be used to accompany all three protocols. At a minimum we recommend that the desktop GIS protocol be used for both Protocol 2 (P2) and Protocol 3 (P3).

How long will it take in the field?

The desktop protocol will probably be relevant to most studies and should take less than 30 minutes to complete, depending on the users familiarity with GIS. The three field protocols range in time required at a site from 5-10 minutes (Protocol 1), 45-60 minutes (Protocol 2) and 2-3 hours (Protocol 3), which reflects the varying levels of data collected. Aspects relating to spatial considerations in the field (i.e. the size of a survey reach) are discussed in the next section.

Table 1 lists the protocols that would provide a user with sufficient data to address possible aims and objectives of some example applications for completing a physical stream habitat assessment.

Table 1. Examples of stream habitat assessment applications and appropriate protocols

Application	Protocol
Site selection/scouting	Desktop + P1
State of the Environment reporting (SOE)	Desktop + P1
Assessment of Environmental Effects (AEE)	Desktop + P2
Consent and compliance monitoring	Desktop + P2
Assessment of restoration efforts	Desktop + P2/P3 (depending on aims)
Fish, macroinvertebrate, algae habitat predictive modelling	Desktop + P3
Fundamental ecological research	Desktop + P2/P3 (depending on aims)

Table 2 provides the user with a summary of resources required for each protocol. It includes the minimum investment required in terms of equipment, time and quality control and assurance for each level of assessment, and also indicates the level of investment required, with darker shading indicating greater investment. The matrix also shows the nature of an assessment in terms of qualitative and quantitative parameters.

Table 2. Selecting the right protocol based on available resources

Resources	Protocols			
	Desktop	P1	P2	P3
Equipment				
GIS software	▒			
Spreadsheet software (e.g., Excel)	▒	▒	▒	▒
Camera, GPS		▒	▒	▒
Water velocity meter, ruled rod, measuring tape, two 1.5m survey poles and inclinometer (or builders level), trowel, range finder (optional - wide streams)			▒	▒
Densiometer, six warratahs (optional - if follow-up measurements of width and depth are intended)				░
Time (mins)	░ <30	░ <15	▒ <60	▓ <180
Quality assurance and control				
Equipment calibration			▒	▒
User training	░	░	▒	▓
Data checking	░	░	▒	▓
Data analysis		░	▒	▓
Nature of assessment				
Qualitative		░	░	
Quantitative			░	░

Part 2 – Protocols

Catchment characteristics

The geological, topographical and climatic conditions within the catchment all influence the physical and hydrological characteristics of the river (Gordon et al. 2004). In these protocols were have incorporated a range of catchment and reach (segment) characteristics extracted from existing databases, specifically REC and FWENZ (Snelder et al. 2004a, Leathwick et al. 2008). All protocols (P1, P2 and P3) can be used in conjunction with a desktop analysis of catchment and reach characteristics and all variables are provided on the CD accompanying this book. Details of the habitat parameters available from the REC and FWENZ databases and their measurement units are provided in Table 3. For further information on how these variables were generated see the relevant REC and FWENZ publications (Snelder et al. 2004a, Leathwick et al. 2008). Depending on the level of detail required, the actual numerical values (proportions) can be recorded, or the REC classifications can be used (Table 4).

Table 3. Parameters and brief description of REC and FWENZ categories.

Parameter name	Description
NZ REACH NUMBER	The universal number that links this reach to the REC and FWENZ databases
CATCHMENT AREA m^2	The area in square meters of the catchment upstream of the study reach
CATCHMENT CALCIUM	Catchment average of calcium
CATCHMENT HARDNESS	Catchment average of hardness (induration)
CATCHMENT PHOSPHOROUS	Catchment average of phosphorous
CATCHMENT PROPORTION ALLUVIUM	% of catchment in Land Resource Inventory (LRI) category (alluvium)
CATCHMENT PROPORTION BARE LAND	% of catchment in Land Cover Database (LCDB) category (bare land)
CATCHMENT PROPORTION EXOTIC FOREST	% of catchment in LCDB category (exotic forest)
CATCHMENT PROPORTION GLACIAL	% of catchment in LRI category (glacial)
CATCHMENT PROPORTION INDIGENOUS FOREST	% of catchment in LCDB category (indigenous forest)
CATCHMENT PROPORTION MISCELLANEOUS LANDCOVER	% of catchment in LCDB category not covered by others
CATCHMENT PROPORTION PASTORAL FARMING	% of annual runoff from LCDB category (pastoral)
CATCHMENT PROPORTION PEAT	% of catchment in LRI category (peat)
CATCHMENT PROPORTION SCRUB	% of catchment in LCDB category (scrub)

Parameter name	Description
CATCHMENT PROPORTION TUSSOCK	% of catchment in LCDB category (tussock)
CATCHMENT PROPORTION URBAN	% of catchment in LCDB category (urban)
CATCHMENT RAINFALL VARIABILITY	Coefficient of variation of annual catchment rainfall
DISTANCE TO COAST (m)	Distance from reach to the coast (m)
FLOW	Total annual runoff volume (mm*m^2/yr)
LOW FLOW	Mean annual low flow l/s
NUMBER OF CATCHMENT RAINDAYS > 25mm	Catchment rain days (greater than 25mm/month)
ORDER	Strahler stream order
REC CLIMATE	River Environment Classification (See Table 4)
REC GEOLOGY	River Environment Classification (See Table 4)
REC LANDCOVER	River Environment Classification (See Table 4)
REC SOURCE OF FLOW	River Environment Classification (See Table 4)
REC VALLEY LANDFORM	River Environment Classification (See Table 4)
SEGMENT MAXIMUM ELEVATION (m)	Elevation at highest point on reach
SEGMENT MINIMUM ELEVATION (m)	Elevation at lowest point on reach
SEGMENT SINUOSITY	The reach length (as the fish swims) divided by the Euclidian reach length (as crow flies)
SEGMENT SLOPE	Ratio of difference between top and bottom of reach/reach length
TEMPERATURE SUMMER	Mean January air temperature
TEMPERATURE WINTER	Mean minimum July air temperature
usXcentroid	NZ map grid point at the top of the reach
usYcentroid	NZ map grid point at the top of the reach

Table 4. The River Environment Classification (REC) classes.

Climate	Notation	Land cover	Notation
Warm-Extremely-Wet	WX	Bare	B
Warm-Wet	WW	Indigenous	IF
Warm-Dry	WD	Pastoral	P
Cool-Extremely-Wet	CX	Tussock	T
Cool-Wet	CW	Scrub	S
Cool-Dry	CD	Exotic Forest	EF
Geology		Wetland	W
Alluvium	Al	Urban	U
Hard-Sedimentary	HS	**Source of flow**	
Soft-Sediment	SS	Glacial-Mountain	GM
Volcanic-Basic	VB	Mountain	M
Volcanic-Acidic	VA	Hill	H
Plutonic	PL	Low-Elevation	L
Miscellaneous	M	Lake	LK
Valley-landform		Spring	SP
High-Gradient	HG	Regulated	R
Medium-Gradient	MG	Wetland	W
Low-Gradient	LG		

Stream habitat parameters and their ecological significance

Hydrology and morphology

Stream hydrology and morphology provide a description of the relationship between flowing water and the physical stream environment including the stream bed, channel and valley. Together these variables can be used to characterise streams into stream types at a broad-spatial scale (e.g., refer to desktop section), or to assess a change in the physical stream environment over time. Where only a general impression of the sites is required, a few basic descriptors of stream hydrology and morphology can be used (e.g., P1). Alternatively, desktop and field measurements can be used to calculate a range of biologically meaningful metrics to assess stream habitat (e.g., P2 and P3). Not all of the metrics may suit all investigations and the user may wish to be selective about some metrics. However, a decision not to collect data needs to be made with care as data not collected is data lost. Protocol 2 includes a minimum amount of data to allow for the calculation of major metrics, while replicate data collected in Protocol 3 allows for more robust calculations.

Flow variables

A more accurate picture of the hydrological character of a streams can be best gained by collating flow variables from long-term data sets. Most often these data sets only exist for sites with permanent stage-height gauges. However, a gauging station close to the study site can be used to estimate flow variables by correlation or modelling. In addition, FWENZ and REC can provide relatively coarse estimates of some hydrological statistics (e.g., mean annual low flow [MALF] and mean flow). Simple measurements gathered in the field can be used to cross-validate these models, or more importantly, to provide information on the discharge and other flow variables at the time of habitat assessment.

The MALF and median flow have been shown to be ecologically important (e.g., Jowett and Davey 2007, Beca 2008). Similarly, mean flow can be useful, especially when used with other statistics such as the MALF and median flow to compute ratio indices of flow variability (Jowett and Duncan 1990). Flow duration curves (a record of the percentage of time that flow exceeds a certain value) when available, provide further insight to the ability of the stream to maintain in-stream habitat and can be used to calibrate flow levels at the time of field sampling.

Ideally habitat assessment surveys should be made at base flow to allow the most precise and easiest measurement of physical parameters. **Base flow** is the stage at which stream discharge is sustained by groundwater inputs only. At this stage the stream is not receiving direct runoff from precipitation or melting snow. Base flow can also be referred to as sustaining, normal, or groundwater flow. If a flow record is not available for a stream, base flow can be difficult to estimate. Generally for many small wadeable streams in New Zealand, base flow is reached about 3 days after a flood peak. However, time to base flow will vary as the size of the catchment increases and with catchment topography and vegetation. If possible, waiting 5-7 days after a flood peak prior to sampling is advisable. Alternatively, habitat assessment may coincide with the collection of biological data, in which case the time of sampling will be guided by those protocols (e.g., some Councils wait 10 days after a flow event 7x median flow when sampling macroinvertebrates; Stark et al. 2001). While it is easier to complete a habitat assessment at base flow, it is still possible to survey during times of lower and higher flows because many physical variables will be independent of flow condition. In these situations estimating flow condition is advisable to provide guidance for the applicability of results to the rest of the flow regime. **Flow conditions** are estimated as low, base, or high[1] flow in P1. In P2 and P3, flow conditions are measured by calculating discharge.

Channel cross section

Several habitat variables that relate to stream morphology, hydraulics and hydrology are measured at a stream channel cross sections or transect (Fig. 3). Morphological variables include channel shape and cross-sectional area. Hydraulic variables and correlates include wetted width, water depth, bankfull width, bank height, bank slope, water velocity, and substrate composition (these variables are defined and discussed below). Mean depth and water velocity are used to estimate discharge (a hydrological variable).

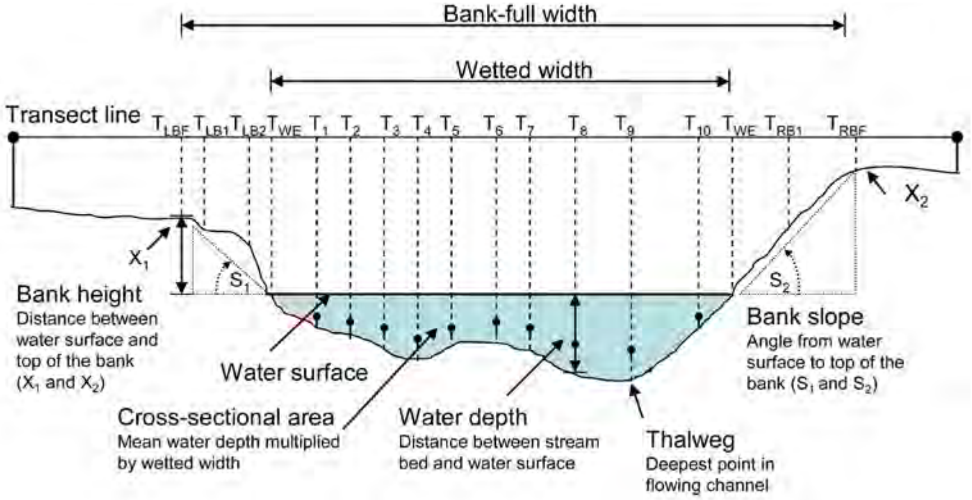

Figure 3. A typical stream channel cross section. The transect line shows the location of offsets at the left bankfull (T_{LBF}), left bank (T_{LB}), water's edge (T_{WE}), water depths (T_{1-10}) water's edge (T_{WE}), right bank (T_{RB}), and right bankfull (T_{RBF}). Circles represent measurements of water velocity at 40% water depth for the calculation of stream discharge.

Wetted width is the distance across the stream (perpendicular to flow) that is submerged by water on the day of sampling. Wetted width may be visually estimated from the stream bank (P1), measured using a measuring tape at a representative transect (P2), or measured at multiple transects (P3) to quantify spatial variability within a given stream reach.

Water depth is the vertical distance from the stream bed to the water surface, and like wetted width it can be estimated or measured. Several depth measurements should be made to estimate mean water depth for the sample reach. Ideally, these are made at cross sections,

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[1] How do you know if flow is high or low? At low flow a base flow water mark may be visible on the bank; this may be further delineated by a moss or algae line or the extent of encroaching vegetation. Alternatively, a metered flow record may be examined for the study stream or a nearby stream with similar rainfall and drainage pattern.

Figure 4. Reading the offset and distance between the measuring tape and ground level at the water's edge during a cross section survey.

with 10 depth measurements made at offsets (recorded distances along a tape or tag line) over a cross section to calculate the mean cross-sectional water depth (Fig. 4).

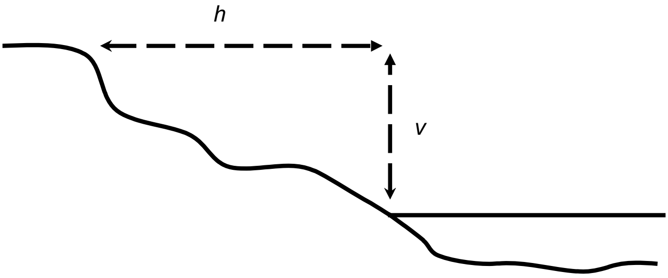
Wetted width and depth are key habitat descriptors as they determine the amount of habitat available for in-stream biota. The amount of available in-stream habitat will, at some level, limit the density and biomass of organisms. Several New Zealand studies have demonstrated this relationship by observing correlations between physical habitat conditions and macroinvertebrate and fish density and composition (Appendix 2).

Bank height is the minimum distance above the stream bed that water can escape from the stream channel. It may be difficult to discern bank height when banks are not level or when there is no clear delineation of the channel from the floodplain (Fig. 5). In this case a change in slope may be the best indication of bank height, along with evidence of hydrological limits such as scour lines, depositional silt and debris extremes. Bank height for any given cross section is the vertical distance between the stream bed and the top of the bank, and is calculated as water depth plus the average of the left and right bank heights above water level.

Bankfull width is the horizontal distance across the stream channel at the average of the left and right bank heights (Fig. 3). Bankfull width and bank height, also known as channel width and channel depth, provide flow-independent measures of stream morphology that are unlikely to alter over short periods. They can be used to calculate maximum stream discharge, which is the amount of water that can be accommodated within the stream channel. This is also known as bankfull discharge or maximum stream flow, and is the stage at which stream flow leaves the channel and enters the floodplain. Bankfull width and bank height are used to calculate **channel shape** metrics in P2 (in runs only) and P3 (e.g., width to depth ratio, Gini coefficient; discussed below). Channel shape is characterised in P1 and P2.

Figure 5. Determining bank height can be difficult where no clear delineation between the channel and floodplain occurs. In this case, changes in slope can be used.

Bank slope is the gradient between the top of the bank and the water's edge. The angle is measured in degrees using an inclinometer, or can be calculated from the height difference between the bank top and the water's edge divided by offset distance between these points (Fig. 6). Bank slope is important in assessing habitat availability at variable flows. A high bank slope constrains the wetted width during high flows, and therefore is associated with more rapid rates of increase in depth and/ or velocity with discharge than banks with low slope. Bank slope can also provide an indication of bank stability and naturally versus artificially constrained channels. Furthermore, the presence of overhanging banks, which produces 'negative' bank slope, can indicate potential fish habitat.



$$\% \text{ slope} = \frac{\text{vertical height}}{\text{horizontal distance}} \text{ X } 100$$

Figure 6. Slope estimation from vertical height (v) and horizontal distance (h) from the top of the bank to the river bed.

Current (or Flow) velocity is the speed at which water travels downstream (measured in m/s) and it varies greatly both temporally and spatially depending on a number of factors including channel slope (gradient), water depth and bed roughness. Velocity is a key defining feature of physical micro-habitat in lotic systems and the relationships between velocity, depth and substrate have been used to construct habitat suitability curves for many macroinvertebrate and most fish species in New Zealand (e.g., Jowett et al. 1991, Hayes and Jowett 1994, Jowett and Davey 2007). Mean flow velocity (across the channel) (V) is used in the calculation of discharge and is estimated as the average of measurements of mean column velocity taken at several points across the channel. Mean column velocity is measured using a velocity meter[2] (flow meter) at four-tenths of the water depth above the stream bed (P2 and P3) (Fig. 7). Velocity measurements are taken at the same offsets as water depths. In P1, average water velocity for a sample reach is estimated as fast, medium or slow.

Figure 7. "Mean" water velocity is measured at four-tenths of water depth from the surface.

The **thalweg** is the deepest point of the actively flowing channel. The longitudinal connection of thalweg points forms the thalweg line, which is the deepest continuous channel running downstream (Fig. 8). The thalweg is usually the fastest velocity in the channel, but this will not always be the case. It is important to define the thalweg as the deepest point in the 'actively flowing channel', because simply following the line of deepest points may lead into a dead-end or backwater (an area of relatively deep water with no continuous surface through flow, hence not part of the deepest continuous channel).

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[2] In the absence of a velocity meter, velocity can be estimated using the 'orange' technique. The time an orange takes to float a known distance in an area of unbroken water is used to calculate velocity in m/s. An alternative is the "ruler" method (see Appendix 3). Neither technique is recommended if any accurate calculation of discharge is required.

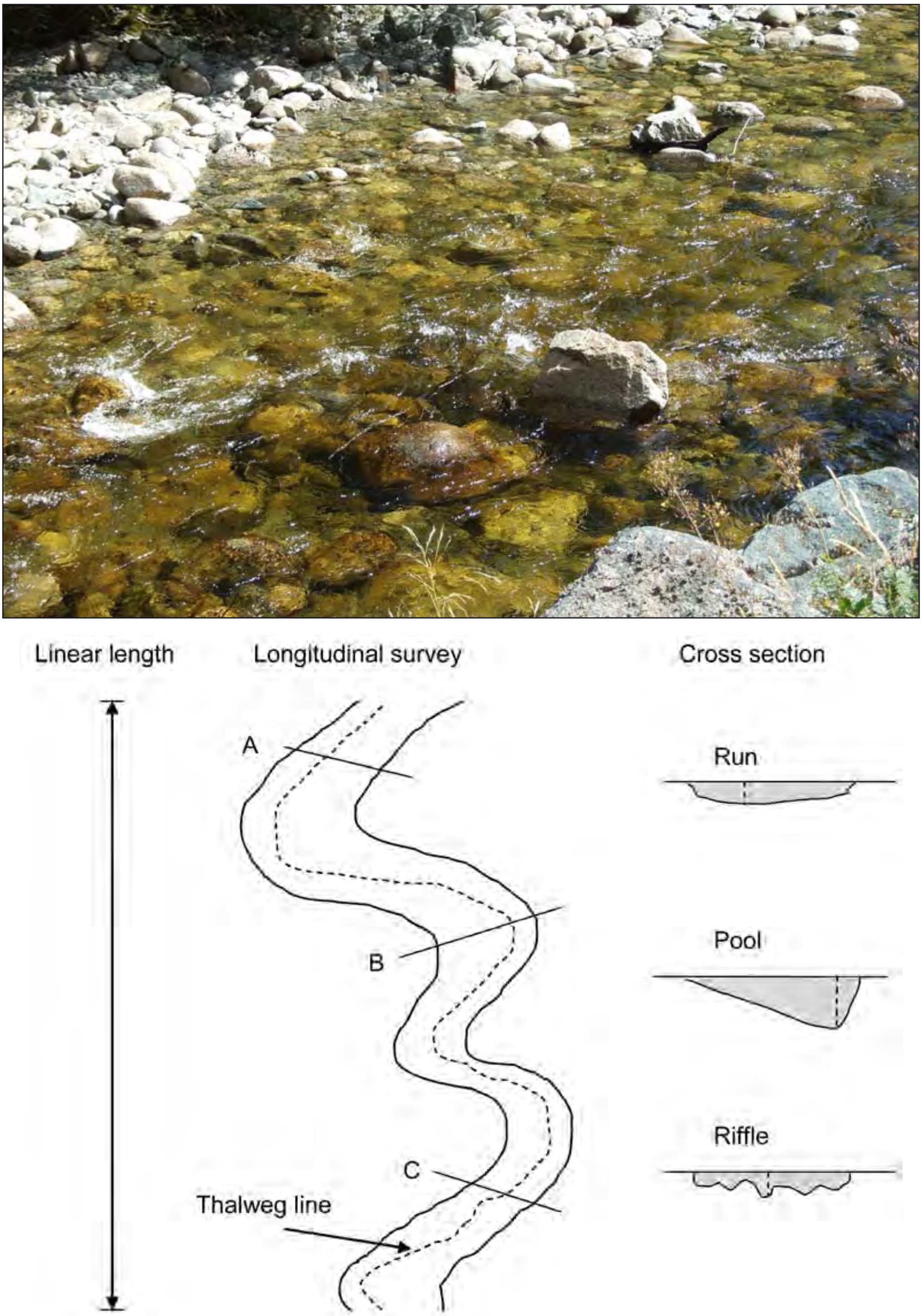


Figure 8. Location of the thalweg line, which is the deepest and often the fastest region along the stream and is used to calculate sinuosity. The potential locations of cross sections are also illustrated.

Longitudinal assessment

Longitudinal channel form is characterised by slope and sinuosity, and these variables along with habitat types are measured during a longitudinal assessment. Longitudinal channel form and can be used with cross section data to present a longitudinal thalweg profile of the stream (Fig. 8).

Channel slope (or channel gradient) is a function of valley slope, floodplain width and meander pattern. Channel slope can be measured in the field as the change in water surface elevation over the length of the reach. If both ends of the reach are not easily visible it is easier to calculate channel slope by desktop. However, the water slope and the channel slope may not necessarily be the same (e.g., Fig. 9), depending on the scale of measurement. If channel is calculated by desktop, rather than from field measurements, this needs to be clearly noted.

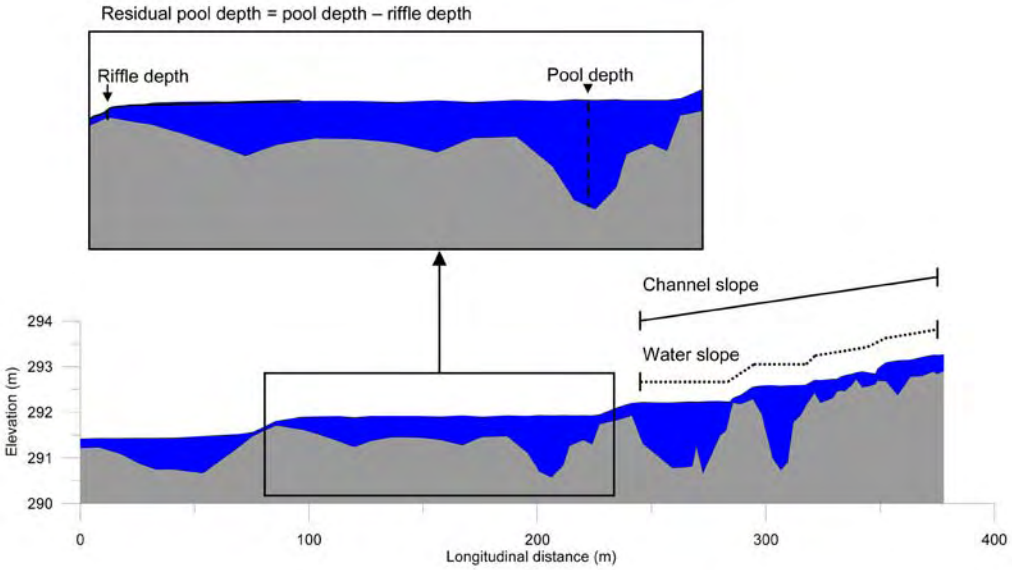


Figure 9. A longitudinal thalweg profile of a stream illustrating slope and residual pool depth.

Sinuosity (*S*) is the channel thalweg length divided by the straight line distance between two given points:

$S = T/L$ T = thalweg length
L = linear length of the reach

In natural landscapes, sinuosity is higher at lower gradients, where stream power is less and bed movement and erosion potential is reduced. High sinuosity also means that there is more stream area and often greater habitat diversity per unit of floodplain length. Sinuosity can be estimated in the field (P1) or measured in a desktop assessment where the sample reach length (along the thalweg line) is divided by the linear distance from one end of the sample reach to the other (from mapped locations in P2 and P3) (Fig. 8).

Residual pool depth is the difference between the maximum water depth of a pool and the water depth at the riffle crest immediately downstream of the pool (Fig. 9, 10). Residual pool depth gives an estimate of the maximum depth that would remain in the pool when the stream dries. It provides an indication of the minimum habitat available at very low flow, but not necessarily remaining habitat quality; i.e. reduced flow may change the suitability of habitat for certain biota. Residual pool depth in conjunction with the substrate composition of pools and erosion indices (see also in-stream protocol) provide an indication of pool infilling and stream aggradation.

Figure 10. Residual pool depth is the water depth measured at the riffle crest immediately downstream of a pool subtracted from the depth at the deepest point in the pool.

Habitat types, also termed meso-habitat types, flow types, and bedform (Morhardt 1986), are characterised by different mean water velocities and depths. These produce characteristic surface flow patterns, and are often associated with different substrate types. The commonest habitat types include riffles, rapids, runs (or glides), pools, backwaters, and cascades. The frequency and length of these habitats are usually predictable and correlated with channel width (Gordon et al. 2004). They are determined by the local channel slope, shape, structure, flow depth, and mean water velocity. For example, stepped pool-run-rapid sequences occur in steep streams, whereas pool-riffle-run sequences characterise low gradient streams. Each flow habitat type can generally be characterised by the depth and surface velocity:

- Rapid – shallow to moderate depth, swift flow and strong currents, surface broken with white water
- Riffle – shallow depth, moderate to fast water velocity, with mixed currents, surface rippled but unbroken
- Pool – deep, slow flowing with a smooth water surface, usually where the stream widens and/or deepens
- Run – habitat in between that of riffle/rapid and pool, slow–moderate depth and water velocity, uniform–slightly variable current, surface unbroken, smooth–rippled
- Backwater – slow or no flow zone away from the main flowing channel that is a surface flow dead-end; although flow could downwell or upwell from the groundwater zone.

These descriptions may be further sub-divided (e.g., slow and fast, or shallow and deep run). Identifying the habitat composition of the reach during the longitudinal assessment allows stratified selection of cross sections within the habitat types to be made. This approach provides a more accurate characterisation of available habitat than random selection of cross sections. However, if the aim of the investigation is to characterise the habitat of a particular river, then random selection of habitats is more statistically accurate. These results can also be used to weight the habitat data from each cross section according to the proportion of the reach that it represents.

One caution is that meso-habitat types are influenced by flow (i.e. they are flow-dependent), as are other hydraulic variables such as water velocity, water depth and wetted width. For instance, riffles can become runs at high flow and deep runs can become pools at low flow. This complicates comparisons between surveys conducted at different flow conditions. Unless flow *per se* is the subject of investigation it is desirable to focus on hydraulic and habitat variables that are independent of flow. Residual pool depth is a good example of a flow independent variable. Other flow independent indices are calculated from bankfull measurements and include channel width to depth ratio, Froude number for defining flow habitat types, and the Gini coefficient for defining channel shape.

Calculating biologically meaningful metrics

Several stream morphological and hydraulic variables are measured and/or estimated during a habitat assessment (Table 5). When they are quantitatively measured, as in P2 and P3, a range of metrics can be calculated to assess stream habitat (Table 6).

Mean water depth is the average water depth for the sample reach. The variation in water depths is calculated as the standard deviation among the average water depths from cross sections. However, when estimating discharge the 'mean water depth' from a run cross

Table 5. Summary of morphological and hydraulic variables measured during habitat assessment protocols. Numbers indicate replication during a single reach assessment. Protocol 1 variables are qualitative estimates and/or categorizations.

Habitat variable	Protocol 1	Protocol 2	Protocol 3
Reach length (m)	1	1	1
Wetted width (m)	1	1	9
Water depth (m)	0	10	90
Water velocity (m/s)	0	10	30
Bank height (m)	0	1	9
Bank slope (° or %)	0	1	9
Bankfull width (m)	0	1	9
Thalweg depth (m)	0	1	9
Channel slope (° or m/m)	0	1	1
Residual pool depth (m)	0	3	6
Sediment depth (m)	0	3	6
Sinuosity	1	1	1
Habitat types: % and length (m)	1	1	1
Channel shape	1	3	9

Table 6. Summary of biologically meaningful metrics calculated from morphological and hydraulic variables. Notes in brackets show what data is used in calculations and hence illustrates the limitations of metrics.

Metric	Protocol 2	Protocol 3
Mean water depth (m)	Y (1x run)	Y (3x run, riffle, pool)
Reach variation in water depth (m)	N	Y (3x run, riffle, pool)
Cross-sectional area (m^2)	Y (1x run)	Y (3x run, riffle, pool)
Mean water velocity (m/s)	Y (1x run)	Y (3x run)
Reach variation in water velocity (m/s)	N	Y (3x run)
Discharge (m^3/s)	Y (1x run)	Y (3x run)
Meso-habitat diversity	Y (%)	Y (m)
Channel shape: width/depth ratio	Y (1x run)	Y (3x run, riffle, pool)
Channel shape: Gini coefficient	Y (1x run)	Y (3x run, riffle, pool)
Froude number	N	Y (3x run, riffle, pool)
Channel roughness	N	Y (3x run)
Generalised habitat models	N	Y (3x run, riffle, pool)

section(s) is used and this is calculated by dividing cross sectional area by wetted width rather than simply averaging depths.

Cross-sectional area of water in-stream is approximated by wetted width multiplied by mean water depth, and is used with mean water velocity to calculate discharge.

Mean water velocity is the average water velocity for the sample reach. Flow guidelines for in-stream values suggest that average velocity below 0.3 m/s is a lower threshold below which stream life may be impacted (Ministry for the Environment 1998). At these velocities silt and periphyton accumulate on the stream bed smothering diatom growth and interstitial spaces. The variation in water velocities is calculated as the standard deviation of the average water velocities from cross sections, rather than each individual velocity measurement. Variation in water velocity and water depth provides an indication of the diversity of in-stream habitat available to biota. When calculating discharge, use the mean water velocity from a run cross section. Each velocity measurement can be weighted by the area of the hydraulic cell it represents on the cross-section (cell boundaries are half way between measured offsets) to give a weighted cross-sectional velocity for the most accurate estimation of discharge.

Discharge (Q), or stream flow, is the rate at which a given volume of water flows past a given point (m^3/s):

$$Q = AV$$

A = cross-sectional area of the water (m^2)
V = mean water velocity (m/s).

A is calculated from wetted width multiplied by mean water depth. Discharge is estimated from variables measured at a run cross section because this habitat represents average in-stream conditions (i.e., medium between fast- and low-flow habitats), has the least substrate and depth variability, and most laminar flow; thereby providing the most accurate estimate of stream discharge (Gordon et al. 2004).

Habitat diversity refers to the number of habitats present in a reach. Several algae, invertebrate and fish species show strong correlations with particular hydraulic conditions, e.g., filter feeders are more abundant in riffles than in pools. Therefore, the presence and/or relative abundance of meso-habitats provides a meso-scale assessment of habitat availability, giving more resolution than wetted width alone. The diversity of habitats can be visually estimated (P1) or categorised (P2) or quantified with habitat mapping and cross section transects (P3).

Channel **width to depth ratio** (*w/d*) provides a relative index of channel shape and can indicate the type of suitable habitat available for in-stream biota. For example, a high *w/d* indicates a wide shallow channel which would provide good algal and invertebrate habitat; in contrast a low *w/d* indicates a deep channel which might provide excellent adult trout and large eel habitat.

The **Gini coefficient** (G) can be used to describe cross-sectional shape (Fig. 11) and is useful for assessing channel form and its change over time (Olson-Rutz and Marlow 1992). The coefficient is the average of the absolute difference between all possible pairs of water depths in a cross-section:

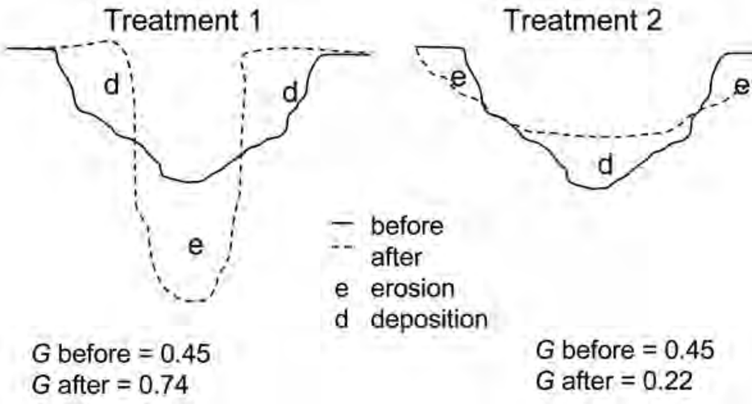


Figure 11. The response of a hypothetical stream channel to two different depth and width conditions and the responding change in habitat metrics (modified from Olson-Rutz and Marlow 1992).

$$G = \frac{\sum\sum|Y_i - Y_j|}{2n^2 Y_{ave}}$$

Y_i and Y_j = the depths at *i*th and *j*th points along a transect
n = the total number of sampling points along a transect
Y_{ave} = the average water depth across a transect.

As this involves a number of calculations this value is easiest computed by spreadsheet. The Gini coefficient approaches 0 when all depths are equal, suggesting a homogenous cross-section, whereas a heterogeneous cross-section would be indicated by values close to the theoretical maximum of 1. Values of *G* can be compared over time where a positive difference shows that the stream is becoming deeper and narrower for example.

Froude number is a hydraulic descriptor of habitat type and provides a number which can be used to differentiate key habitats, particularly during different flows. It is a dimensionless velocity/depth ratio:

$$Fr = \frac{V}{\sqrt{(gY)}}$$

V = mean water velocity of a cross section (m/s)
Y = mean depth of a cross section (m)
g = acceleration due to gravity (9.81 m/s).

When *Fr* = 1 flow is critical; a threshold where flow changes sub-critical to supercritical. Sub-critical flow (*Fr* < 1) is slow, tranquil, non-turbulent, or streamlined, whereas supercritical flow (*Fr* > 1) flow is fast, rapid, turbulent/broken (Chow 1959). In a New Zealand study, pool habitats had Froude numbers less than 0.18, riffles had Froude numbers greater than 0.41 and runs had intermediate values (Jowett 1993).

Channel roughness like sinuosity can affect stream power through effect of direct friction on water velocity and flow diversity. The rougher the channel (e.g., as a result of large wood, boulders or a matrix of different sized substrates) the greater the friction and turbulence, and the lower the mean water velocity. Bed roughness can be estimated from an assessment of stream substrate composition (P1 and P2). Alternatively, roughness (*n*) can be approximated from hydraulic variables using Manning's equation to explain the resistance of the channel to stream flow (P3).

In low gradient streams, *n* values range from 0.025 in clean, straight channels to 0.150 in weedy, sluggish channels (Chow 1959). However, steep channels have higher values of n, even when bed material size is similar (Jarrett 1984, in Duncan et al. 1999). Jarrett found that Manning's n varied directly with slope and inversely with depth. He derived a predictive equation of n in natural mountain channels with cobble or boulder substrates, based on observations in 21 stream with slopes between 0.02 and 0.052 m/m. Jarrett's equation is:

$$n = \frac{R^{2/3} S^{1/2}}{v}$$

R = hydraulic radius (m), being cross sectional area divided by wetted perimeter – which is the distance measured along the stream bed surface from one waters edge to the other (in relatively wide or rectangular channels the average stream depth can be used in place of *R*)
S = water surface slope
v = mean stream velocity (m/s).

Subsequent work has shown this equation is reasonably applicable for slopes up to 0.09 m/m (Cheadle & Thorne 1988, cited in Duncan et al. 1999).

Generalised habitat models use data from channel cross sections to predict changes in relative habitat quality for a given species with flow (e.g., Lamouroux and Jowett 2005). Generalized habitat models can be applied using the software package WAIORA (Water Allocation Impacts on River Attributes; NIWA 2004). Alternatively, the models can be applied in a spreadsheet using the coefficients and functional form of the model described in the WAIORA manual, using discharge and stream width data that is either measured or predicted for a range of flows:

$$n = 0.32 S^{0.38} R^{-0.16}$$

The generalized models applied in WAIORA were developed by modelling the predicted habitat quality versus flow relationships for given species from a large number of full in-stream habitat modelling datasets. Prior to model fitting the results from different sized streams were standardized by dividing flow by width (giving flow per unit width, or Reynolds number). The resulting statistical models can be used with information on the rate of change of average width with flow in a given stream to predict changes in relative habitat quality with flow (Fig. 12). A description of the models and how they are applied along with a list of species for which generalized habitat models are available can be found in the WAIORA users guide (NIWA 2004).

However, these models were based on in-stream habitat modelling datasets from typical gravel/cobble bed streams, so they may not function well in deeply incised streams (e.g., many spring-fed systems) or very broad unconfined channels (e.g., braided rivers).

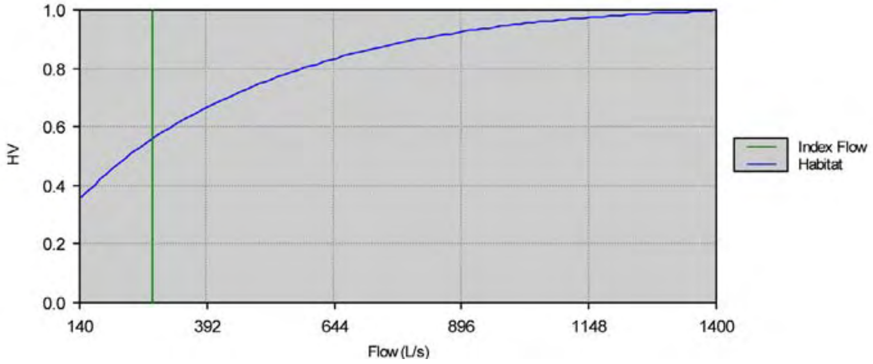


Figure 12. Relationship between relative habitat quality (HV) and flow predicted for brown trout fry in a hypothetical stream using WAIORA's generalized habitat modelling capability.

Generalized habitat models require data on the rate of change of average width with flow (WAIORA also requires data on the change in depth with flow). Ideally, wetted width and water depth are measured at the same cross sections at different flows. The most accurate way to measure the change in water depth is with a temporary staff gauge, where the change in water level between flow 1 and flow 2 relative to the top of the staff gauge is recorded (P3). Measurements made for at least two flow levels (e.g., base flow and low flow) allow a rating curve to be constructed for the cross section. The rating curve describes the relationships between water level (depth), wetted width, and flow.

Alternatively, the relationship between depth, wetted width and flow can be roughly estimated from data from cross section data using Manning's equation (P3). This method assumes that Manning's n (roughness coefficient) does not vary with flow, and requires accurate data on the cross sectional shape of the channel. Manning's n can be derived (using the equation above) from calculations of average velocity (*v*), and hydraulic radius (*R*) from field measurements, and an estimate of slope from the desktop analysis (refer to desktop protocol). The discharge (*Q*) at alternative flows (e.g., the mean flow, or MALF) can then be calculated using:

$$Q = \frac{1}{n} A R^{2/3} S^{1/2}$$

with the differences in cross-sectional area (*A*) and hydraulic radius (*R*) calculated from incremental increases in depth based on the cross-sectional survey data. These models can be applied by using field measurements from protocols P2 or P3. However, it is preferable to base them on P3, since the single cross-section surveyed in P2 does not give any indication of spatial variation in cross-sectional channel form, and therefore habitat, at a given flow.

A general hydraulic geometry relationship can be applied using information developed from 73 New Zealand rivers by Jowett (1998), to give an estimate of the rate of change of width with flow. However, because there is considerable variation in this relationship between rivers, it is advisable to collect field data specific to the study stream rather than rely on a general hydraulic relationship.

In-stream habitat

The in-stream habitat is defined as the area below the vegetated bank and streambed that is submerged below water. The streambed is home for many aquatic organisms, it is their preferred habitat, the site for the deposition and incubation for their eggs, the source of their food and refuge from predators, floods and droughts (Hynes 1970, Minshall 1984, Statzner et al. 1988). Not surprisingly, the physical character of the streambed has an important effect on almost components of the stream food web (Quinn & Hickey 1990a, Jowett et al. 1991). Considerable literature exists on in-stream habitat assessments and internationally a large number of differing parameters have been measured (see review in Appendix 2). However, there is considerable overlap between what is measured among these assessments. In these protocols we have selected a group of key parameters which are consistently used to characterise in-stream condition.

In particular, the size, distribution and condition of the stream substrate influences the habitat quality for algae, invertebrates and fish, and determines the quantity and quality of refugia from floods and predators. The suitability of substrate for different species depends on the dominant particle size, the range of substrate sizes, the degree of packing and compactness and the availability of interstitial spaces for refuge (Gordon et al. 2004). Numerous studies have documented the effect of substrate size and heterogeneity (see review by Death 2000, and Appendix 2). In broad terms we might expect that substrate type and size can be predicted from our understanding of geology, climate, topography and position along the river continuum (Fig. 13). Boulders typically dominate in the headwaters of catchments and substrate size decreases downstream. Near river mouths the substrate is usually composed of gravels, silt and sand. The relative size and range of substrate is often controlled by catchment conditions (e.g., climate and geology). For example, streams from catchments with igneous or metamorphic geology (e.g., granite) are likely to have larger substrate particles than comparable streams from catchments dominated by more easily fractured sandstones or mudstones.

Internationally, particle or substrate size has been categorised by the Wentworth scale (Table 7), this scale has been further divided into sub-categories by Cummins (1962), Brakensiek et al. (1979), Minshall (1984). For consistency and ease of visual estimation, we have used the unmodified Wentworth Scale in these protocols which classifies substrate into six size classes. We have added a seventh category - bedrock. Brakensiek et al. (1979) created 24 size classes including very large boulders up to 4 metres. Users who require greater definition of substrate may use these additional categories for Protocol 2. However, in Protocol 3 we suggest actual measurement of 30 randomly selected particles. In the field, particle size can be measured using a gravelometer (Fig. 14).

Jowett & Richardson (1990) proposed a Substrate Index (SI) which used a modified form of the IFIM substrate codes (Bovee 1982). We have further modified this slightly to represent the Wentworth Scale particle sizes:

Substrate Index (SI) = 0.08 %bedrock + 0.07 %boulder + 0.06 %cobble + 0.05 %pebble + 0.04 %gravel + 0.03 %sand & silt

A stream bed consisting entirely of bedrock will have an SI = 0.08 x 100% bedrock i.e., 8, while a sandy bottom stream will have a SI = 0.03 x 100% sand i.e., 3.

The influence of the bed substrate on stream communities is compounded by the range of substrate size occurring within a reach (**substrate heterogeneity**) and their embeddedness and compactness. A bed which has highly variable substrate size classes (e.g., Fig 13a) may provide abundant potential refugia for invertebrates and fish, while a bed with uniform substrate size (e.g., Fig 13c) provides little refuge. Measuring or estimating the range of size classes present at a site can give some indication of substrate heterogeneity. Substrate heterogeneity can be indicated by data collected in Protocol 2 and calculated from particle sizes measured in Protocol 3.

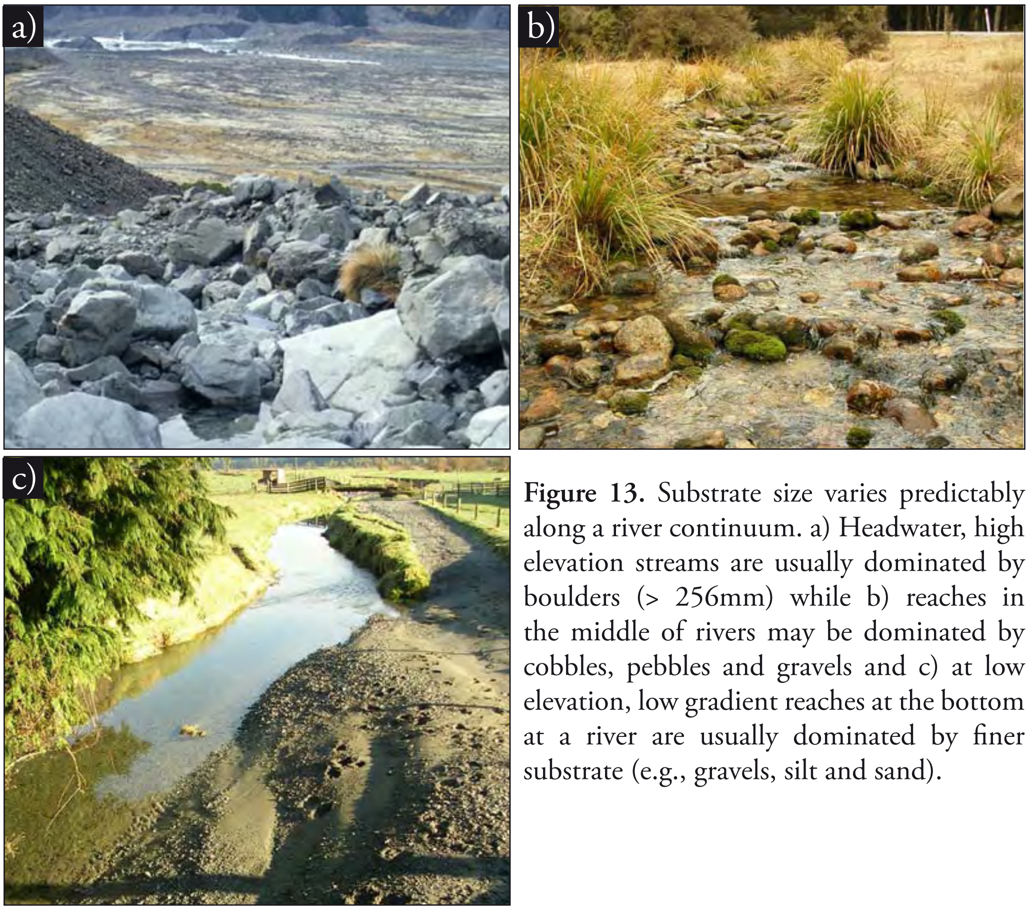


Figure 13. Substrate size varies predictably along a river continuum. a) Headwater, high elevation streams are usually dominated by boulders (> 256mm) while b) reaches in the middle of rivers may be dominated by cobbles, pebbles and gravels and c) at low elevation, low gradient reaches at the bottom at a river are usually dominated by finer substrate (e.g., gravels, silt and sand).

Table 7. The Wentworth Scale for particle size classification

Size category	Particle diameter (range)
Bedrock*	> 4000mm
Boulder	> 256 mm to 4000m
Cobble	> 64 to 256 mm
Pebble	> 16 to 64 mm
Gravel	> 2 to 16 mm
Sand	> 0.063 to 2 mm
Silt	< 0.063 mm

* includes concrete and hard artificial structures

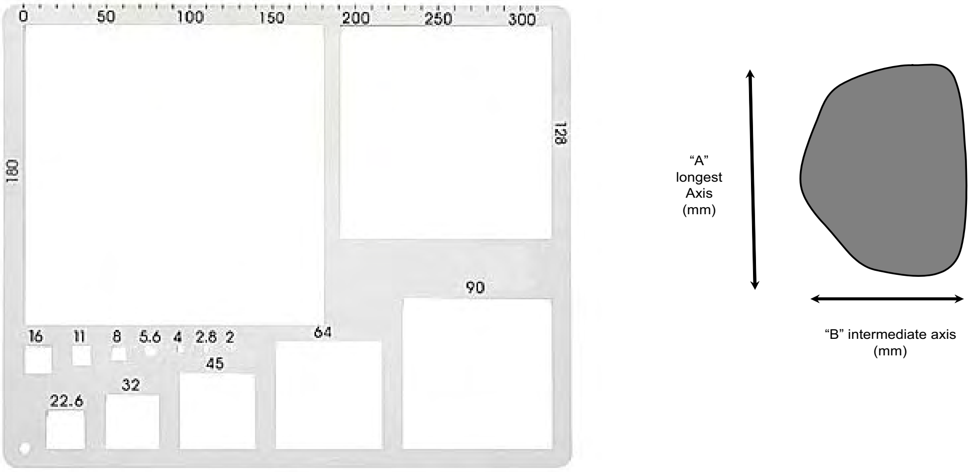


Figure 14. A gravelometer is a template which particles can be passed through to easily determine particle size. In Protocol 3, 30 particles are measured along their intermediate (“B”) axis that would prevent the stone passing through the gravelometer grid

Another method which can be used to characterise the bed substrate is the Brusven index method (1977) also modified by Bovee (1982). This method can be used to generate a three digit code which described both substrate size and **degree of embeddedness** by fine sediment (e.g., 62.9). A modified version of the Brusven Substrate Index (BSI) to use Wentworth size classes can be calculated from data obtained in Protocols 2 and 3:

BSI = DS.F

D = the dominant substrate size class in a habitat based on a 1 - 7 scale, with 7 indicated bedrock and 1 indicating silt (Table 8).

S = the substrate surrounding the dominant substrate and is classified using the same 1-7 scale.

F = the percentage of fine sediment surrounding the dominant substrate D. This is based on a 0 – 9 scale with 0 indicating no fine sediment (i.e. sand or silt) and 9 indicating >90% fine sediment surrounding the dominant substrate.

For example, a boulder dominated stream with pebble substrate around the boulders and very little fine sediment may have a BSI of 64.1 while a bed totally covered in sand with no other substrate would score 11.9.

Substrate compactness can be used to indicate the degree of stability of the substrate. Under certain conditions (e.g., high sedimentation, frequent flow fluctuations, metal precipitation and biofilm or moss accumulation) bed particles can become highly compacted (Fig. 15). This compaction can be caused by embedded substrate (where fine sediment surrounds and buries larger substrate) or armouring (where larger stable substrate protects the bed from erosion). Compaction may also result from the substrate becoming cemented by chemical or physical processes. When this happens the bed substrate can be very stable, but interstitial spaces between particles may be greatly reduced (causing loss of refugia). Compaction may also restrict the exchange of water and organisms between the bed and the hyporheic zone under the stream.

Table 8. Modified Brusven Substrate Index (BSI)

Code	Size category	Particle diameter (range in mm)
7	Bedrock	> 4000 mm
6	Boulder	> 256 mm to 4000 mm
5	Cobble	> 64 to 256 mm
4	Pebble	> 16 to 64 mm
3	Gravel	> 2 to 16 mm
2	Sand	> 0.063 to 2 mm
1	Silt	< 0.063 mm

Figure 15. Substrate compactness due to biological growth (*Didymo* algae), metal precipitation (iron hydroxide from mining) and sedimentation.

Figure 16. Deposition of sand in slow water behind a stable boulder and in a transition zone between fast and slow water.

The degree of bed stability can also be assessed by determining the amount of **deposition and scouring** that occurs across the riverbed. Depositional zones are indicated by fine sediment or gravels accumulating in bars, zones of slower water velocities and sometimes behind large stable obstructions (e.g., boulders and logs) (Fig. 16). Similarly, if a stream is under-going frequent erosion, scouring of the bed can frequently be seen behind stable obstructions and in faster water zones.

Algae, bryophytes (**moss**) and **macrophytes** can all influence reach-scale depth and velocities, and can provide important habitat for stream invertebrates and fish (Fig. 17). In these protocols we are not concerned with the role these may have in providing food, only on their effects on as habitat.

Similarly, large **wood accumulations** (often technically referred to as large woody debris or LWD) and **leaf packs** can cause changes in stream depth and velocity, and cause zones of scouring and deposition. Wood also frequently creates refugia for fish and both wood and leaf packs are commonly used by invertebrates as substrate (Fig. 17).

As we have already indicated long-term stable substrates such as large boulders and wood may act as significant **obstructions to flow** and function as both scouring and depositional structures depending on variations in flow levels. These micro-habitats have also been shown to provide stable habitats for algae, moss and invertebrates, and in some streams may be the only stable habitat.

The presence of **undercut banks** is often an indication of high flows and bank instability, while these and **overhanging vegetation** provide important fish habitat.

The in-stream habitat assessment is made within the wetted width of the stream bed, and is carried out in three habitats (e.g., a riffle, a run and a pool) within the reach.

Figure 17. a) large wood accumulations can alter reach morphology, and b) create refugia for fish, c) provide habitat for invertebrates, d) while macrophytes also provide refugia.

Riparian cover and vegetation

Riparian zones are defined as the areas where direct interaction between land and water occur (e.g., in terms of shading, inundation at normal high flows, input of wood and litter, provision of in-stream habitat as cover, use for spawning by stream biota) (Gregory et al. 1991, Naiman and Decamps 1997) (Fig. 18). Riparian zones have a disproportionately large influence on stream habitat and water quality relative to their proportion of catchment area, due to their proximity to the stream and their function in reducing contaminant inputs from the broader landscape. Consequently, stream restoration efforts in New Zealand have focused on management of riparian areas (MFE 2001), as occurs in Victoria, Australia (Brooks and Lake 2007) and the USA (Palmer et al. 2007). Riparian management typically involves fencing to exclude livestock and planting with native trees and shrubs in a riparian **buffer**, i.e. part of the entire riparian zone that is managed differently to the adjacent land. Thus, stream habitat assessment protocols need to include consideration of the influences of the riparian zone and the presence of riparian buffers. These protocols characterise key aspects of riparian zones from a stream habitat perspective rather than as ecosystems in their own right.

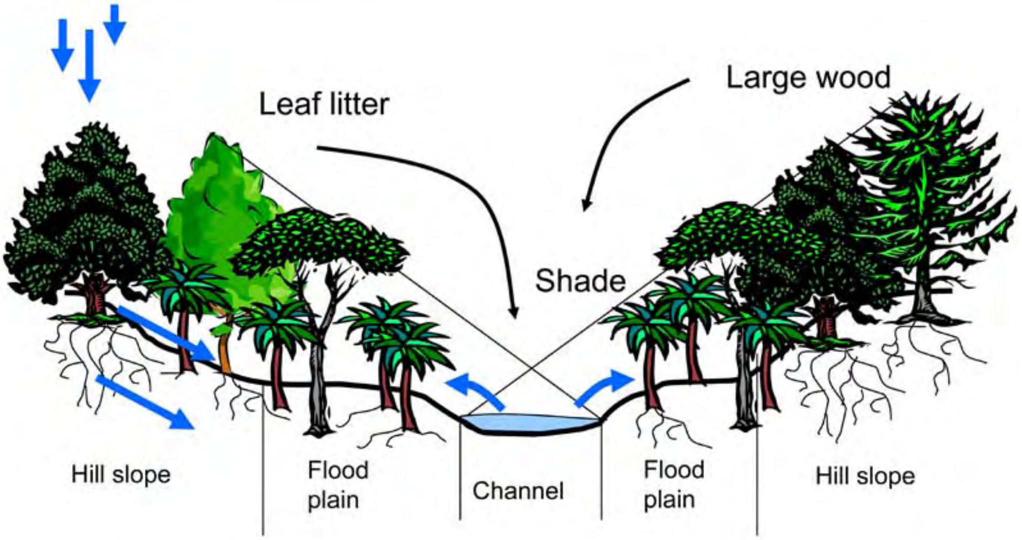


Figure 18. Schematic of a natural riparian zone showing influences on stream habitat. Blue arrows indicate movement of water and black arrows the input of resources.

Existing riparian-focused assessment protocols include the Rapid Appraisal of Riparian Condition (RARC) (Jansen et al. 2004) developed for SE Australia and a field-based evaluation tool for assessing water quality benefits of riparian buffer zones in agricultural catchments in the UK (Ducros and Joyce 2003). However, the scope of RARC method includes more inherent riparian ecology than is required for these protocols. The UK method was designed for evaluating riparian buffers established specifically for mitigating agricultural activities, whereas these protocols require a more general assessment. The protocols we have developed build on these existing methodologies.

The riparian assessment in Protocol 1 provides a basic, qualitative characterisation of the key features of a stream reach that can be determined along with other aspects of stream habitat and land use during half-hour site visit.

Riparian Protocols 2 and 3 provide more detailed assessment of the attributes that determine riparian influence on stream habitat (i.e. shade, leaf and wood input, fish spawning/adult insect habitat, fish and crayfish off-channel habitat, retention of particulates during high flows, and stream bank stability) and the input of contaminants from altered land use (i.e. livestock access, nitrogen control through denitrification of groundwater in riparian wetlands, uptake of nutrients from groundwater inflows by vegetation, and filtration of particulates in surface runoff). These protocols aim to provide a basis for assessing riparian condition and functions, enabling inter-site comparisons and assessing long-term changes in the effect of riparian areas on stream habitat at a given site. Riparian P2 is qualitative but allows scores to be derived for 12 key riparian attributes. Riparian P3 goes further in quantifying those attributes for which there are quantitative measurements that could be routinely applied within an acceptable timeframe.

Riparian attributes are assessed on both sides of the stream. Left and right refer to "true left" and "true right" which is assessed looking downstream. Most riparian attributes are self-explanatory, but some need further definition and explanation of the purpose of assessment. For example, the scores in Riparian P2 involve vegetation classes whereas some reaches may have mixes of these (e.g., a mix of short grazed pasture grass and sparse deciduous trees). In these cases the user will need to make a value judgement to assign an integrative score that captures the balance of the site conditions.

Shade plays an important role in the regulation of stream temperature and light, which in turn, influences the growth of in-stream plants and the measurement of shading has been well studied (Davies-Colley and Rutherford 2005). Shade is assessed at the water surface. Examples of differing shade levels measured using paired canopy analysers, are shown to assist these assessments (Fig. 19). In these protocols the average stream shading is assessed, not that in the middle of the channel, where shading can be less due to less canopy effects. Shading is considered at all points across the water surface throughout the reach and through the full 180°, so that the influence of stream banks, stream bank vegetation, and hill slopes are included. These geomorphic influences can be particularly important in small streams, where topographic features provide 21-26% shade in streams with minimal riparian vegetation (see Fig. 19).

Shade = 99%
3 m channel
Mature pine

Shade = 95%
1 m channel
5 yr old native planting

Shade = 84%
2 m channel
5 y regen post-logging

Shade = 84%
4 m channel
6 y regen post-logging

Shade = 81%
8 m channel
Native forest buffer

Shade = 70%

Shade = 70%
1.5 m channel
5 y poplars

Shade = 68%
1.5 m channel
5 y post-livestock removal

Shade = 64%
6 m channel
Native forest buffer

Shade = 26%

Shade = 23%

Shade = 21%

Figure 19. Reach photographs and shade levels measured with paired canopy analysers. Note that topography and streambank overhanging vegetation provide shade in small streams and that increasing channel width reduces shading effect of forest.

In Protocol 3 we recommend estimating overhead shading using a densiometer (Fig. 20).

The riparian buffer width refers to the area managed differently to the rest of the catchment to reduce the effects of wider land use on stream habitat. This riparian buffer (i.e. the managed area) may differ in extent to the riparian zone as defined above.

Buffer intactness is an assessment of the gaps in the managed vegetation that may reduce the effectiveness of the riparian vegetation in providing habitat and intercepting contaminant inputs. Riparian vegetation has a strong influence on **bank stability**, along with the natural geology and flow regime. This influences stream habitat by reducing siltation of the bed and increasing cover habitat for fish and adult aquatic invertebrates.

Figure 20. A spherical densiometer which is divided into 25 squares. Counting the number of squares with shading gives an accurate and repeatable estimate of the proportion of canopy cover over the reach.

Livestock access is important because of the direct input of nutrients and sediment, and the habitat disturbance that livestock cause (Trimble and Mendel 1995, Bagshaw 2002).

Wetlands, boggy areas and moist soils in the riparian zone can be important sites for **denitrification** (conversion of nitrate to nitrogen gases) in groundwater inputs before entry to streams (Cooper 1990). The key factors that control this process are low oxygen, which is a product of water logged soils, and high soil organic content. The protocols assess the potential for riparian denitrification by the presence and extent of moist riparian soils and the absence of artificial drainage that allows groundwater to bypass these denitrification areas.

Several factors combine to influence the ability of riparian areas to filter particulates from surface runoff, and thus reduce inputs of sediment and nutrients to streams. The protocols assess these individually as the **riparian land slope** (increases the flow velocity of runoff), **groundcover** (increases the resistance to flow leading to settling and provides some direct filtration), **soil drainage** (determines infiltration of water and the attenuation of particulates and dissolved nutrients), and the presence of **rills/channels** that bypass riparian filtering.

Soils become compacted when under pressure from machinery (such as tractors or haulers) or livestock. **Pugged** soils are formed when stock intensively trample wet soil, the soil aggregates are broken down, and pore spaces in the soil are reduced. Compaction has similar effects to pugging. A **rill** is a narrow shallow incision or depression into soil resulting from erosion by overland flow that has been focused into a thin channel by soil surface roughness.

The connectiveness of the floodplain can be another important characteristic which influences floodplain width and slope. **Floodplain width** can often be discerned by changes in topography, vegetation and debris lines (Fig. 21).

Figure 21. Examples showing assessment of floodplain widths

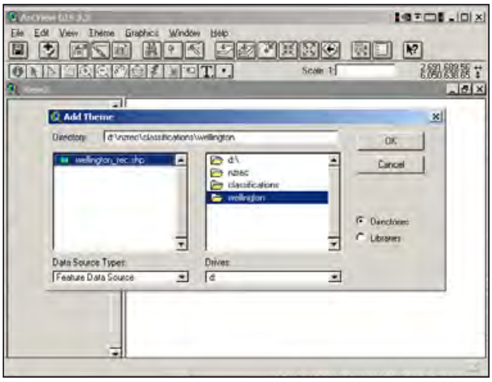
P1a, P2a, P3a Desktop protocol

How to access GIS information for your study reach

To get the relevant GIS information for the site you are assessing you first need to know the River Environment Classifications (REC) reach number (a “reach” in the REC is a length of stream between two consecutive tributaries). The CD supplied with this Protocol contains all REC reaches for New Zealand and these are the same reach numbers that are used in the Freshwater Environments of New Zealand (FWENZ). The relevant catchment level parameters from these two databases have been combined for each region on spreadsheets for you. You will need to use some sort of GIS software to do this and the one most commonly used is ArcView or ArcGIS (ESRI). A brief tutorial is provided below on how to do this, and this procedure is similar for Arc Map.

A tutorial for ArcView

In ArcView, you firstly open the shape file (suffix *.shp) for your region. To do this use *add event theme* from the pop-down menu under the View icon on the toolbar. When in the view pane, navigate to the CD and click on the shape file for your region e.g., in the screen capture below the shape file is Wellington_REC.shp (Screen 1). In the view pane you will see your region’s stream network. You now need to find where the sites you have assessed are in that network.



Directory: d:\nzrec\classifications\wellington

wellington_rec.shp

d:\
nzrec
classifications
wellington

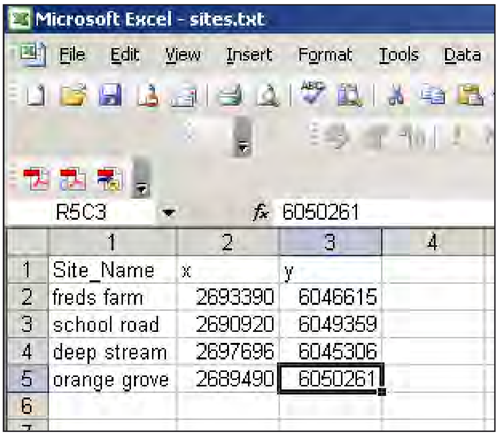
Data Source Types: Feature Data Source

Drives: d:

Screen 1.

To find the reach number for the length of stream that you are assessing you need to enter the geographical location into ArcView. If you are doing a few sites at a time the easiest way is to load them all together as a text file with names for each location.

You can make this file in Excel, you need to have 3 columns, each with a header row named something like: site; x; y;, and then for each named site location put in the NZ map coordinates from a GPS or directly from a Topomap (see Screen 2). Make sure you have 7 figures, e.g., 2510840 6754156 (add zeros to the end if you don’t have enough), and then select *save as* in Excel, choose space delimited text file and save somewhere you can then access later from ArcView.

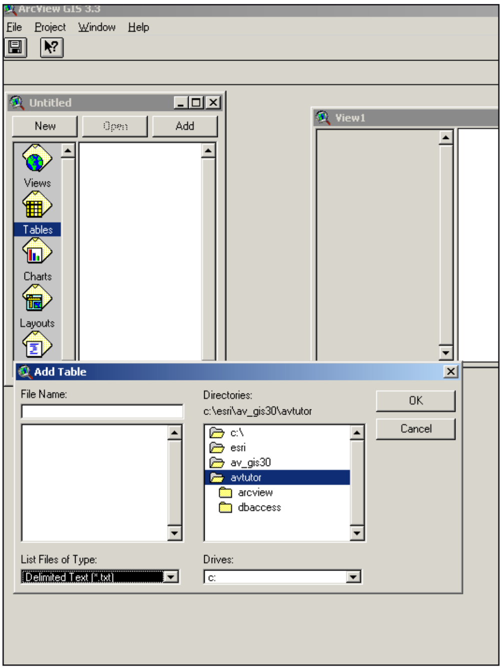


R5C3 = 6050261

	1	2	3	4
1	Site_Name	x	y	
2	freds farm	2693390	6046615	
3	school road	2690920	6049359	
4	deep stream	2697696	6045306	
5	orange grove	2689490	6050261	
6				

Screen 2.

Now back in ArcView add the text file as a table. In the tables pane, use add icon (top right of mid left panel – see screen shots below). Then navigate to your folder, select the co-ordinate text file you made earlier and it will load as a table. Make sure you change bottom



File Name:

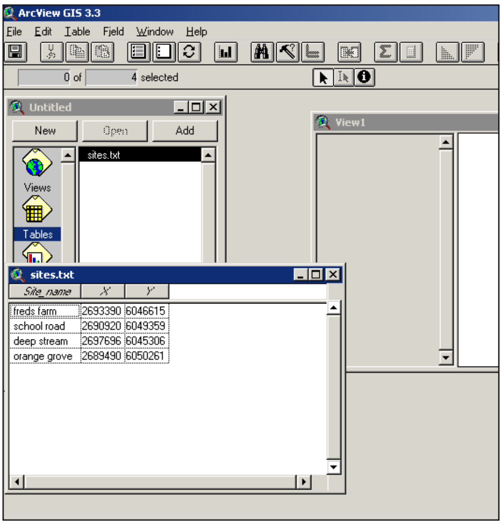
Directories: c:\esri\av_gis30\avtutor

- c:\
- esri
- av_gis30
- avtutor
  - arcview
  - dbaccess

List Files of Type: Delimited Text (*.txt)

Drives: c:

Screen 3.



sites.txt

Site_name	X	Y
freds farm	2693390	6046615
school road	2690920	6049359
deep stream	2697696	6045306
orange grove	2689490	6050261

Screen 4.

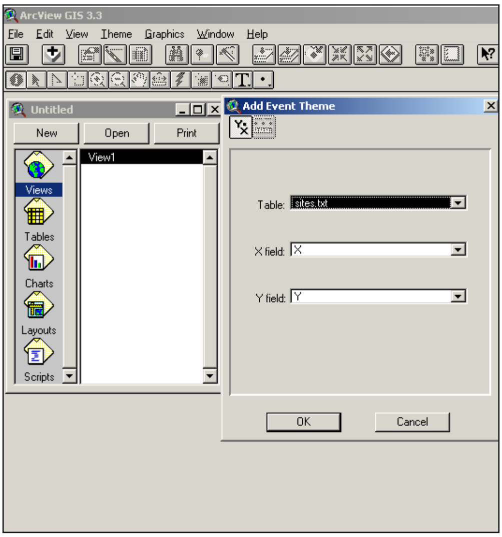


Table: sites.txt

X field: X

Y field: Y

Screen 5.

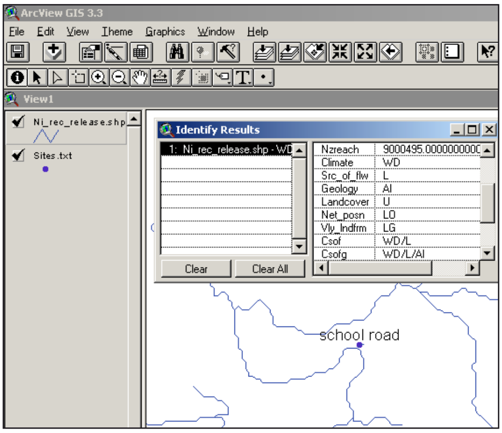
left *List Files of Type (*.txt)* to Delimited Text then click add (see Screens 3 & 4).

Now go back to the view window, click on View tab on the toolbar and select *add event theme* from the drop-down menu. The field columns should line up with x and y as in Screen 5 - if not, then change them to suit. Select ok and it will be loaded into view window.

Now there will be a point on your map for each location you entered. To help identify the location, you can label these site points. To do this, go to Theme on the toolbar and select *auto label* from the dropdown menu. The points will then be labelled and you can then select the correct reach from the stream network which should be right next to or under point (see point 'school road' below). Now to get the reach number, change the cursor to identity (click on the small ***i*** icon on the far left of the second row of icons). Make sure the REC shapefile is selected (has a light raised line around it), then click on the river line on the view and a box will appear containing the reach number (Nzreach) as well as the other data in the REC (Screen 6).

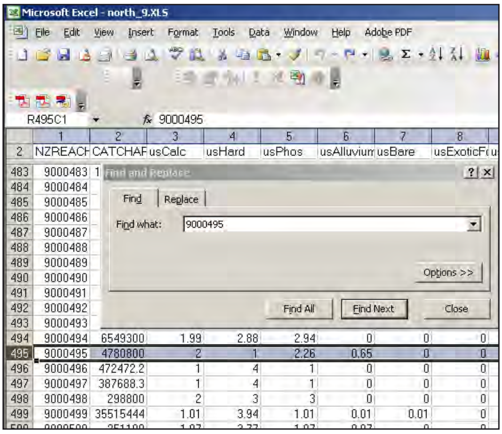
Now you have the REC number for your location and you can match this up with the relevant row in the Excel file we have provided on the CD containing the relevant catchment and reach environmental variables.

Next, open the Excel file for your region, choose the Edit menu from the toolbar and select Find (binoculars icon) then in the find tab find enter the reach number in this box and then click on Find Next. This will take you to the row containing the data you want. This data can then be pasted into a new sheet or into a word file along with the header row (Screen 7).



Nzreach	9000495.000000000
Climate	WD
Src_of_flw	L
Geology	Al
Landcover	U
Net_posn	LO
Vly_lndfrm	LG
Csof	WD/L
Csofg	WD/L/Al

Screen 6.



Find what: 9000495

	1	2	3	4	5	6	7	8
2	NZREACH	CATCHAF	usCalc	usHard	usPhos	usAlluvium	usBare	usExoticF
483	9000483	1						
484	9000484							
485	9000485							
486	9000486							
487	9000487							
488	9000488							
489	9000489							
490	9000490							
491	9000491							
492	9000492							
493	9000493							
494	9000494	6549300	1.99	2.88	2.94	0	0	0
495	9000495	4780800	2	1	2.26	0.65	0	0
496	9000496	472472.2	1	4	1	0	0	0
497	9000497	387688.3	1	4	1	0	0	0
498	9000498	298800	2	3	3	0	0	0
499	9000499	35515444	1.01	3.94	1.01	0.01	0.01	0

Screen 7.

How to interpret your GIS outputs

Table 9 contains the output for a reach to illustrate how to interpret values. The catchment area is 47 square kilometres. The proportion of the catchment in pastoral farming is 60%, 36% is urban, 2% scrub vegetation and 65% of the catchment geology is alluvium. The values for calcium, hardness and phosphorous are dimensionless and thus can only be used only for comparison with other sites. Rainfall variability again is useful for comparison only as it is the coefficient of variation. The distance to the coast is 5.03km, the average flow is 0.15 cumecs. The low flow for this reach is 37 litres/sec, the mean number of days a year rainfall exceeds 25mm is 0.81 and the reach is second order. The next code letters are the REC classes, so this reach is Warm-dry climate, geology is alluvium, source of flow is lowland, land cover is urban and valley-landform is low gradient. The reach is 11m elevation at the lower end and 13m at the top. The sinuosity of the reach is 1.18 (that is the length the fish swims divided by the distance the crow flies). The slope is minimal, the average January air temperature is 17°C and the average June air temperature is 4.3ºC. The map coordinates are for the centre of the reach, which is useful to check that you are in the right place.

Table 9. Catchment and reach variables for an example reach from the CD provided

Parameter name	Variable
NZ REACH NUMBER	9000495
CATCHMENT AREA m^2	4780800.00
CATCHMENT CALCIUM	2.00
CATCHMENT HARDNESS	1.00
CATCHMENT PHOSPHOROUS	2.26
CATCHMENT PROPORTION ALLUVIUM	0.65
CATCHMENT PROPORTION BARE LAND	0.00
CATCHMENT PROPORTION EXOTIC FOREST	0.00
CATCHMENT PROPORTION GLACIAL	0.00
CATCHMENT PROPORTION INDIGENOUS FOREST	0.00
CATCHMENT PROPORTION MISCELLANEOUS LANDCOVER	0.00
CATCHMENT PROPORTION PASTORAL FARMING	0.60
CATCHMENT PROPORTION PEAT	0.00
CATCHMENT PROPORTION SCRUB	0.02
CATCHMENT PROPORTION TUSSOCK	0.00
CATCHMENT PROPORTION URBAN	0.36
CATCHMENT RAINFALL VARIABILITY	154.53
DISTANCE TO COAST (m)	5028.30
FLOW	0.15
LOW FLOW	37.80
NUMBER OF CATCHMENT RAINDAYS > 25mm	0.81
ORDER	2.00
REC CLIMATE	WD
REC GEOLOGY	Al
REC LANDCOVER	U
REC SOURCE OF FLOW	L
REC VALLEY LANDFORM	LG
SEGMENT MAXIMUM ELEVATION (m)	13.80
SEGMENT MINIMUM ELEVATION (m)	11.67
SEGMENT SINUOSITY	1.18
SEGMENT SLOPE	0.00
TEMPERATURE SUMMER	17.20
TEMPERATURE WINTER	4.30
usXcentroid	2691063.00
usYcentroid	6049039.00

Protocol 1 (P1) Site characterisation

Sample time	5-10 minutes
Site length	As far as you can easily see upstream and downstream
Equipment	Camera, GPS or relevant topography map
Overview	This protocol is designed to provide a quick characterisation of a site. It is most appropriate for situations where some record of the condition of a site may be wanted, such as during site selection. The protocol is *not* intended to provide data that can be statistically analysed as virtually all the information collected is subjective. This protocol is not appropriate for any robust long term comparison or monitoring changes at a site (see "Selecting the right protocol" section).
Components	Possible desktop assessment A single field form

Site characterisation procedure

This protocol is designed to be conducted from the stream bank or a roadway. The assessor is not required to measure anything, so all parameters are estimates only. It may be appropriate to circle or note multiple conditions for some parameters e.g., runs, riffles and pools may all be present in a reach.

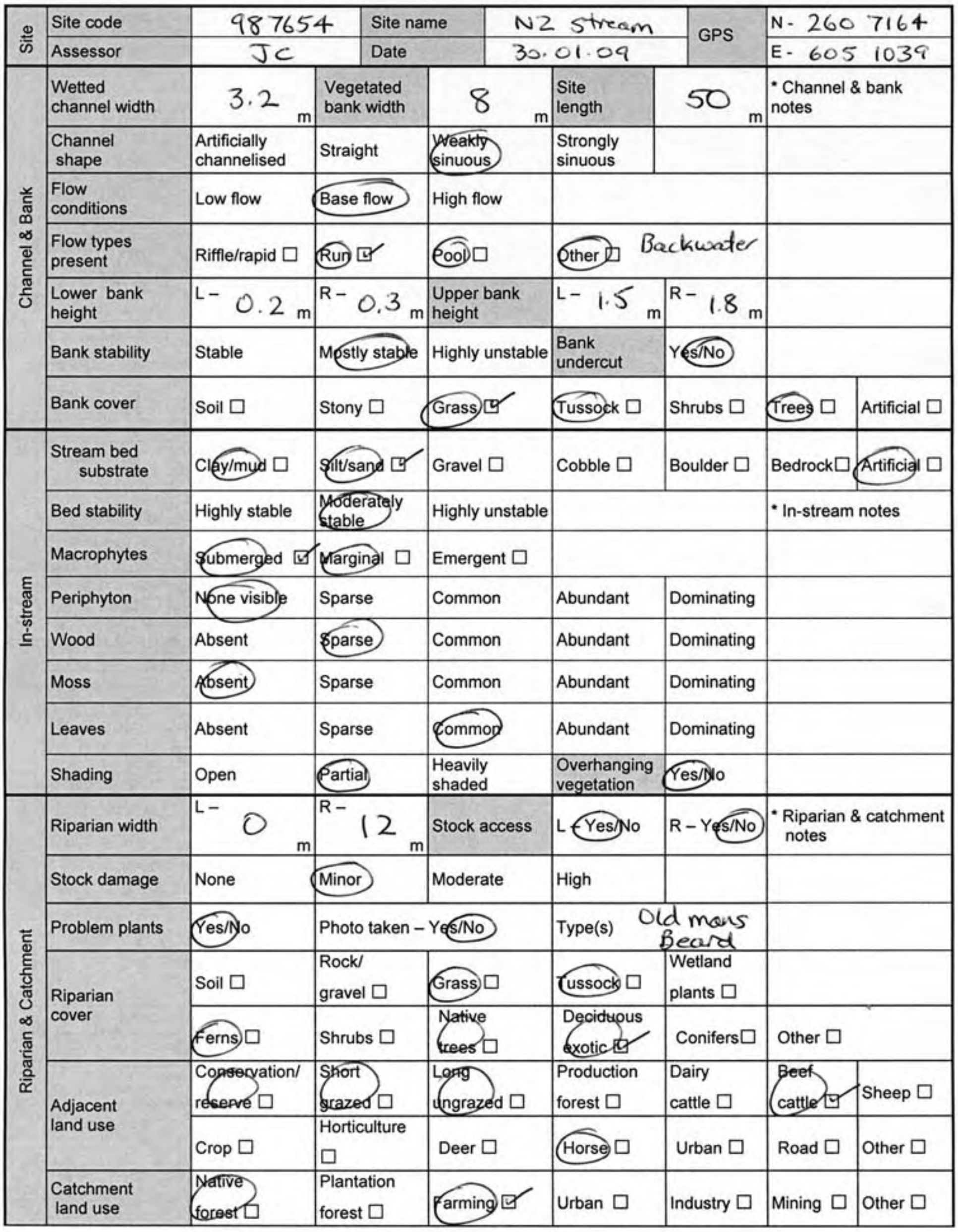
1. Record site details such as **site code** (REC number), **site name**, **GPS** or grid reference points, as well as the name of the **assessor** and the **date**.
2. Estimate **wetted channel width** as the zone currently under water, this also includes non-flowing water.
3. Vegetated bank to **vegetated bank width** is the zone from the edge of vegetation on one bank to the other and may include the dry floodplain and exposed lower banks.
4. Record **site length** as the combined upstream and downstream reach that can be easily observed from one spot without necessarily walking either direction.
5. Determine the **channel shape** i.e., whether the channel seems to be artificially straightened (e.g., wooden box culverts, redirected along field boundary) or seems naturally straight, whether it has gentle bends or has sharp corners or meanders (i.e., strongly sinuous).
6. Visually compare the current water level with any plants, moss and algae growing on the substrate to note **flow conditions**. Indications of past or current high flows may be seen as bent or broken bank vegetation, and debris deposited on the banks. During low flows, dried plant and algal material may be visible on substrate on the non-wetted bed.
7. Circle all **flow types** present and tick the box for the most dominant. Runs are fast flowing but non-broken water, riffles and rapids usually include portions of broken flowing 'white' water. Pools have slow flowing, deep water with a smooth surface.
8. Estimate **bank height** for left (L) and right (R) banks. The "true" left bank is the left

bank looking downstream. Bank height is the vertical height from the water level to the bank. **Upper** & **lower** banks may be differentiated by a change in slope. Where there is no obvious change, lower bank height equals upper bank height.

9. Assess **bank stability** of the vegetated banks. Unstable banks may have bank undercutting, slumping, livestock tracks, obvious erosion, fallen trees and exposed soil or stony substrate. Highly stable banks will often be covered in vegetation and have few exposed soils or gravels. Record the presence of **bank undercut** separately.
10. Circle all types of **bank cover** present *and* tick the dominant cover type.
11. Circle all types of **streambed substrate** present *and* tick the most dominant. Clay/mud is very fine substrate which typically holds together in clumps when handled. Silt and sand are coarser, larger particles and typically disperse when handled. Gravel substrate is >2 mm, cobble 60-255 mm, boulders are 256-4000 mm and bedrock >4000 mm.
12. Assess **bed stability** where a highly stable bed may have many large, stable boulders and embedded logs that are unlikely to be moved in high flows, while a highly unstable bed could be dominated by fine gravels, silt, and sand and have obvious deposition and scouring zones.
13. **Macrophytes** are large plants with stems and leaves (vascular plants). Only note if there are significant growths present (i.e., >10% of the wetted bed) and tick the most dominant. Marginal macrophytes occur along the shallow water of one or both banks, while emergent macrophytes grow from the bed up to the waters' surface.
14. Assess the abundance of **periphyton** or visible algae on the wetted stream bed.
15. Assess the abundance of **wood** including trees, branches and log jams in the non-vegetated channel and wetted channel.
16. Assess the abundance of **moss** including lichen and liverworts growing in the non-vegetated channel and wetted channel.
17. Assess the abundance of **leaves** i.e., leaf packs in the wetted channel.
18. Estimate in-stream **shading,** where an "open" stream will have little shade (e.g., <20% of the bed) and sunlight reaches most of the wetted bed. Whereas, a heavily shaded reach will contain riparian vegetation, topography and/or human structures which shade >80% of the bed. Note the presence of **overhanging vegetation** separately (i.e. bank vegetation touching or within 5cm of the water).
19. Estimate the **riparian width** of the left and right banks; this is the zone which has different land cover or management than the wider catchment. If there is no difference (e.g., all forest), then note this.
20. Identify **stock access** to the left and right banks and whether there is any **stock damage**. Minor damage might include limited stock trails (e.g., sheep trails) but no bank slumping. High damage might include areas of pugging, bank slumping and multiple stock entrance and exit points along the reach.
21. Note the presence of **known pest plants** or weeds. Record the name if known, otherwise take a photo for identification.
22. Circle the types of **riparian cover** *and* tick the most dominant.
23. Circle the types of **adjacent land use** evident at the site *and* tick the most dominant.
24. Circle the types of wider **catchment land use** evident from the site *and* tick the most dominant.

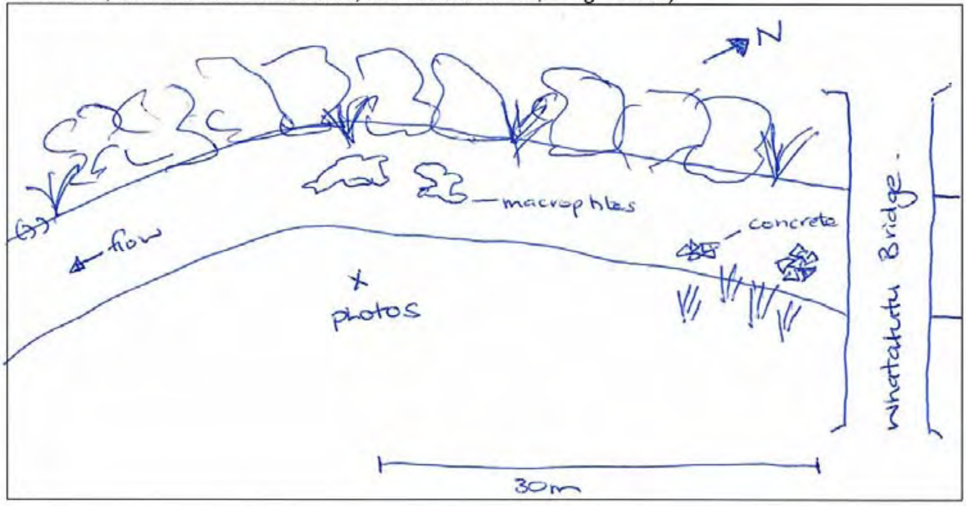
25. Complete a **plan diagram** (bird's eye view) of the site including photo points, significant land marks, access points, N direction, direction of stream flow, location of roads and a rough scale.
26. Complete a **cross section** diagram of the site including the shape of the floodplain, riparian vegetation and channel shape.
27. Take **site photos** looking upstream and downstream which include the floodplain, riparian vegetation and in-stream channel.
28. Record additional information where appropriate, e.g., landowner information, directions to find the site, hazards.

Example of a completed P1 field form

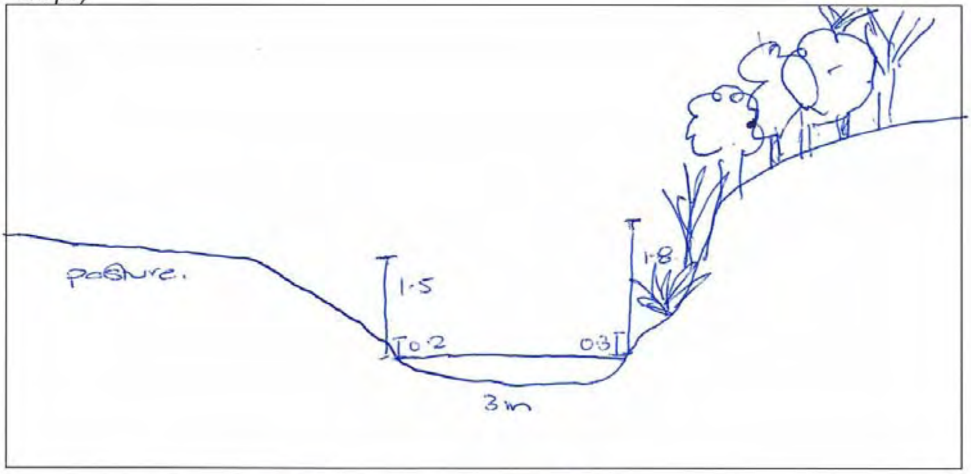


Site	Site code	987654	Site name	NZ stream		GPS	N- 260 7164	
	Assessor	JC	Date	30.01.09			E- 605 1039	
Channel & Bank	Wetted channel width	3.2 m	Vegetated bank width	8 m	Site length	50 m	* Channel & bank notes	
	Channel shape	Artificially channelised	Straight	[✓ Weakly sinuous]	Strongly sinuous			
	Flow conditions	Low flow	[✓ Base flow]	High flow				
	Flow types present	Riffle/rapid ☐	[✓ Run] ☑	[✓ Pool] ☐	[✓ Other] ☐	Backwater		
	Lower bank height	L – 0.2 m	R – 0.3 m	Upper bank height	L – 1.5 m	R – 1.8 m		
	Bank stability	Stable	[✓ Mostly stable]	Highly unstable	Bank undercut	Yes/[✓ No]		
	Bank cover	Soil ☐	Stony ☐	[✓ Grass] ☑	[✓ Tussock] ☐	Shrubs ☐	[✓ Trees] ☐	Artificial ☐
In-stream	Stream bed substrate	[✓ Clay/mud] ☐	[✓ Silt/sand] ☑	Gravel ☐	Cobble ☐	Boulder ☐	Bedrock ☐	[✓ Artificial] ☐
	Bed stability	Highly stable	[✓ Moderately stable]	Highly unstable			* In-stream notes	
	Macrophytes	[✓ Submerged] ☑	[✓ Marginal] ☐	Emergent ☐				
	Periphyton	[✓ None visible]	Sparse	Common	Abundant	Dominating		
	Wood	Absent	[✓ Sparse]	Common	Abundant	Dominating		
	Moss	[✓ Absent]	Sparse	Common	Abundant	Dominating		
	Leaves	Absent	Sparse	[✓ Common]	Abundant	Dominating		
	Shading	Open	[✓ Partial]	Heavily shaded	Overhanging vegetation	[✓ Yes]/No		
Riparian & Catchment	Riparian width	L – 0 m	R – 12 m	Stock access	L – [✓ Yes]/No	R – Yes/[✓ No]	* Riparian & catchment notes	
	Stock damage	None	[✓ Minor]	Moderate	High			
	Problem plants	[✓ Yes]/No	Photo taken – Yes/[✓ No]		Type(s)	Old mans Beard		
	Riparian cover	Soil ☐	Rock/ gravel ☐	[✓ Grass] ☐	[✓ Tussock] ☐	Wetland plants ☐		
		[✓ Ferns] ☐	Shrubs ☐	[✓ Native trees] ☐	[✓ Deciduous exotic] ☑	Conifers ☐	Other ☐	
	Adjacent land use	[✓ Conservation/ reserve] ☐	[✓ Short grazed] ☐	[✓ Long ungrazed] ☐	Production forest ☐	Dairy cattle ☐	[✓ Beef cattle] ☑	Sheep ☐
		Crop ☐	Horticulture ☐	Deer ☐	[✓ Horse] ☐	Urban ☐	Road ☐	Other ☐
	Catchment land use	[✓ Native forest] ☐	Plantation forest ☐	[✓ Farming] ☑	Urban ☐	Industry ☐	Mining ☐	Other ☐

Plan diagram of site *(include photo points, significant land marks, access points, N direction, direction of stream flow, location of roads, rough scale)*



Cross section diagram of site *(include shape of floodplain, riparian vegetation, channel shape)*



Site photos - Upstream ☑ Downstream ☑

Landowner information/contact

Jack Black # 021234567

Directions to find site

Whatatutu Rd
6km south of Hira.

Additional notes

Protocol 2 (P2) Semi-quantitative protocol

Sample time	45-60 minutes
Site length	20x the mean wetted width at base flow (with a minimum of 50m and maximum of 500m).
Equipment	Camera, GPS or relevant topographic map. Flagging tape or similar, 30m+ measuring tape, water velocity meter, 1m ruler, range finder (optional), two 1.5m survey poles & inclinometer or builder's level, trowel or soil corer.
Overview	This protocol is designed to provide a semi-quantitative assessment of a site, it includes some rigorous measurements but places more emphasis on visual estimates. It is most appropriate for State of the Environment monitoring, consent monitoring, AEE and long-term trend monitoring. Data is limited by the subjective and categorical assessment of some habitat variables (see notes on qualitative vs. quantitative parameters), but may be used to estimate a range of habitat metrics. The protocol is intended to provide data that can be statistically analyzed but is not as rigorous as P3.
Components	P2a – Desktop protocol P2b - An in-stream hydrological and morphological assessment P2c - An in-stream physical habitat assessment P2d - A riparian habitat assessment

P2b Hydrology and morphology procedure

1. Record site details such as **site name**, **site code** (REC number) as well as the name of the **assessor** and the **date**. Establish **reach start** by marking with a flagging tape or similar and GPS.
2. Measure stream **wetted width** and calculate the **site length** approximately 20x wetted width. (If time allows, walk the length of the reach to familiarise yourself with the site and to begin thinking about where to measure habitat parameters). Walk along the stream at the water's edge following the thalweg for the length of the reach measured by tape measure or pacing. Whilst walking record the **meso-habitat length** in meters for each meso-habitat encountered. GPS the **reach end** point.
3. At each pool (maximum of three) measure residual pool depth by measuring the **maximum depth** of water at the deepest part of the pool and the **crest depth** of water at the riffle crest immediately downstream of the pool (An estimate of maximum pool depth is sufficient if it is too deep to measure, but note that it was estimated).
4. At the deepest part of each pool (maximum of three) measure the soft **sediment depth** by gently forcing your 1m ruler or wading rod into the substrate.
5. Estimate the **floodplain shape** for the site.
6. Locate three representative channel cross sections, one in a run, one in a riffle and one in a pool (if present). At each cross section estimate **bankfull channel shape**, **wetted**

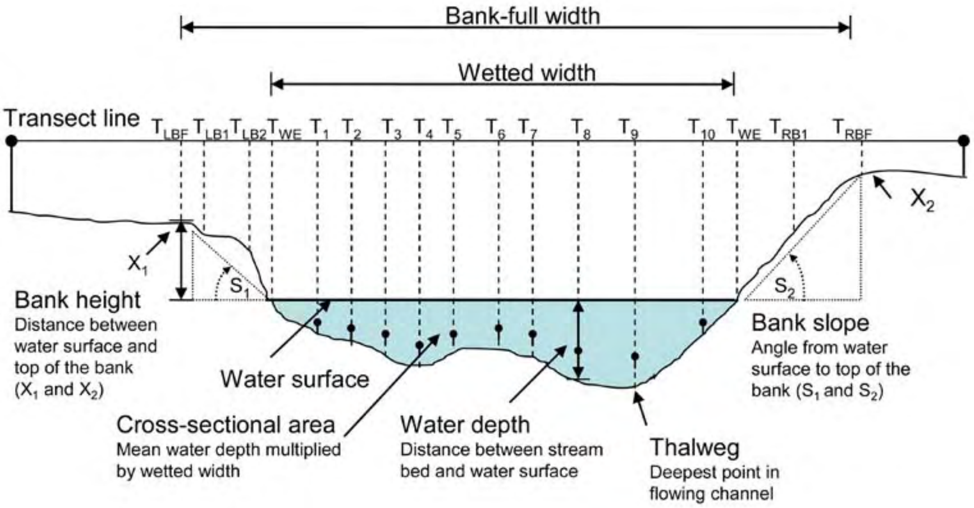
width channel shape, and measure the average width of **undercut bank** with 1m ruler (no undercut = 0). At least one run cross section should be included and it should be suitable for estimating discharge.

7. Locate a **run** cross section suitable for estimating discharge (e.g., of uniform flow and free from undercuts, back eddies) and extend a measuring tape across the channel perpendicular to stream flow.

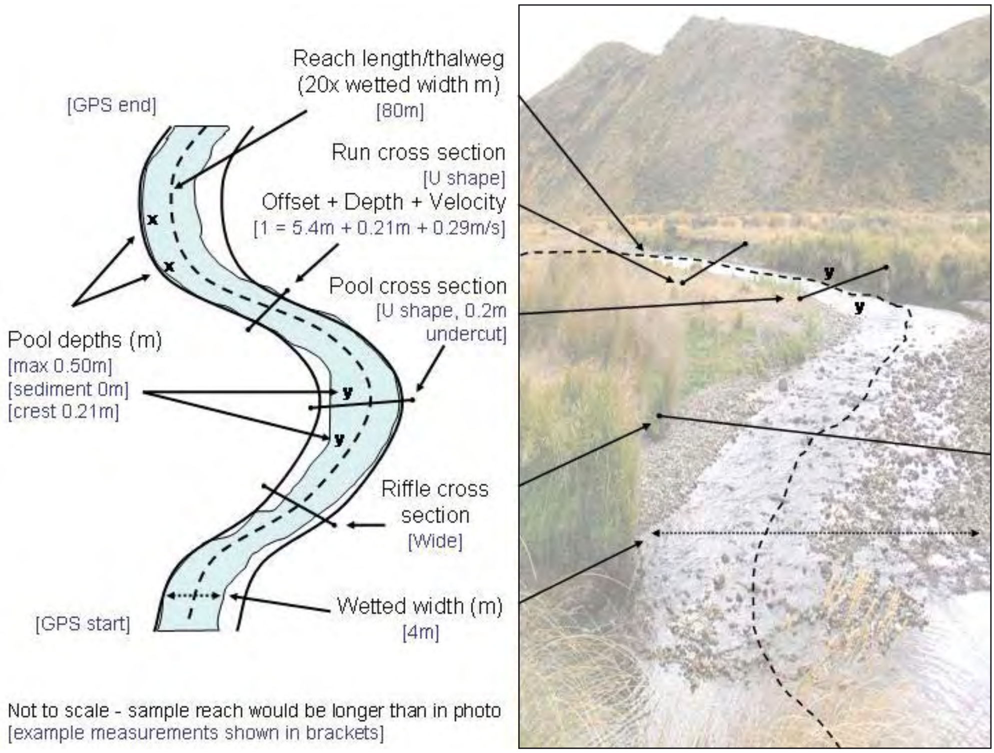
   At left bankfull height (LBF) and at up to three points between bankfull and the water's edge (i.e., LB_1, LB_2, LB_3) record the **offset** (distance along the tape) and distance between the ground and horizontal measuring tape (record this height in the water depth cells). Aim to position the LB measurements at the points of greatest change in bank slope. Also record the offset and distance to the measuring tape at the water's edge (WE). See the diagram below.

   Record **water depth** and **water velocity** at up to 10 offsets across the transect. The aim is to define the cross-sectional area with as few offsets as possible (minimum = 5) whilst recording the variation in the stream bed. A rule of thumb is to choose the offsets at points where depth and/or water velocity change noticeably. Read water depth on the downstream side of a ruler or wading rod. Water velocity is measured four-tenths of water depth up from the bed. Repeat bank measurements on the right bank.
8. Complete a **plan diagram** (bird's eye view) of the site including photo points, significant land marks, access points, N direction, direction of stream flow, location of roads and a rough scale.

Diagram of a channel cross section

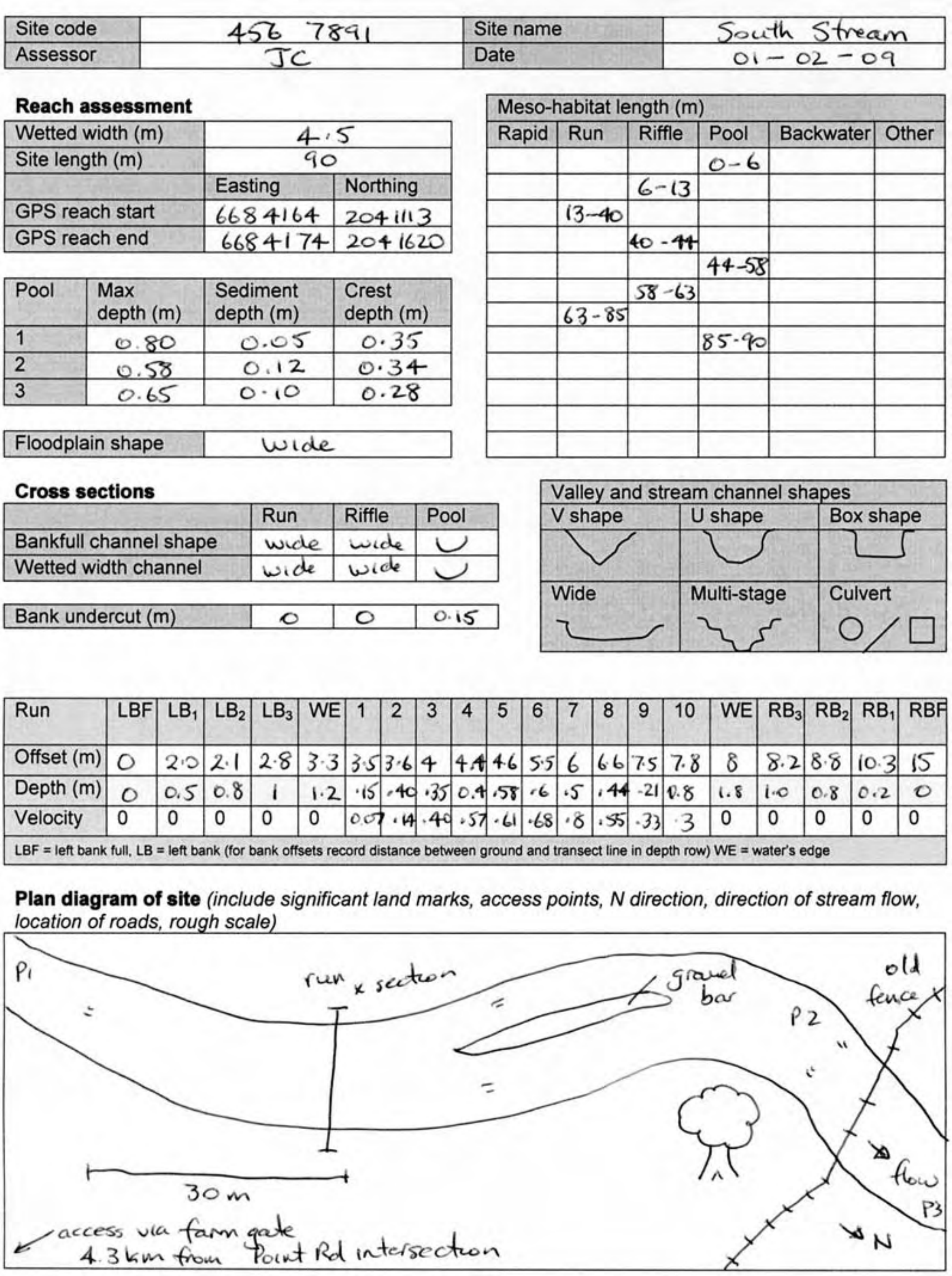


Summary diagram of the variables assessed during P2b



Not to scale - sample reach would be longer than in photo
[example measurements shown in brackets]

Example of a completed P2b field form



Site code	456 7891	Site name	South Stream
Assessor	JC	Date	01 – 02 – 09

Reach assessment

Wetted width (m)	4.5	
Site length (m)	90	
	Easting	Northing
GPS reach start	6684164	2041113
GPS reach end	6684174	2041620

Pool	Max depth (m)	Sediment depth (m)	Crest depth (m)
1	0.80	0.05	0.35
2	0.58	0.12	0.34
3	0.65	0.10	0.28

Floodplain shape	wide

Meso-habitat length (m)

Rapid	Run	Riffle	Pool	Backwater	Other
			0–6		
		6–13			
	13–40				
		40–44			
			44–58		
		58–63			
	63–85				
			85–90		

Cross sections

	Run	Riffle	Pool
Bankfull channel shape	wide	wide	◡
Wetted width channel	wide	wide	◡

Bank undercut (m)	0	0	0.15

Valley and stream channel shapes

V shape	U shape	Box shape
Wide	Multi-stage	Culvert

Run	LBF	LB$_1$	LB$_2$	LB$_3$	WE	1	2	3	4	5	6	7	8	9	10	WE	RB$_3$	RB$_2$	RB$_1$	RBF
Offset (m)	0	2.0	2.1	2.8	3.3	3.5	3.6	4	4.4	4.6	5.5	6	6.6	7.5	7.8	8	8.2	8.8	10.3	15
Depth (m)	0	0.5	0.8	1	1.2	.15	.40	.35	0.4	.58	.6	.5	.44	.21	0.8	1.8	1.0	0.8	0.2	0
Velocity	0	0	0	0	0	0.07	.14	.40	.57	.61	.68	.8	.55	.33	.3	0	0	0	0	0

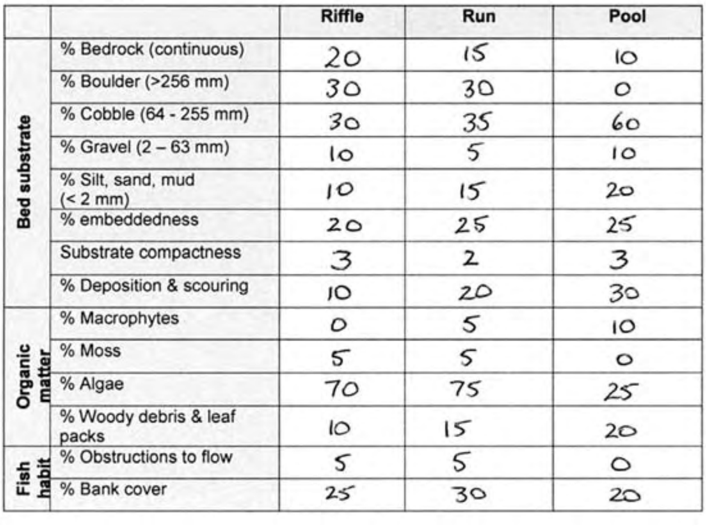
LBF = left bank full, LB = left bank (for bank offsets record distance between ground and transect line in depth row) WE = water's edge

Plan diagram of site *(include significant land marks, access points, N direction, direction of stream flow, location of roads, rough scale)*

P2c In-stream habitat procedure

1. This assessment is made across the bankfull width of the stream. It should be carried out in the three habitats (e.g., a riffle, a run and a pool) where possible used in P2b.
2. Select a representative **riffle**, **run** and **pool**. At each habitat conduct the following:
3. Looking over the entire meso-habitat, estimate the percentage of bed dominated by each of main **substrate size classes**.
4. Determine which size class is the most dominant, then estimate the percentage of **embeddedness** i.e. the amount of fine sediment which surrounds the dominant substrate.
5. Walk across part of the riverbed and estimate **substrate compactness.** Compactness is assessed on a 1- 4 scale. (1 = Loose, easily moved substrate, 2 = Mostly loose, little compaction, 3 = Moderately packed, 4 = Tightly packed substrate).
6. Visually estimate the percentage of wetted bed where there are **scouring and depositional** zones. These are usually apparent behind boulders, logs and along the stream margin.
7. Assess **macrophytes** by visually estimating the percentage of the wetted bed with aquatic vascular plants greater than 10 cm^2 in area.
8. Visually estimate the percentage of wetted bed where there are **moss** and/or bryophytes present.
9. Visually estimate the percentage of the wetted bed with **algal beds** greater than 0.1m x 0.1m in area.
10. Visually estimate the percentage of the wetted bed with **wood and leaf packs** including trees, branches and roots.
11. Visually estimate the percentage of the wetted bed with significant **obstructions to flow**, e.g., large boulders and log jams (> 0.5m in size), do *not* include macrophytes.
12. Observing both banks upstream and downstream, visually estimate the percentage of banks with **undercutting & overhanging vegetation**.

Example of a completed P2c field form



		Riffle	Run	Pool
Bed substrate	% Bedrock (continuous)	20	15	10
	% Boulder (>256 mm)	30	30	0
	% Cobble (64 - 255 mm)	30	35	60
	% Gravel (2 – 63 mm)	10	5	10
	% Silt, sand, mud (< 2 mm)	10	15	20
	% embeddedness	20	25	25
	Substrate compactness	3	2	3
	% Deposition & scouring	10	20	30
Organic matter	% Macrophytes	0	5	10
	% Moss	5	5	0
	% Algae	70	75	25
	% Woody debris & leaf packs	10	15	20
Fish habit	% Obstructions to flow	5	5	0
	% Bank cover	25	30	20

P2d Riparian procedure

1. Conduct this survey along the full length of the sample reach and assess riparian zones on both banks.
2. On the field sheet write your results in the two columns “LB” (left bank), and “RB” (right bank).
3. Assess **shading of water** at the water surface; consider shading at all points across the water surface throughout the reach, so that the influence of banks, bank vegetation, and hill slopes are included in the assessment.
4. Assess the riparian **buffer width** from the stream bank in-land that is managed differently from the rest of the catchment. This riparian buffer (i.e., the managed area) may differ in extent to the riparian zone. If there is no difference in management use a width of 30m.
5. **Buffer intactness** - estimate the percentage of gaps in the riparian vegetation that may reduce the effectiveness of the riparian buffer in providing habitat and interception of contaminant inputs.
6. Assess the **riparian vegetation** composition within the riparian buffer and the remaining area between the stream bank and 30 m in-land. If no buffer is present (i.e., no managed riparian vegetation) write “NB” in the space below “Buffer” in the boxes for LB and RB scores and fill in scores for the whole area to 30 m from the stream bank in space beneath “Adjacent land”.
7. Walk the length of the reach and evaluate the typical condition of **bank stability** of both banks.
8. Assess **livestock access** by the presence of fencing, evidence of riparian vegetation grazing, presence of stock access tracks and other signs of animal access, such as cowpats.
9. **Riparian soil denitrification potential** - walk the reach and assess soil wetness and presence of sub-surface drains (e.g., tile drains in stream banks) and open surface drains that enable groundwater to bypass moist riparian soils. Water-logged soils will sink underfoot and often have wetland plants present, such as sedges, flax or raupo.
10. Assess average **land slope** from the stream bank to 30 m landward on each bank. Several measurements should be made initially “to get your eye in” using two survey poles and an inclinometer or builder’s level.
11. Assess the **groundcover** for both the buffer (if present) and adjacent land to 30 m from the stream bank.
12. Use a trowel, soil corer or spade to dig into the riparian soil at 3-5 locations along each side of the stream to assess the soil texture and **soil drainage** potential i.e., boggy or free draining.
13. Count the number of **rills** that are likely to concentrate surface runoff through the riparian area and hence bypass filtering vegetation and soil infiltration.

Example of a completed P2d field form

Attributes	L	R	Scores 1	Scores 2	Scores 3	Scores 4	Scores 5
Shading of water	4		Little or no shading	10-25% shading	25-50%	50-80%	>80%
Buffer width	1	4	<1 m	1-5 m	5-15 m	15-30 m	>30 m
Buffer intactness	1	5	Buffer absent	50-99% gaps	20-50% gaps	1-20% gaps	Completely intact
Vegetation comp. of buffer and/or adjacent land to 30 m from streambank	**Buffer** 1 **Adjacent** 1	**Buffer** 3 **land** 4	Short grazed pasture grasses to stream edge, or impervious surfaces	Exotic weedy shrubs Gorse, blackberry, broom, or mainly high grasses or low native shrubs 0.3-2 m	Deciduous tree dominated; native shrub dom. (2-5 m); or plantation with <25% cover of >5 m trees; or tussock where natural	Regen. native forest or woodlot evergreens with >25% cover sub-canopy (>5 m) trees but <10% canopy trees (>12 m)	Maturing native forest including >10% cover canopy trees (>12 m); or native wetland or natural tussock veg.
Bank stability	2	4	Very low: uncohesive sediments & few roots & >40% recently eroded	Low: uncohesive sediments & few roots/ low veg. cover & >15-40% recently eroded	Moderate: stabilized by geology (e.g. cobbles), veg cover &/or roots & >5-15% recently eroded	High: stabilized by geology (e.g. bedrock), veg. cover &/or roots; & 1-5% recently eroded	Very high: stabilized by geology (e.g. bedrock), veg. cover &/or roots; <1% recently eroded
Livestock access	1	4	High: unfenced and unmanaged with active livestock use	Moderate: some livestock access	Limited: Unfenced but with low stocking, bridges, troughs, natural deterrents	Very limited: Temporary fencing of all livestock or naturally v limited access	None: Permanent fencing or no livestock
Riparian soil denitrification potential	2	4	Soils dry/firm underfoot <u>or</u> moist-wet but frequent tile drains bypass riparian soils (≥3 per 100 m)	1-30% streambank soils moist but firm <u>or</u> moist-wet with infrequent bypass drains (1-2 per 100 m)	≥30% streambank soils moist but firm underfoot. No drains.	1-30% streambank soils water-logged, soft underfoot with black soil. No drains.	≥30% of streambanks water-logged, surface moist/fluid underfoot. No drains.
Land slope 0-30 m from stream bank	2	1	>35°	>20 - 35°	>10 - 20°	>5 -10°	0 - 5°
Groundcover of buffer and/or adjacent land to 30 m from streambank	**Buffer** 2 **Adjacent** 2	**Buffer** 5 **Land** 4	Bare	Short/regularly grazed pasture (<3 cm)	Pasture grass/ tussock with bare flow paths or 2-3 cm tree litter layer	Moderate density grass or dense (>3 cm) tree litter layer	High density long grass
Soil drainage	2	4	Impervious (e.g. sealed) or extensively pugged and/or compacted soil	Low permeability (e.g. high clay content) or moderately pugged/compacted soil	Low-moderate permeability (e.g. silt / loam) and not pugged/compacted	Mod-high permeability (e.g. sandy loam) & not pugged/compacted	Very high permeability (e.g. pumice / sand) & not pugged/compacted
Rills / Channels	4	5	Frequent rills (> 9 per 100 m) or larger channels carry most runoff	Common rills (4-9 per 100 m) or 1-2 larger channels carry some runoff	Infrequent rills (2-3 per 100 m) and no larger channels	Rare rills (1 per 100 m) and no larger channels	None

Protocol 3 (P3) Quantitative protocol

Sample time	120-180 minutes
Site length	20x the mean wetted width at base flow (with a minimum of 50m and maximum of 500m)
Equipment	Camera, GPS or relevant topographic map. Flagging tape or similar, two or three 30m+ measuring tapes, water velocity meter, 1m ruler, range finder (optional), two 1.5m survey poles & inclinometer or builder's level, trowel or similar. A convex densiometer or a paired light sensor, and six temporary staff gauges (e.g., pieces of reinforcing bar or Warratahs) (optional, if follow up measurements of change in wetted width and depth are intended).
Overview	The aim of this protocol is to provide an intensive quantitative characterisation of a study site. It is suitable for baseline surveys and research projects where accurate data is required or long-term assessment of a site is expected. Sufficient data is obtained to calculate habitat metrics as well as conduct additional generalized habitat modelling.
Components	P3a – Desktop protocol P3b - An in-stream hydrological and morphological assessment P3c - An in-stream physical habitat assessment P3d - A riparian habitat assessment

P3b Hydrology and morphology procedure

1. Record site details such as **site code** (REC number), **site name**, as well as the name of the **assessor** and the **date**. Establish **reach start** by marking with a flagging tape or similar and GPS.
2. Measure the stream **wetted width** at a representative cross section (or measure 2-3 widths and calculate an average) and calculate the **reach length** as 20x wetted width.
3. Walk along the stream at the water's edge following the thalweg for the length of the sample reach measured by tape measure, tagline or pacing. Whilst walking record the **meso-habitat length** in meters for each meso-habitat encountered. (Identify areas to measure habitat parameters).
4. GPS the **reach end** point.
5. At each pool (maximum of six) measure residual pool depth by measuring the **maximum depth** of water at the deepest part of the pool and the **crest depth** of water at the riffle crest immediately downstream of the pool (an estimate of maximum pool depth is sufficient if it is too deep to measure, but note that it was estimated).
6. At the deepest part of each pool (maximum of six) measure the soft **sediment depth** by gently forcing your 1m ruler or wading rod into the substrate.
7. Locate a maximum of nine channel cross sections that represent the major meso-habitat types identified, e.g., three riffle, three run, and three pools. Within each meso-habitat

type, cross sections should be positioned in an attempt to encompass the range of variability represented, e.g., in the head, middle and tail of pools. However, locations that are not typical of the stream habitat should be avoided (e.g., extraordinarily wide riffles), as these 'habitat outliers' would bias the overall results.

8. At the channel cross section of a **run**, record location (e.g., head, middle, or tail) and extend a measuring tape across the channel perpendicular to stream flow. [Optional - mark the location of the cross section on both banks if follow up measurements of change in wetted width and depth are intended at a later date. Drive a temporary staff gauge into the stream bed and measure the water level relative to the top of the staff gauge. This gauge should be sufficient depth that it will not be dry by the time of the next measurement and protected from floods and debris. Do this for *run* cross sections only].
9. At left bankfull height (LBF) and at up to three points between bankfull and the water's edge (i.e., LB_1, LB_2, LB_3) record the **offset** (distance along the tape) and distance between the ground and horizontal measuring tape (record this height in the water depth cells). Aim to position the LB measurements at the points of greatest change in bank slope. Also record the offset and distance to the measuring tape at the water's edge (WE).
10. Record **water depth** and **water velocity** at up to 10 offsets across the transect. The aim is to define the cross-sectional area with as few offsets as possible (minimum = 5) whilst recording the variation in the stream bed. A rule of thumb is to choose the offsets at points where depth and/or water velocity change noticeably. Read water depth on the downstream side of a ruler or wading rod. Water velocity is measured at four-tenths of water depth up from the bed. Repeat bank measurements on the right bank.
11. Repeat cross sections at two more runs recording all variables.
12. Repeat the cross section at three **riffle** and three **pool** habitats, excluding water velocity readings.
13. Complete a **plan diagram** (bird's eye view) of the site including photo points, significant land marks, access points, N direction, direction of stream flow, location of roads and a rough scale.

Example of a completed P3b field form

P3b is similar to P2b with an additional 8 transects.

P3c In-stream habitat procedure

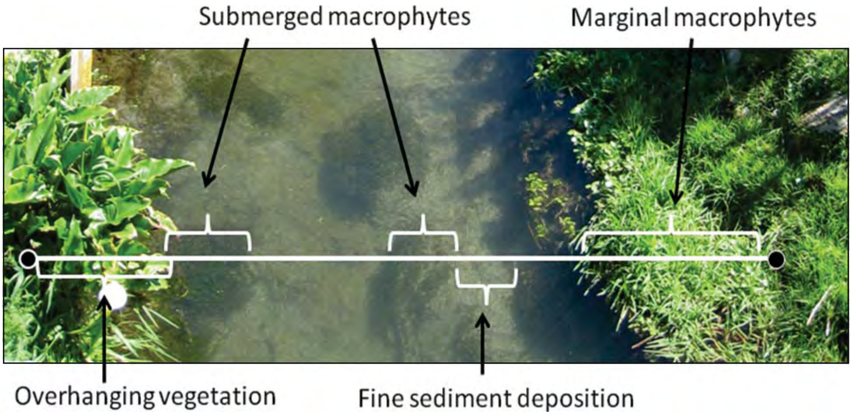
1. This assessment is made across the bankfull extent of the stream; it includes lower banks, any dry river bed and the wetted width of the stream.
2. Measure six cross-sections including two riffles, two runs and two pools. These cross-sections should be a subset of those used in the morphology and hydrology assessment (P3a). At each cross-section conduct the following:
3. Measure the **substrate size** of 10 randomly selected particles whilst wading across the stream cross-section. Measure the second narrowest axis of each particle.
4. For each of the 10 randomly selected particles, note the degree of **substrate embeddedness** using the 1-4 scale (Score 1 – Not embedded, the substrate on top of the bed. Score 2 – Slightly embedded, < 25% of the particle is buried or attached to the surrounding substrate. Score 3 – Firmly embedded, approximately 50% of the substrate is embedded

or attached to the surrounding substrate. Score 4 – Heavily embedded, >66% of the substrate is buried).

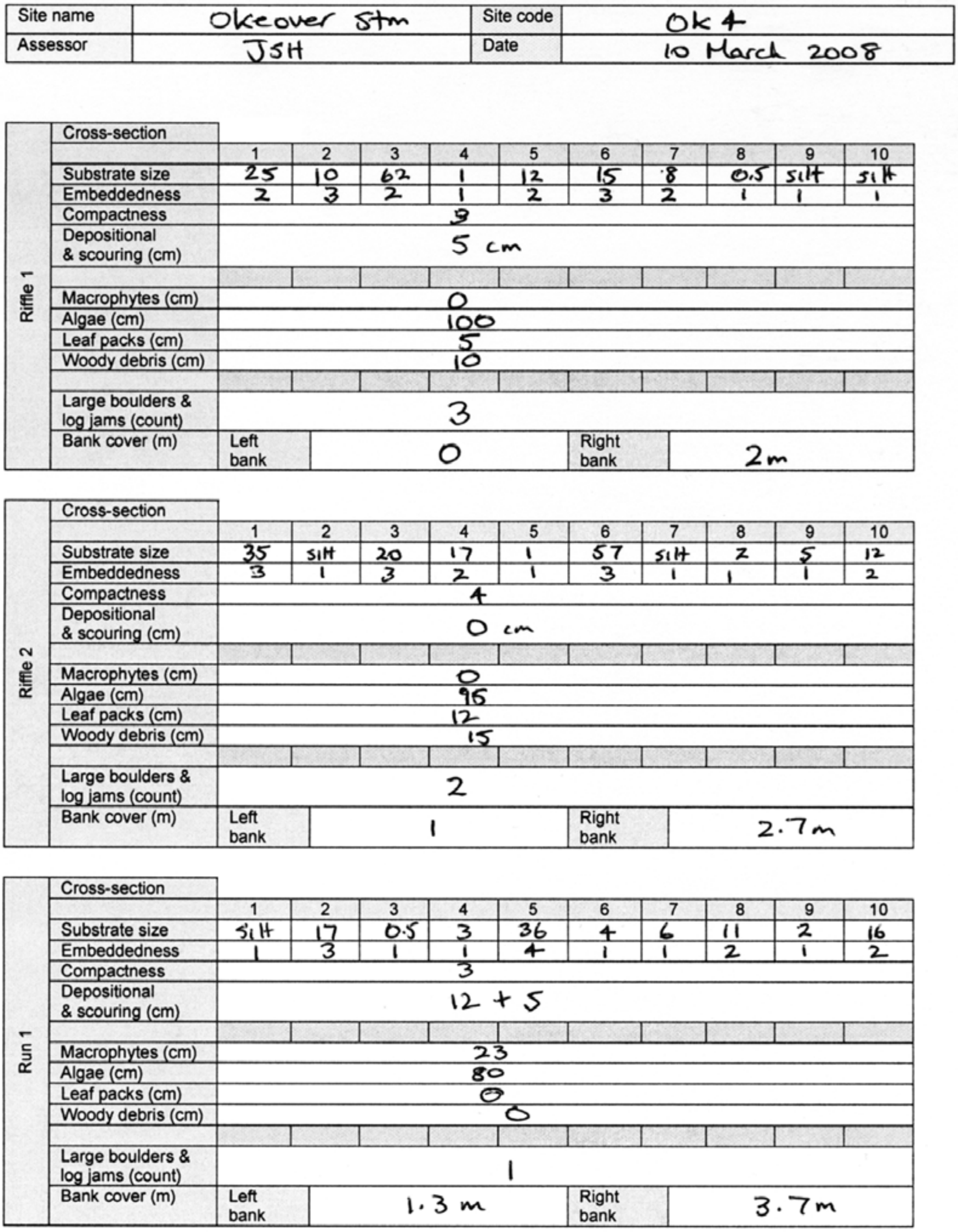
5. **Substrate compactness** - Walk across part of the riverbed and estimate the degree of compactness. Compactness is assessed on a 1- 4 scale. (1 = Loose, easily moved substrate, 2 = Mostly loose, little compaction, 3 = Moderately packed, 4 = Tightly packed substrate).
6. Measure the total amount of **depositional or scouring** zones across the measuring tape.
7. Measure the width of **macrophyte** beds that intersect the tape. Note if macrophytes are submerged, emergent or marginal (see glossary).
8. Measure the total width of **visible algal** growths that intersect the tape.
9. Measure the total width of visible **leaf packs** (> 10 cm^2) that intersect the tape.
10. Measure the longest axis of any large **wood** (> 20 cm longest axis) that intersect the tape.
11. Count the number of significant **obstructions to flow** such as large boulders and log jams (> 0.5m in size) that intersect the tape.
12. Measure the amount of wetted stream bed with **bank cover** referring to overhanging banks or vegetation (< 30 cm above water surface) across the cross section.
13. Repeat these measurements for another five cross-sections.

Diagram of in-stream features

Black circles denote water's edge; the white line represents the measuring tape. Brackets indicate length of transect intersected by a given habitat feature.



Example of a partially completed P3c field form



Site name	Okeover Stm	Site code	Ok 4
Assessor	JSH	Date	10 March 2008

	Cross-section	1	2	3	4	5	6	7	8	9	10
Riffle 1	Substrate size	25	10	62	1	12	15	·8	0.5	silt	silt
	Embeddedness	2	3	2	1	2	3	2	1	1	1
	Compactness	3									
	Depositional & scouring (cm)	5 cm									
	Macrophytes (cm)	0									
	Algae (cm)	100									
	Leaf packs (cm)	5									
	Woody debris (cm)	10									
	Large boulders & log jams (count)	3									
	Bank cover (m)	Left bank	0				Right bank	2m			

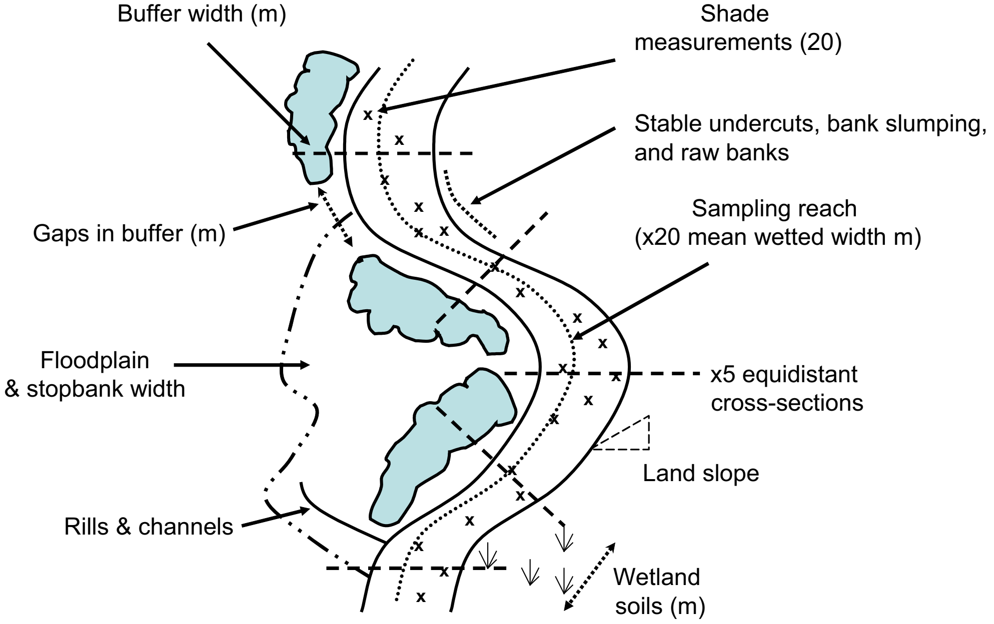
	Cross-section	1	2	3	4	5	6	7	8	9	10
Riffle 2	Substrate size	35	silt	20	17	1	57	silt	2	5	12
	Embeddedness	3	1	3	2	1	3	1	1	1	2
	Compactness	4									
	Depositional & scouring (cm)	0 cm									
	Macrophytes (cm)	0									
	Algae (cm)	95									
	Leaf packs (cm)	12									
	Woody debris (cm)	15									
	Large boulders & log jams (count)	2									
	Bank cover (m)	Left bank	1				Right bank	2.7m			

	Cross-section	1	2	3	4	5	6	7	8	9	10
Run 1	Substrate size	silt	17	0.5	3	36	4	6	11	2	16
	Embeddedness	1	3	1	1	4	1	1	2	1	2
	Compactness	3									
	Depositional & scouring (cm)	12 + 5									
	Macrophytes (cm)	23									
	Algae (cm)	80									
	Leaf packs (cm)	0									
	Woody debris (cm)	0									
	Large boulders & log jams (count)	1									
	Bank cover (m)	Left bank	1.3 m				Right bank	3.7m			

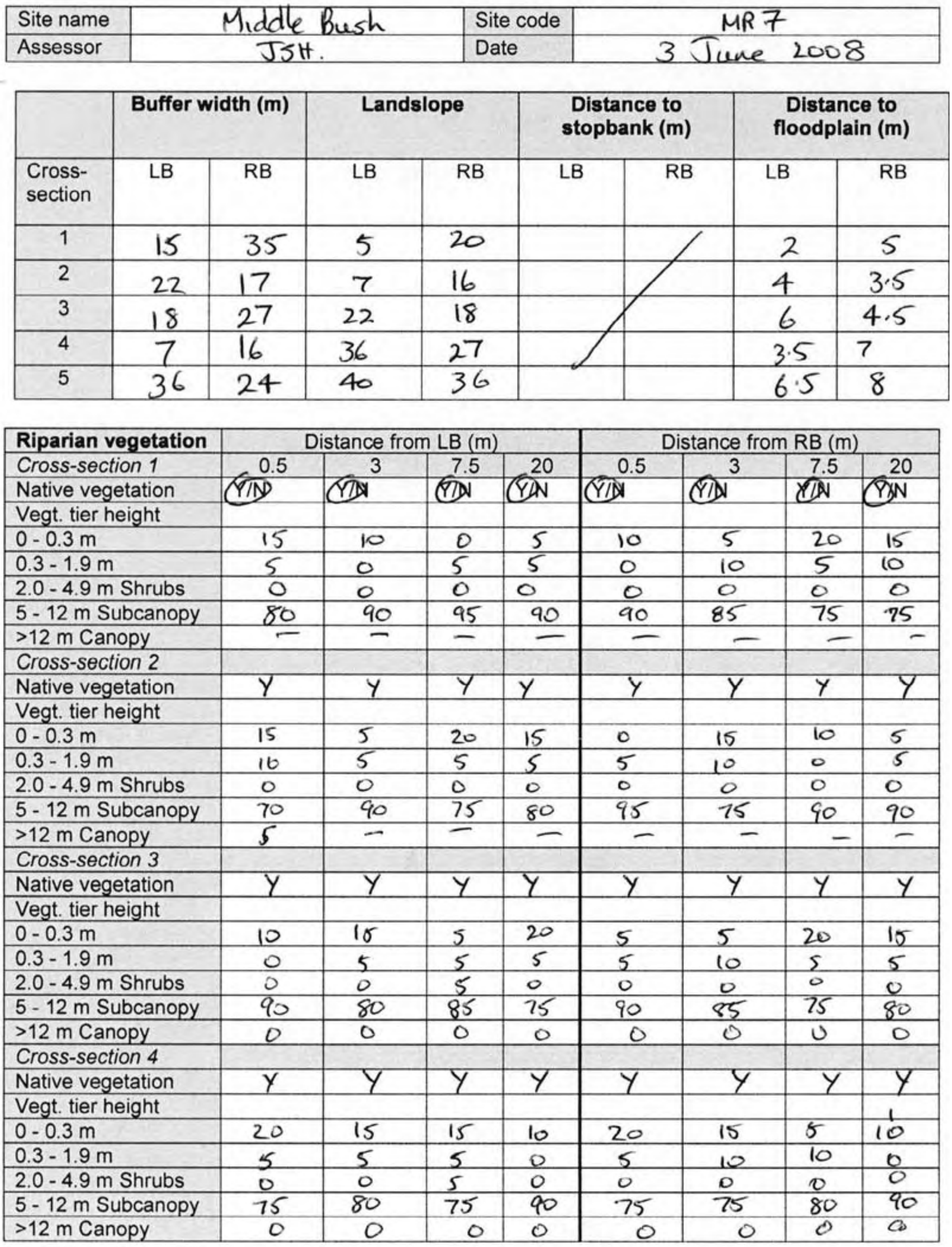
P3d Riparian procedure

1. At five equidistant points along the reach record the **buffer width** and **floodplain width** (or **stopbank** width) by measuring the perpendicular distance from edge of the stream bank on each side of the stream to the in-land edges of the buffer (i.e. area managed differently to reduce the effects of the wider land use on stream; may be indicated by livestock exclusion fencing) and any stop banks or natural landward margins to the floodplain. Measurements can be by tape, hip chain or laser-based distance finder. Where the buffer comprises horizontal zones of management (e.g., native forest on stream banks, then production forest then grass filter strip to landward edge of buffer area), measure the width of these separately. Floodplain widths can often be discerned by changes in topography, vegetation and debris lines.
2. Measure riparian **land slope** (over the first 30 m from the stream bank edges) at each of five equidistant points along the reach. The simplest method involves using an inclinometer and two survey poles to measure the angle from the stream bank to 30 m from the bank.
3. Characterise, at five equidistant points along the reach, the **riparian vegetation** cover. Assess vegetation within 0.5, 3, 7.5 and 20m from the stream bank and note the presence of **native vegetation** and the percentage of vegetation at five different vegetation tier heights. The total of the vegetation at these five heights should total 100%.
4. Measure the stream bank length affected by **gaps in the buffer** (to the nearest 0.1 m).
5. Assess riparian **wetland soils** by measuring the length of stream bank with saturated or near saturated soils, i.e. soils that are soft/moist underfoot.
6. Measure the length of the stream bank with **stable undercuts**, often these are stabilised by vegetation roots.
7. Count the number of **livestock access** points.
8. Measure the length of the site subject to active **bank slumping**. This category includes only obvious slips and erosion.
9. Measure the length of **raw bank** on the left and right banks indicated by exposed unvegetated banks, including an absence of moss, lichen and small plants.
10. Measure the cross sectional area of eroded **rills and channels** along the length of the site.
11. At 20 random points measure the **shading of water** using a convex densiometer or paired (stream/open site) light sensor measurements (note reading and time).

Summary diagram of the variables assessed during P3d



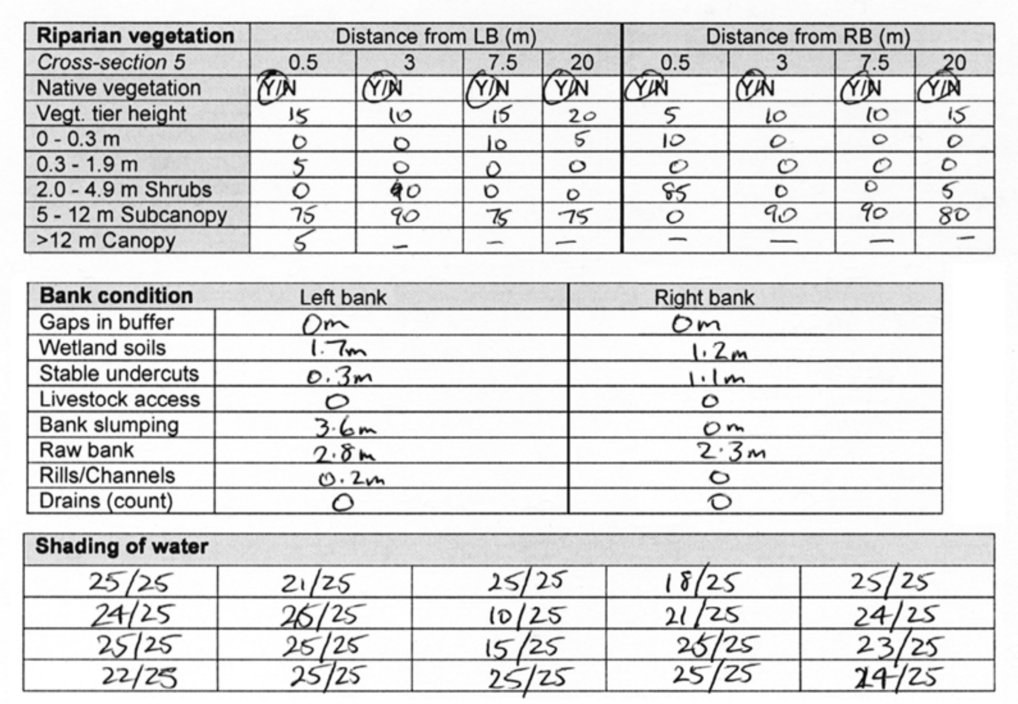
Example of a completed P3d field form



Site name	Middle Bush	Site code	MR 7
Assessor	JSH.	Date	3 June 2008

	Buffer width (m)		Landslope		Distance to stopbank (m)		Distance to floodplain (m)	
Cross-section	LB	RB	LB	RB	LB	RB	LB	RB
1	15	35	5	20			2	5
2	22	17	7	16			4	3·5
3	18	27	22	18			6	4·5
4	7	16	36	27			3·5	7
5	36	24	40	36			6·5	8

Riparian vegetation	Distance from LB (m)				Distance from RB (m)			
Cross-section 1	0.5	3	7.5	20	0.5	3	7.5	20
Native vegetation	[✓ Y]/N	[✓ Y]/N	[✓ Y]/N	[✓ Y]/N	[✓ Y]/N	[✓ Y]/N	[✓ Y]/N	[✓ Y]/N
Vegt. tier height								
0 - 0.3 m	15	10	0	5	10	5	20	15
0.3 - 1.9 m	5	0	5	5	0	10	5	10
2.0 - 4.9 m Shrubs	0	0	0	0	0	0	0	0
5 - 12 m Subcanopy	80	90	95	90	90	85	75	75
>12 m Canopy	–	–	–	–	–	–	–	–
Cross-section 2								
Native vegetation	Y	Y	Y	Y	Y	Y	Y	Y
Vegt. tier height								
0 - 0.3 m	15	5	20	15	0	15	10	5
0.3 - 1.9 m	10	5	5	5	5	10	0	5
2.0 - 4.9 m Shrubs	0	0	0	0	0	0	0	0
5 - 12 m Subcanopy	70	90	75	80	95	75	90	90
>12 m Canopy	5	–	–	–	–	–	–	–
Cross-section 3								
Native vegetation	Y	Y	Y	Y	Y	Y	Y	Y
Vegt. tier height								
0 - 0.3 m	10	15	5	20	5	5	20	15
0.3 - 1.9 m	0	5	5	5	5	10	5	5
2.0 - 4.9 m Shrubs	0	0	5	0	0	0	0	0
5 - 12 m Subcanopy	90	80	85	75	90	85	75	80
>12 m Canopy	0	0	0	0	0	0	0	0
Cross-section 4								
Native vegetation	Y	Y	Y	Y	Y	Y	Y	Y
Vegt. tier height								
0 - 0.3 m	20	15	15	10	20	15	5	10
0.3 - 1.9 m	5	5	5	0	5	10	10	0
2.0 - 4.9 m Shrubs	0	0	5	0	0	0	0	0
5 - 12 m Subcanopy	75	80	75	90	75	75	80	90
>12 m Canopy	0	0	0	0	0	0	0	0



Riparian vegetation	Distance from LB (m)				Distance from RB (m)			
Cross-section 5	0.5	3	7.5	20	0.5	3	7.5	20
Native vegetation	[✓ Y]/N	[✓ Y]/N	[✓ Y]/N	[✓ Y]/N	[✓ Y]/N	[✓ Y]/N	[✓ Y]/N	[✓ Y]/N
Vegt. tier height	15	10	15	20	5	10	10	15
0 - 0.3 m	0	0	10	5	10	0	0	0
0.3 - 1.9 m	5	0	0	0	0	0	0	0
2.0 - 4.9 m Shrubs	0	90	0	0	85	0	0	5
5 - 12 m Subcanopy	75	90	75	75	0	90	90	80
>12 m Canopy	5	–	–	–	–	–	–	–

Bank condition	Left bank	Right bank
Gaps in buffer	0m	0m
Wetland soils	1.7m	1.2m
Stable undercuts	0.3m	1.1m
Livestock access	0	0
Bank slumping	3.6m	0m
Raw bank	2.8m	2.3m
Rills/Channels	0.2m	0
Drains (count)	0	0

Shading of water				
25/25	21/25	25/25	18/25	25/25
24/25	25/25	10/25	21/25	24/25
25/25	25/25	15/25	25/25	23/25
22/25	25/25	25/25	25/25	24/25

Recommendations for quality control

Training

All users should read these protocols in full prior to conducting their first assessment.

In order to get users familiar with the protocols we recommend that each user should carry out habitat assessments (P2 or P3) at a minimum of three sites with markedly different physical characteristics. Ideally a minimum of three people should work through the protocols together. Sites used for training should be located in areas that are less likely to undergo dramatic changes in habitat and might be semi-permanent sites that can be used again for training and calibration.

All experienced and novice field workers should carry out P1 and P2 qualitative assessments independently then have results reviewed by others in the team. If results vary by more than 5%-10% then the assessment should be repeated until the cause of the measurement error is determined and consistently more accurate measures are made. Any changes to field sheets should be marked in red.

Cross validation of results can be aided by group discussions. Collecting accurate and consistent data with these protocols can only be achieved by using them frequently.

Sources of error

Qualitative methods are likely to be those which have the most inherent variability. If not properly performed they are susceptible to operator bias and inaccuracy. Training and discussing methods amongst users will reduce variability and error. The main sources of error and corrective action for P2 are shown in Table 10.

Table 10. The main sources of error and corrective action for P2

Common Sources	Actions to Reduce Error
Under or over-estimating spatial coverage (e.g., recent erosion, groundcover).	Use metre square quadrats to count sub-samples and then calibrate your eye. Always use a feature for scale in photographs.
Under or over-estimating shading due to sun angle (time of day or season).	Ensure that estimates are made by assessing true canopy cover rather than shading by sun. Field workers should look directly up to make this assessment. A camera with a fish-eye lens or a densiometer can be used as a check.
Error in estimating buffer width and gap measurement inaccuracy.	This requires walking the whole buffer length, particularly if it is wooded. For wider buffers, try to walk in the middle of the buffer to get a more accurate distance (if it is impenetrable and therefore difficult to estimate, then this should be recorded).
Determining riparian habitat composition.	The height of plants can be better estimated using a meter ruler. Identification of plants may require collecting leaves or taking photos to get accurate identification.
Determining floodplain connectivity.	Use the photos in these protocols to help calibrate connectivity.
Difficulty in determining potential and actual erosion.	Use signs left by stock, human activity (includes root-raking) or debris from flood flows.
Inability to determine stock type, particularly if stock are absent at the time of assessment.	Provide fieldworkers with pictures of common hoof-prints or interview land owners.
Livestock damage over-estimated when stock are in the riparian area.	Provide diagrams of coverage of soil-made-bare by stock, i.e. hoof-print density coverage patterns over a quadrat relating to high, moderate and limited.
Riparian soil denitrification potential.	Assess by estimating well wetted soils.
Slope poorly estimated.	Inclinometers should be used in at least 10% of sites by all field workers and at start of an assessment program.
Soil moisture permeability over or under-estimation.	Training in visual soil assessment methods required.
Assigning substrate pieces to an incorrect substrate size class.	Place substrate pieces close to the threshold between two size classes through a template to calibrate the observer.

For data that will be used for resource consent hearing or environment court, duplicate or triplicate assessments should be done where possible and mean values for parameters calculated.

It is also essential the users periodically check fieldsheets for accuracy. In the field transcription errors can easily occur and there is often a tendency to record numbers from meters and equipment without checking that these numbers make sense.

Data Processing

It is advisable to process field data within 2 days of collection for each new batch of fieldwork and within 2 weeks of collection at any other time. This will help ensure that any deficiencies in data collection can be addressed and will reduce the chance of photographic records being mis-labelled.

Data Analysis

Always try to check your data once it is in the database for potential transcription errors.

Glossary

Algae are non-vascular photosynthetic organisms and in streams are found in the water column or attached to a substrate (see Periphyton).

Backwater is a slow or non-flow area away from the main flowing channel, a surface flow dead-end.

Bankfull or active channel, is the area that is filled by moderate-size flood events that typically occur every one or two years.

Bank height is the minimum distance above the stream bed that water can overflow from the stream channel.

Bank slope is the gradient between the top of the bank and the water's edge.

Base flow is the level of stream discharge in the absence of any recent precipitation events.

Cascade is similar to rapid but with a series of small waterfalls over boulders or bedrock.

Catchment is the surface area of a landscape drained by a given stream network.

Channel roughness (n) is a measure of the physical turbulence of the stream bed due to substrate.

Deposition is an area of recent substrate accumulation in a streambed typically deposited by receding high flows.

Discharge (Q) or stream flow is the rate at which a given volume of water flows past a given point.

Embeddedness is the degree to which coarse stream bed substrate such as gravel, cobble and rocks, is surrounded and buried by fine substrate such as silt and sand.

Floodplain is the level area near a stream channel that is inundated by moderate floods, and was formed under present climatic conditions by deposition of sediments during over bank flooding.

Froude number (F) is a dimensionless velocity/depth ratio that can be used to quantitatively differentiate key meso-habitats.

Gini coefficient (G) is a measure of dispersion or inequality between metrics; in stream habitat assessment it can be calculated to provide a measure of channel shape variability.

Hyporheic zone is the area beneath the stream bed where there is a mixing of stream water and shallow groundwater.

Interstitial spaces are the open spaces between substrate particles.

Large woody debris (LWD) is plant matter, such as logs or branches, that is greater than 10cm in diameter and longer than 1m in length.

Macrophytes are aquatic vascular plants.

Meander is a lateral movement of a streambed across a floodplain, typically S-shaped curves.

Mean water column velocity is measured at four-tenths of the water depth above the stream bed because this provides the best estimation of average velocity.

Meso-habitat is the definition of in-stream habitats (e.g., run, riffle, or pool) when viewed at a middle range scale.

Periphyton is benthic (streambed) algae attached to submerged substrate.

Peri-urban is the zone of transition between urban and rural land-use (e.g., lifestyle block development).

Pool is an area of deep, slow flowing water with a smooth surface, usually where the stream widens and/or deepens.

Quality assurance (QA) is used to control and minimise error whilst ensuring a robust and accurate data set.

Quality control (QC) is used to monitor quality.

Rapid is an area of shallow, moderate depth, swift flow and strong currents, surface broken with white water.

Residual pool depth is the depth of water remaining in a pool when flow ceases.

Riffle is an area of shallow depth, moderate to fast water velocity, with mixed currents, surface rippled but unbroken.

Riparian buffer is the area from the water's edge (under base flow conditions) to a distance from the bank under a different management regime from the surrounding landscape, e.g., fenced-off or specific vegetation.

Riparian zone is the area from the water's edge (under base flow conditions) to a distance from the bank where the stream still interacts with and influences the type and density of the bank-side vegetation.

Run has a character in between that of riffle and pool, it is slow–moderate in depth and water velocity, uniform–slightly variable current, surface unbroken, smooth–rippled.

Scouring is substrate or bank erosion in a streambed caused by high flow events.

Sinuosity is the degree of meandering of a stream bed quantified by the ratio of 'fish swims' distance to 'bird flies' distance.

Thalweg is the deepest point of the actively flowing channel.

Velocity is the distance water travels with respect to time (e.g., metres per second).

Water depth is the vertical distance from the stream bed to the water surface.

Wetted width is the distance across the stream (perpendicular to flow) that is submerged by water on the day of sampling.

Acronyms

AEE: Assessment of Environmental Effects
AUSRIVAS: Australian Rivers Assessment Scheme
CREAS: Christchurch Rivers Environmental Assessment
FWENZ: Freshwater Environments of New Zealand
GIS: Geographic Information System
GPS: Global Positioning System
HCI: Habitat Condition Index
IFIM: Instream Flow Incremental Methodology
LCDB: Land Cover Database
LRI: Land Resource Inventory
LWD: Large woody debris
MALF: Mean Annual Low Flow
RARC: Rapid Appraisal of Riparian Condition
RCE: Riparian, Channel and Environmental Inventory
REC: River Environment Classification
RIVPACS: River Invertebrate Prediction and Classification System
RPB: Rapid Bioassessment Protocol
SHA: Stream Habitat Assessment
SHAP: Stream Habitat Assessment Protocol
SHMAK: Stream Health Monitoring and Assessment kit
SOE: State of Environment
SWIG: Stream Water Information Group
USEPA: United States Environmental Protection Agency
USHA: Urban Stream Habitat Assessment method
WIS: Waterway Impact Score

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Part 3 – Supporting documentation

Appendix 1 - Survey of Regional Councils & Agencies use of Stream Habitat Assessments

Introduction

This Appendix summarises the outcomes of a survey of freshwater management agencies and other organizations conducted in September 2006, designed to inform the development of these Stream Habitat Assessment Protocols (SHAP). Specifically, the survey aimed to:

- understand why people currently undertake stream habitat assessments
- identify how assessments are currently conducted in each organisation
- identify how these assessments could be improved

Thirteen responses were received, including 7 from Regional Councils, 3 from Department of Conservation conservancies and 3 from Regional Fish and Game Councils. All respondents are included in the summary below.

The need for a nationwide SHAP

Who wants a Stream Habitat Assessment Protocol (SHAP)?
All but one Council confirmed they would commit to using the protocols if developed. Some Councils have already committed to assessing and developing new habitat assessment tools, but would like to ensure that it is nationally consistent. In addition to the responses from this survey, the Surface Water Information Group (SWIG; which is now Surface Water Integrated Management, SWIM) has consistently voted over several years that SHAP is the top priority technical transfer project.

Why are new methods required?
Respondents expressed concern about the lack of consistency in current SHAPs among freshwater managers nationwide, and the robustness of methods being used. Specific advice was sought on:

- the validity of habitat parameters being assessed under current SHA programs
- which parameters are most important to measure and their weighting in the scoring process
- how the subjectivity in SHAPs removed or controlled

These requirements are expanded on in the next section.

Desired outcomes from a SHAP

What are the main management questions the SHAP needs to answer?

- What is the current state and trend of stream habitat in the region?
- What is the relationship between habitat properties and biodiversity?

What must the SHAP be able to do?

- Must work at different scales, such that assessment of reach & valley segment can be scaled up to a regional level assessment. Therefore, protocols should provide robust information on the state of habitat for fish and invertebrates on a regional scale, and detail at the reach scale where a biological survey is being carried out.
- Field procedures should be relatively rapid, especially at the valley segment or reach scales. For example, fine scale GPS or manual surveying is generally too time consuming, but protocols can include more detail than SHMAK habitat assessment procedures.
- Method(s) must cover urban, rural and natural streams, and apply to a range of flow regimes.
- Should be consistent with current protocols such as SHMAK, USHA (Urban Stream Habitat Assessment) and sampling macro-invertebrates in wadeable streams.
- Must come with a user-friendly manual such as the macro-invertebrate sampling protocols (Stark et al. 2000).

What monitoring programmes should SHAPs be able to work under or be integrated with?

- Fish & invertebrate surveys (including drift diving, electric fishing and spotlighting)
- Surface water quality monitoring
- Restoration projects
- River environment classification
- State of the Environment (SOE) monitoring
- Riparian classification

What do the SHAP guidelines need to address?

Respondents ranked six potential outcomes of SHAP in order of their relative importance. The highest weight was given to the sampling/assessment methods and rationale of SHA programs, with analytical procedures being considered of medium importance (Table 1). Predictive procedures and reporting were the least important outcomes among respondents.

Table 1: Summary of the most important outcomes for the SHAP to include

Ranked importance	SHAP outcomes
1	What methods should be used in what situations
2	The rationale for the design of SHA programmes
3	What data analysis & interpretation systems should be applied
4	Metrics or scoring systems for modules and overall summary scores
5	Methods for predicting the SHA quality of stream habitat
6	What are the reporting format options

Respondents identified other aspects that the SHAP needs to address, including:

- At what frequency monitoring should occur
- Where and when modelling should be used in analysing and predicting stream habitat values

What scale should SHAPs be able to work under?
SHA at the reach scale was desired by 92% of the respondents; however, 30% of these said they were unlikely to change from current procedures unless resources increased. Thirty seven percent (37%) of respondents indicated valley segment scale assessment was also necessary.

Alternatives in SHAP scope and methodology
All but one respondent would like different levels of rapidness and detail in SHAP, depending on the requirements of the user. Respondents suggested this could be accomplished by either leaving out some attributes/parameters in the more rapid assessments, or devising alternative methods of quantification or qualification of habitat parameters.

The majority of agencies surveyed (60%) indicated different modules for different stream types would be useful (e.g., non-wadable or ephemeral streams) if the justification for alternative methods was outlined. However, developing protocols for wadeable streams should be prioritised if resources were not available to develop methods for non-wadeable streams. Most respondents suggested different modules for alternative SHA applications (as outlined in Fig. 1) were not necessary.

Should Functional Assessments be part of the SHAP?
Just under half (46%) of respondents indicated functional components should be included in SHAPs, 46% did not express an opinion, and the remaining 8% suggested the inclusion of functional indicators in SHAP were unnecessary. However, concern was expressed over the practical applications of functional assessment among positive respondents, with some indicating they would be more useful for detailed activities (such as AEE) rather than routine SOE monitoring.

Current SHA methods in use

The majority (70%) of respondents undertake some form of SHA, mostly as part of SOE monitoring of macroinvertebrate and fish communities, or to assess the success of restoration/mitigation activities (Fig. 1). SHA for monitoring water takes and other compliance issues is less common, and only one respondent conducts stand alone SHA (Fig. 1).

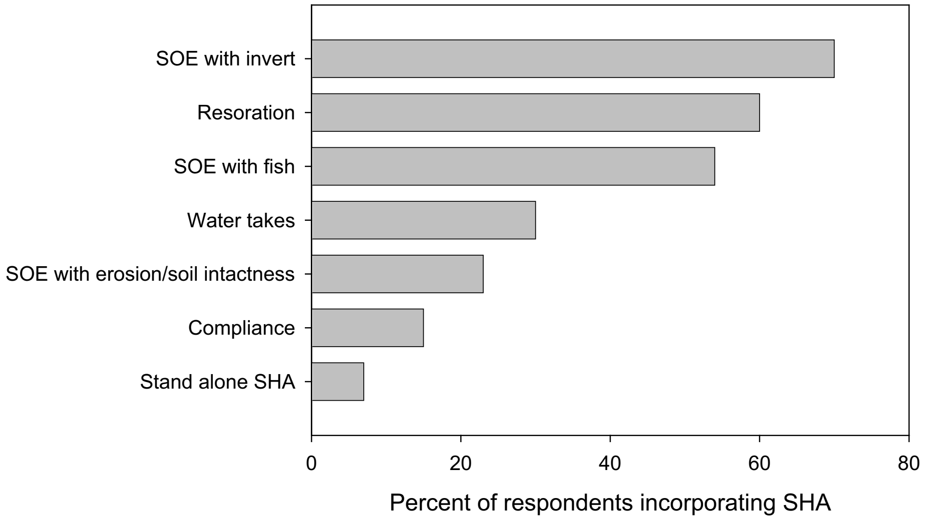


Figure 1. The current or potential use of SHAP for various management and reporting activities.

What Attributes are assessed as part of your SHAP?

The most common attributes currently assessed by regional freshwater managers were basic in-stream biological (periphyton and invertebrates) and physical (substrate, depth, width, sedimentation) parameters, as well as external attributes such as riparian shade and adjacent land use. A range of other attributes were assessed to a lesser extent (Fig. 2), and notably few respondents currently estimate social values such as recreation, amenity, or aesthetic qualities.

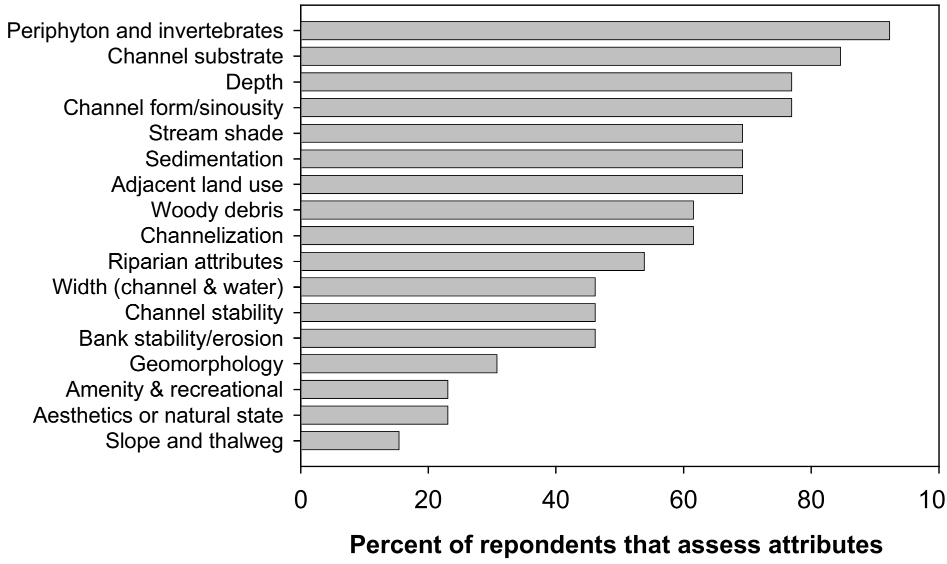


Figure 2. Stream habitat attributes currently being assessed by survey respondents (Regional Councils, DoC Conservancies and Fish and Game Councils).

Spatial and temporal extent of sampling
The overwhelming majority conduct SHA at the reach scale (92%), but some respondents also assess parameters within valley segments (42%) and whole catchments (25%). Consequently, the length of stream assessed in current SHA ranges from 20 to 2000m with the majority of sampling conducted within 50-100m stream segments (60%). Habitat assessment is conducted at 60 sites on average, but there was a large range (3-300). In addition, the majority respondents (77%) include reference sites within their sampling regime.

Stream habitat assessment is performed annually by most organisations and has been carried for between 2 and 20 years, with the majority of Regional Councils conducting SHA for the past 7-11 years. Time spent in SHA at a given site varied from 5-60 minutes. Assessment conducted during invertebrate or periphyton sampling took an average 30 min (range 5-60 min), with 5 minute assessments undertaken with drift dives and, on average, 20 min assessments (range 15–60 min) with fish surveys. More time was spent undertaking stand alone SHA (average of 60 minutes).

How is sampling conducted?
Most SHA is undertaken by walking and visually observing the stream bank, and by inspecting both aerial and ground photographs (Fig. 3). Interestingly, three respondents used kayaks during SHA, particularly for assessing non-wadable streams and those with dense riparian vegetation.

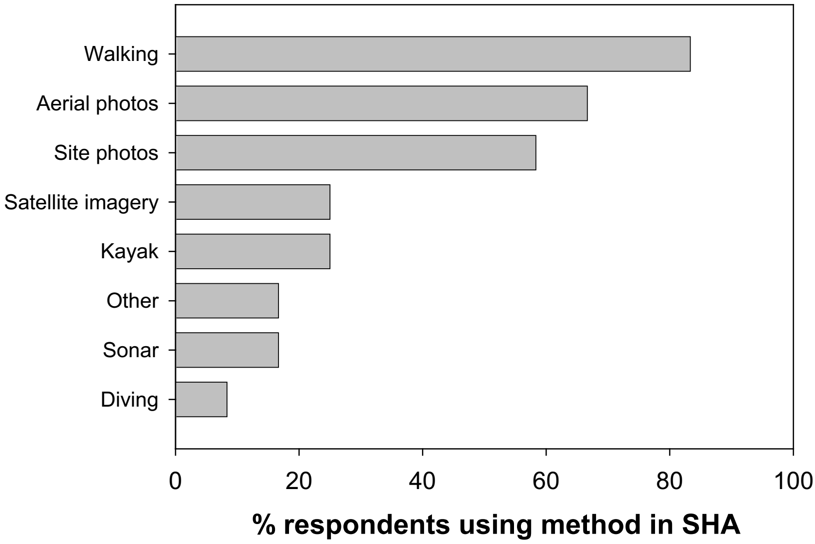


Figure 3. Physical methods used by respondents to conduct current SHA programs.

River classification systems (FWENZ and REC) and GIS are used frequently by 45% of respondents during SHA, with 15% using these tools in a more limited capacity. In addition, 23% use spatial databases to extract stratified random sites prior to SHA.

Where did the current methods/protocols come from?
The majority of methods currently used for SHA were developed in-house (85%), with some (15%) adapted from other New Zealand agencies (e.g., Regional Councils). One respondent uses methods derived from USEPA wadeable stream protocols.

Physical limitations to current SHA programs
Many respondents expressed difficulty in conducting SHA (especially in-stream assessments) in streams with limited visibility such as those influenced by high turbidity or dissolved organic matter (i.e., peat stained). Others experienced difficulty in sites with limited foot access, such as deep non-wadable streams, or those with incised channels with dense riparian cover.

Current data analysis procedures
The majority of data collected from respondents currently conducting SHA is stored in databases including Excel spreadsheets, Microsoft Access, or DoC national database. Many of those who carry out SHAs (60%) produce overall habitat scoring metrics, but only 54% have undertaken more comprehensive data analysis. Although some respondents have conducted multivariate analyses, most data analysis has been descriptive and/or focused on a limited set of variables or sites. Only one respondent had utilised data obtained from SHA for predicting region-wide habitat, and three respondents indicated a desire to do so in the future.

In general, respondents identified limited time, expertise and resources as factors constraining more extensive data analysis.

Current quality control/assessment procedures
One quarter of respondents currently undertaking SHA had undertaken no quality control or assessment (QC/QA) procedures. Methods applied by the respondents that have incorporated QC/QA in SHA were, in order of frequency of use:

- Documented protocols and training
- Group discussions of assessment methodology
- Peer review of programs, analyses and reports
- Replicate assessment by multiple operators
- Other methods, such as site replication

Appendix 2 - Literature review of stream physical habitat methodologies

Introduction

This appendix summarises an extensive literature review conducted to guide the development of the stream habitat assessment protocols. First, we present a summary of current national and international stream habitat assessment protocols, and secondly, we identify the parameters commonly measured during stream habitat assessment and their standard methods of quantification or qualification. An additional review of New Zealand stream ecological literature has been incorporated to ensure the relevance of selected stream habitat parameters to the structure and function of stream invertebrate and fish communities in New Zealand.

Review of selected assessment methods

Historically, physical habitat parameters have been commonly measured in order to classify or categorise river reaches (see Rosgen 1985, 1994; Frissell 1986; Snelder and Biggs 2002, Snelder et al. 2004b). More recently however, attempts have been made to use physical habitat parameters to assess and monitor the condition of lotic waterways (Maddock 1999), based on the assumption that 'healthy' biotic communities that underlie well-functioning stream ecosystems are reliant on good habitat conditions (Parsons et al. 2002b).

Below we outline the key aspects of selected quantitative and qualitative stream habitat assessment protocols.

Quantitative stream habitat assessment protocols

We have selected the following stream habitat assessment protocols as examples of highly intensive habitat assessments:

- Wadeable Streams Assessment, USEAP 2004 - Kaufmann and Robison 1998, Kaufmann et al. 1999 (USA)
- AUSRIVAS Physical Assessment Protocol – Parsons et al. 2002a, 2002b, 2004 (Australia)
- CREAS and WIS – McMurtrie and Suren 2006, Suren and McMurtrie 2006 (NZ)
- River Habitat Survey and Habitat Quality Assessment - Fox et al. 1998, Raven et al. 1998 (UK)

These methods were considered intensive because they include a substantial quantitative component, involving intensive measuring of a large number of variables/parameters. However, data analysis in these protocols differed substantially.

1. Wadable Stream Assessment (WSA)

USEPA 2004, an update of Kaufmann and Robison (1998), provides a detailed field operations manual on the procedures for evaluating physical habitat in wadeable streams. It forms one component of a comprehensive evaluation including all aspects of stream fauna and habitat, undertaken with the view that "effective environmental policy decisions require stream habitat information that is accurate, precise, and relevant". The WSA includes "concepts, rationale, and analytical procedures for characterizing physical habitat in wadeable streams based on raw data generated from methods similar or equal to those of Kaufmann and Robison (1998)". The WSA provides a physical characterisation containing information useful for interpreting impacts of human activities (USEPA 2004) and includes 18 variables considered to be the most important in analysing associations between habitat, landscape disturbance and biota. However, USEPA (2004) recommend that researchers examine the suite of variables and take into consideration measurement precision, geographic region, and biotic characteristics of their own research objectives. Therefore no method of assessing stream quality is provided. Rather, the WSA focuses on presenting a detailed methodology and guidelines about maintaining accuracy, precision and ecological relevance in characterising physical stream habitat.

2. Australian River Assessment System Physical Assessment Protocol (AusRivAS PAP)

The AusRivAS PAP is a standardised protocol for stream physical condition designed to complement the AusRivAS biological assessment programme which uses macroinvertebrates to assess stream condition. Parsons et al. (2002a) undertook a comprehensive review and critique of methods that assess stream condition, such as the State of the Rivers Survey (Anderson 1993), Index of Stream Condition (Ladson et al. 1999, Ladson and White 2000) and Habitat Predictive Modelling (Davies et al. 2000). Following this review, a comprehensive stream habitat assessment protocol was developed that combined the favourable elements of reviewed methods to create a protocol that uses reference condition concepts, rapid survey techniques, and is able to predict a target state of desirable condition (Parsons et al. 2002b). The assessment of habitat parameters in AusRivAS PAP follows the hierarchical arrangement of river networks, including catchment, segment, reach, meso-habitat (pool/riffle) and microhabitat scales. The resulting protocols are very intensive with over 90 field and office-based variables of all scales, nearly all of which are measured quantitatively, and many are not usually included in biologically-based river assessments.

The AusRivAS approach is based on the Habitat Predictive Model (Davies et al. 2000). Predictive models are generated using all 90 variables from a number of references sites (minimally disturbed sites which can include sites that have been affected by humans, but are the best representative of that type available). The test/impacted site data is entered into the model, and the condition of the site is determined by comparing the habitat features *expected* to occur at a test site to the features that were actually *observed* at the test site. The deviation between the two factors gives a quantitative indication of stream condition (Parsons et al. 2002b).

Physical Assessment Protocol process:

- Large number of references sites sampled extensively (> 90 quantitative variables)
- Predictive models generated
- Test sites sampled and data entered into models
- Observed/expected ratios generated, determining condition of test site

The power of this approach is the ability to produce quantitative predictions. That is, the assessment of stream condition is based on the comparison of numerous quantitative measures with the predicted values based on reference conditions. However, as mentioned earlier, this is a highly intensive protocol, requiring (a) selection of references sites across a number of different types/areas, (b) the generation of predictive models using over 90 habitat parameters and (c) the calculation of how much the test site deviates from the reference condition using those statistical models. Each of these steps is likely to require considerable time and funding.

3. Christchurch River Environment Assessment Survey and Waterway Impact Score

Christchurch River Environment Assessment Survey (CREAS) (McMurtrie and Suren 2006) methodology was developed for "broad-scale habitat mapping, providing general information on habitat condition" in Christchurch waterways. The protocol collects detailed, mainly quantitative measurements of 22 different habitat parameters at regular intervals along each waterway. The protocol also includes taxonomic assessment of the composition of native and invasive macrophytes, and riparian weeds. CREAS is mainly designed for wadable urban and peri-urban waterways with permanent flow, and does not include parameters relevant to agricultural impacts (e.g., stock damage) or wider valley segment of catchment-scale analysis. Selected parameters were considered to be (a) important in influencing habitat quality, (b) potentially affected by human activities, and (c) show a difference between a perceived 'natural' condition and an 'impacted' condition, based on the subjective assessment of peri-urban reference sites. However, the CREAS, of itself, does not provide an assessment of relative stream condition.

The waterway impact score (WIS; Suren and McMurtrie 2006) was developed as a complementary data analysis system for CREAS to assess stream condition. WIS focuses on quantifying the degree to which streams have been modified by human activities. It uses a presence/absence scoring system, where the presence of a particular parameter scores one point and the absence subtracts one point. Subsequent assessments of stream condition are based on the sum of these scores. If the parameter is present or its value falls within the desired range, the feature is considered in 'natural condition'. The higher the final score, the closer the stream is to a 'natural condition'. WIS uses 13 parameters, with all except channel meander being collected using CREAS. These parameters are limited to a mix of in-stream and bank/riparian features. While it uses quantitative measures, all parameters are given equal importance. However, Suren and McMurtrie (2006) indicated the WIS is an interim tool until something more sophisticated is developed. While developed specifically for Christchurch, CREAS would be applicable for urban/peri-urban streams throughout NZ. However the urban focus of this assessment precludes the assessment of catchment-scale features, such as consideration of surrounding land use. This limits the applicability of CREAS protocols to streams impacted by agriculture, forestry, mining and other non-urban stressors. An additional limitation is that CREAS relies on the assumption that the parameters and their relative ranges correctly classifies natural vs. impacted stream states. This assumption would need more rigorous testing before CREAS could be applied outside Christchurch urban streams.

4. River Habitat Survey (RHS) and Habitat Quality Assessment (HQA)

The RHS is a comprehensive system for assessing the character of rivers based on their physical structure (Fox et al. 1998). During the field survey, more than 200 data points are physically measured of in-channel, bank and river corridor features and derived from maps (e.g., altitude, slope, geology, and distance from source). Parameters are largely recorded as present or absent along the 500 m stream reach, but some are quantified through direct measurements. All data is then entered into a database.

As a first step to assessing the habitat quality of rivers, the RHS can group similar rivers together to enable habitat quality to be compared across similar habitat types. The RHS groups rivers based on any chosen criteria, such as slope, altitude and height of source. This way, natural variability is minimised in the application and assessment of quantitative scoring systems (Raven et al. 1998). The HQA is a quantitative scoring system based on the presence/absence of features at the sampled site noted during the RHS field survey and measures the diversity and 'naturalness' of the physical structure in the channel and river valley segment. Ten features that represent habitat features of known wildlife value (based on expect opinion) are incorporated in analysis, including flow type, channel substrate, channel features, bank features, bank vegetation structure, point bars, in-stream vegetation, land use within 50m riparian features and special features. However, naturalness does not necessarily indicate native state. For example, vegetative categories do not discriminate between native and exotic species. Although only ten features are included, broad scale descriptors such as land-use are also included.

In comparison to the WIS (Suren and McMurtrie 2006) which includes quantitative measures in presence/absence scoring systems (e.g., whether the velocity is ≥ 0.2 ms^{-1}), the HQA only records the actual presence or absence of a habitat feature (e.g., are point bars present in a stream reach). In addition, HQA scoring system does not account for the regional variability of natural landscapes (e.g., lowland forested versus high alpine grassland streams) (Raven et al. 1998). Reviewers have also suggested measurements made during RHS protocol rely on observer experience and consistency, and the HQA is based on the assumption of a link between physical habitat parameters and ecosystem function (Raven et al. 2002).

Qualitative stream habitat assessment protocols

The above four methods have some quantitative component. The other general type of habitat assessment uses a more rapid pre-determined categorisation of features, which are applied to a scaling system. This is a more *qualitative* measure of physical habitat.

Some of the better known methods of this approach to sampling are:

- USEPA Rapid Bioassessment Protocol - Barbour et al. 1999 (USA)
- Riparian, Channel and Environmental Inventory - Petersen 1992 (Sweden)
- Habitat Condition Index - Oliveira and Cortes 2005 (Portugal)

1. *US Environmental Protection Agency Rapid Bioassessment Protocol: A Visual-based Habitat Assessment*

The USEPA RPB's were developed to fill the need for rapid, cost-effective biological survey techniques, and the discussion presented here is limited to the recent revision (Barbour et al. 1999) of the original RPB's (Plafkin et al. 1989). This protocol, which uses fish, macroinvertebrates or periphyton to assess stream condition, also includes an evaluation of habitat quality. This consists of a rapid, visually-based habitat assessment method that uses a subjective, categorical scoring system to rate habitat condition. The RPB habitat assessment is focused on the structure of the surrounding physical habitat that is assumed to influence the water quality and the condition of the biotic community.

There are a total of ten parameters that cover in-stream (e.g., substrate embeddedness, sediment deposition), meso-scale (e.g., channel gradient, channel sinuosity and riffle-pool sequence) and riparian habitat features. Alternative protocols are provided for low and high gradient streams which reflect differences in the meso-habitat conditions. These parameters include (high vs. low gradient): embeddedness vs. pool substrate character, velocity/depth regime vs. pool depth variability, and frequency of riffles vs. channel sinuosity.

Each parameter is divided into hierarchical subjective categories, where each of four categories (optimal, suboptimal, marginal and poor) are subdivided into five fine-scale categories. Thus, parameters are scored from most to least impacted on a scale of 1 – 20. Parameter scores are totalled and the site-habitat is rated as optimal, suboptimal, marginal or poor. The total can also compared with a reference condition to provide a percent comparability measure. As with other habitat assessment scoring systems (WIS, HQA), each variable is weighed evenly.

The RPB's were designed to be cost-effective yet scientifically valid, allow rapid site investigation, with quick turn-around of results for management decisions and reports that are easily understood by managers and the public. The protocols are sound, well described general qualitative habitat assessment. The subjectivity of the assessment approach is also recognised by the authors (Barbour et al. 1999). For example, quality control suggestions such as "a biologist who is *well versed* in the ecology and zoogeography of the region can *generally* recognise optimal habitat structure" and "criteria… for each parameter should minimise subjectivity through either quantitative measure or specific categorical choices" are presented throughout the manual (Barbour et al. 1999). Regardless, the main criticism of the RPB's, which pertain most qualitative assessment, is the high levels of subjectivity can lead to a lack of precision and repeatability.

2. *The Riparian, Channel and Environmental Inventory (Petersen 1992)*

The RCE was developed in Europe to assess the habitat features of small, low gradient streams in the agricultural landscape that have undergone a degree of physical modification. However successful tests tested in alpine Italian streams, and similarities in the results obtained by the RCE and USEPA RBP's in three streams in Idaho, USA, indicate the wider applicability of the RCE protocols (Petersen 1992). This broad applicability of RCE may have been enhanced by focusing protocols on the presence and condition of the riparian zone, rather than the wider stream catchment (Petersen 1992). While not being omnipresent, the RCE does appear in recent literature, cited as a method used to evaluate environmental degradation (Buss et al. 2004).

The RCE is modelled after Pfankuch (1975) and was developed to provide a rapid assessment method, similar to the USEPA RBP's. During initial testing the average time taken to do the inventory was 20 minutes, which was approximately twice as rapid as the RBP (Petersen 1992). While similar to the RBP's, the RCE protocol has a wider ambit. The 16 parameters included describe the riparian zone and surrounding land-use, as well as aspects of in-stream habitat and channel morphology. The RCE also includes several biotic parameters such as the presence of native fishes and a quick estimation of the number of invertebrate species. Each parameter is given one of four possible scores, with a low score indicating the most modified or degraded assessment. Parameters are weighted by adjusting the value of the maximum score to give greater influence to the parameters that are either more important to stream habitat or those that can be estimated more accurately. Petersen (1992) gives a detailed rationale for the inclusion for each parameter, but few references are presented. There is also a strong core assumption that modification/disturbance of the physical structure of the stream is a major driver of degraded biological structure and function. However, this assumption underlies all habitat assessment protocols, and would need to be examined in any proposed method. Moreover, the RCE was positively correlated to benthic macroinvertebrate indices (Extended Biotic Index and Shannon Diversity Index) in a case study of fifteen Italian streams (Petersen 1992).

3. Habitat Condition Index (Oliveira and Cortes 2005)

The HCI was developed in Portugal and is described as an index for assessing stream habitats in northern Portugal. However, if its development methodology was replicated it could then provide a habitat index specific to streams in New Zealand.

The index uses 10 variables, six at the reach scale and four for the valley scale, with five conditions for each one. An unmodified or reference site would score 5 for each variable, and the most disturbed sites score a 1. The habitat condition is then the sum of the scores for all variables.

Multivariate analysis techniques were used on physical and biological datasets to determine the relative importance of variables (both local and regional scales) in the classification of the invertebrate assemblages. An initial list of over 70 physical habitat variables were refined by removing highly intercorrelated and redundant variables. This was achieved by using an iterative multivariate process including (a) direct gradient analysis (CCA) of biological and environmental variables, (b) discriminate functions analysis (DA) of *a-priori* site clusters based on physical habitat divisions, and (c) comparisons of site classification based on physical data with biological community patterns using non-metric multidimensional scaling (NMDS) (summarised in Figure 2, Oliveira and Cortes 2005). This process resulted in the identification of 10 local scale variables that had significant, independent effects on biological communities. Thus HCI selects a small number of variables at a single (local) scale (hence minimising the duration and cost of assessment) that have strong underlying biological significance that is independent from natural variation. The HCI does not require extensive fieldwork however, and produces a clear separation of sites according to the degree of human impact (Oliveira and Cortes 2005).

The scoring of each variable is, again, based on classification of parameters according to one of 5 qualitative categories determined by visual estimates. Therefore, although there is a strong objective rationale for the choice of parameters in the HCI protocols, their scoring is still limited by the constraints of subjective, qualitative assessment.

What parameters to measure in a physical assessment of stream habitat?

The rationale for physical habitat assessment in streams is that physical parameters influence biological structure and function. Thus a key aspect of developing a method of physical habitat evaluation involves determining which habitat features are biologically relevant. Table 1 summarises the commonly measured parameters in 16 existing stream habitat assessment protocols. Parameters are presented from those used in most protocols to those included in only a few instances. Specific aspects of habitat parameters and their methods of measurement or qualification are also presented (Table 1).

An additional review of New Zealand literature was conducted to justify the biological relevance of parameters assessed in protocols 1, 2 and 3 in this manual (Table 2). This is by no means an exhaustive review, but provides a rationale for the why habitat or parameter should be included in an assessment. Additional discussions of the relevance of specific parameters are provided in protocol descriptions for the riparian, hydrology/morphology and in-stream assessment.

Table 1: Physical habitat parameters commonly assessed in current SHAPs. n/d, not described in protocol.

Reference:	Scoring system? (qualitative)	What is measured	How parameter is measured	See also
Channel or stream depth				
Frappier and Eckert 2007		Mean and maximum water depth (m)		USEPA2004 (update of Kaufmann et al. 1998)
McMurtrie and Suren 2006		Depth of free water, the macrophyte and soft sediment/sand depth-type	One measurement taken in the middle of the channel, two others 1/6 in from each bank	
Kaufman and Robison1998, USEPA 2004		Thalweg (maximum) depth	Locate deepest point and measure to the nearest cm	
Thomson et al. 2001		Maximum depth recorded (for each hydraulic unit)		
Davies et al. 2000		Estimate the mean depth in each habitat of the reach		Davies 1994 (updated in Parsons 2002b)
Kaufmann 2000 (non-wadable rivers, see footnote)		1. Thalweg depth 2. Littoral depth at five locations within the plot	1. A thalweg depth approximated by a sonar or sounding rod profile while floating downstream along the deepest part of the channel 2. Using a sonar or sounding rod	
Barbour et al. 1999		Estimated stream depth (m)	Estimate vertical distance from the water surface to stream bottom at a representative depth of most the abundant habitat type	
Petersen 1992		Stream depth		
Channel or stream (wetted) width				
Frappier ad Eckert 2007		Mean channel width (m)		USEPA 2004
McMurtrie and Suren 2006		Wetted width	Measure of the wetted width of channel	
Kaufman and Robison1998, USEPA 2004		Wetted width	Measured across and over mid-channel bars and boulders, to the nearest 0.1m for widths up to 3m, or 5% or widths >3m	
Bjorkland et al. 2001		Active channel width	n/d	
Davies et al. 2000		Stream width (m)	Wetted width, mean of three transect measurements in each 1/3 of the study reach	Davies 1994
Kaufmann 2000		Wetted width	Laser range finder	

Barbour et al. 1999		Estimate distance from bank to bank at a representative transect	If variable widths, use an average to find that which is representative	
Petersen 1992		Stream width		
Water velocity				
Kaufmann and Robison1998, USEPA 2004		Mean velocity across the channel	Measurements with a velocity meter ≥15 intervals across the channel	
Thomson et al. 2001		Velocity (depth average)	Measured with a current meter at 0.4 x depth for 20s	
Davies et al. 2000		Maximum and minimum velocity	Velocity meter	Davies 1994
Barbour et al. 1999		Surface velocity in the thalweg	Measure velocity, or estimate the as slow, moderate or fast	
Channel slope/gradient				
Kaufmann 1998, USEPA 2004		Overall stream slope or gradient	‘Backsighting’ downstream between transects	
Parsons et al. 2002b		Stream gradient	Change in elevation from upstream to downstream of segment (m) divided by the segment length (1000x the bankfull width)	
Roper et al. 2002		Reach gradient	Divide average elevation change (to the nearest cm) by reach length (to the nearest 0.1m); elevation estimated as the average of two measurements of elevation change using a 20X level transit	
Bjorkland et al. 2001		Gradient	n/d	
Kaufmann 2000		Stream gradient	Gradient between two cross-section measured with clinometer or Abney level	
Organic substrate composition (%)				
Frappier and Eckert 2007		Mean % cover of filamentous algae, and macrophytes	Visual assessment	USEPA 2004
McMurtrie and Suren 2006		1. The amount of the streambed covered by different plants (macrophytes and filamentous algae), leaf litter, or woody debris 2. Dominant macrophyte species	1. Esitmate % of each organic material type 2. Identify the presence/absence of common macrophyte species	
Kaufmann and Robison1998, USEPA 2004	Y	RBP: Epifaunal substrate/ available cover assessment	Visual assessment	Barbour 1999

Parsons et al. 2002b		1. % stream covered by macrophytes 2. % cover of the stream area for each species	1. Visually estimate % of cover of submerged, floating and emergent macrophyte types of any species 2. Record and visually estimate the % cover of each common species	
Thomson et al. 2001		1. % cover of emergent, floating, submerged filamentous algae and moss types 2. % cover of twigs, leaves and detritus	1 & 2,Visual assessment	
Davies et al. 2000		1. % macrophyte and snag cover 2. % of detrital cover	1 & 2, Visual assessment	Davies 1994
Barbour et al. 1999	Y	1. Record the dominant species and the portion of the reach with aquatic vegetation 2. Record % of other organic materials 3. RBP: epifaunal substrate/ available cover	Estimate the cover/substrate available for fish and other colonisation. Includes snags, logs, undercut banks, cobble	
Raven et al. 1998	Y	In stream channel vegetation	Vegetation types are grouped into six categories; score 1 for each category recorded within the site, and 2 for those categories recorded either as present or extensive at four or more spot-checks; filamentous algae do not score	
Petersen 1992	Y	1. Aquatic vegetation 2. Detritus	Ratings depend on how much aquatic vegetation (moss and algae) and detritus/leaves are present.	
Inorganic substrate sizes/composition				
Frappier and Eckert 2007		Coarse gravel %, cobble %, boulder %, bedrock %	Visual assessment	USEPA 2004
McMurtrie and Suren 2006		% cover of each substrate class	Visual assessment. within a 2 m band across the channel	
Kaufmann and Robison1998, USEPA 2004		Substrate size class	Estimate the size of the substrate particle at the base of the measure stick at 4 locations across channel; record the size class code on the form	
Parsons et al. 2002b		The % cover of each of the 7 size categories	Visually assess the relative % cover of each seven size classes within 10m area	
Bjorkland et al. 2001		Place a tick next to the 'dominant substrate' i.e., boulder, graven, sand, silt or mud	Visual assessment	

Thomson et al. 2001		Proportion of bedrock, boulder, cobble, pebble etc	Estimate the proportion of each substrate, and calculate weighted average of grain size within each hydraulic unit	
Davies et al. 2000		Percent of substratum of each habitat type	Estimate % bedrock, boulder, cobble, pebble, gravel, sand, silt or clay	
Kaufmann 2000		1. Dominant substrate as part of thalweg profile 2. Dominant and subdominant substrate size class at 5 systematically-spaced locations	1.Record the dominant substrate (bedrock/hardpan, boulder, cobble, gravel, sand, silt & finer) while dragging the sounding rod along the bottom	
Barbour et al. 1999	Y	1. Composition of the inorganic substrate 2. RBP: epifaunal substrate/ available cover	1. % composition of each substrate type 2. Estimate the cover/substrate available for fish and inverts; includes snags, logs, undercut banks, cobble	
Raven et al. 1998	Y	Channel substrate	Each predominant natural substrate type (i.e., bedrock, boulder, cobble, gravel, pebble, sand, silt, clay, peat) recorded scores 1; if it occurs at two to three spot-checks it scores 2; if it occurs at four or more spot-checks, it scores 3	
Petersen 1992	Y	Stony substrate – feel and appearance	Judge whether stones are clean and rounded cf sharp with gritty cover	
Sinuosity				
Kaufmann and Robison1998, USEPA 2004		Compass bearings between cross sections allow estimate of the sinuosity	Dividing reach length by the straight line distance of the reach	
Parsons et al. 2002b		Sinuosity of the sampling site	Channel length divided by the valley length	
Roper et al. 2002		Sinuosity	Dividing reach length by the straight line distance of the reach	
Davies et al. 2000		Compass bearings between cross-section and the next one downstream		USEPA 2004
Barbour et al. 1999	Y	RBP: number of bends in stream	Only for low gradient streams. Record if "the bends in the stream increase the stream length 3 to 4 times longer than if it was in a straight line"	
Silt coverage/fine substrate				
Frappier and Eckert 2007		The % of fine material, sand, fine gravel	Visual assessment	USEPA 2004
McMurtrie and Suren 2006		Coverage of sand or silt as a %	Estimation of streambed substrate covered by silt or sand	
Parsons et al. 2002b		Part of a 'bed stability' rating	Three level visual classification: severe erosion, stable, severe deposition	

Roper et al. 2002		Percent fines	Percent of the substrate an intermediate axis diameter < 6mm	
Petersen 1992	Y	Channel sediments	Estimate the sediment accumulation	
Substrate embeddedness				
Frappier and Eckert 2007		Mean % embeddedness	Visual assessment	USEPA 2004
McMurtrie and Suren 2006		How much the interstitial spaces have been infilled with fine sediment	Excavate a depression in the streambed and estimate the amount (%) of silt and sand particles	
Kaufmann and Robison1998, USEPA 2004		Average % of embeddedness	Estimate the average percentage embeddedness of particles in a 10cm diameter circle	
Parsons et al. 2002b		Part of a classification on sediment matrix	Visual assessment of overall character of the sediment matrix as one of five categories, which also indicate interstitial space available within the riverbed	
Bjorkland et al. 2001	Y	Riffle embeddedness	Pick up particles of gravel or cobble and estimating what % of the particle was buried	
Davies et al. 2000	Y	RBP: extent to which gravel, cobbles, boulders and snags are covered or sunken into the silt, sand, or mud	Visual assessment	Barbour 1999
Barbour et al. 1999	Y	RBP: extent to which gravel, cobbles, boulders and snags are covered or sunken into the silt, sand, or mud	Only for high gradient streams; % to which the particles are surrounded by sediment	
Petersen 1992	Y	Stony bottom	Judge how the stones are packed together i.e., with interstices obvious	
Bankfull channel width and depth/height (W:D ratio) (see glossary)				
Frappier and Eckert 2007		Mean bankfull width and depth (m)		USEPA 2004
Kaufmann and Robison1998, USEPA 2004		Height of bankfull flow and channel width	Estimate height from the present water level to the top of the bankfull level (in analysing data, the mean thalweg depth is added)	
Parsons et al. 2002b		Mean bankfull width and height	Measure width of bank only, and add that to the wetted/stream width; bankfull height is height of the bank plus the baseflow stream depth measurements	
Roper et al. 2002		Average bankfull W:D ratio	Measure the average bankfull width and divide by the average bankfull depths (taken over 10 evenly spaced depths)	
Davies et al. 2000		Bankfull width and height (height above the surface of the water)	Measure width with a laser rangefinder; height estimated using a rod held vertically at the water's edge	
Petersen 1992	Y	Channel structure	Visual ratings for the W/D ratio	

Water flow type (rifle, run, pool, glide etc)				
Frappier and Eckert 2007		Pool, glide, riffle, rapids sample sites	% of each	USEPA 2004
McMurtrie and Suren 2006		Dominant flow type at each survey point: riffle, run or pool	Classify the dominant flow type	
USEPA 2004 Kaufmann and Robison1998		Habitat class and pool forming element codes	Visual habitat classifications made at the thalweg	
Thomson 2001		Record the surface flow type	Visual habitat classification of freefall, chute, broken standing waves, and upwelling zones	
Davies et al. 2000		Classify habitat types	Habitat recorded during the thalweg profile, classified according to Table 6-3	
Barbour et al. 1999	Y	1. Proportion of reach represented by each stream types 2. Frequency of riffles/bends also measured	2. For high gradient streams, estimate riffle frequency.	
Raven et al. 1998	Y	Flow type	Each predominant flow-type recorded scores 1; if it occurs at two to three spot-checks, it scores 2; if it occurs at four or more spot-checks, it scores 3; if only one type occurs at all 10 spot-checks, the score will be 3; dry channel scores 0	
Petersen 1992	Y	Riffles and pools, or meanders	Judge whether they are distinct or have been channelised	
LWD (number, size, total volume and distribution of wood)				
Frappier and Eckert 2007		Density of large woody debris in bankfull channel and density of large woody debris above the bankfull		USEPA 2004
Kaufmann and Robison1998, USEPA 2004		Number, size, total volume and distribution of wood within the reach	Visually estimate the length, diameter and count each piece of wood (see section 7.4.2 and table 7-4)	
Parsons et al. 2002b		% cover of sampling site by LWD	Visually estimate the percent cover of LWD within the bankfull channel area, LWD is defined as logs and branches that are greater than 10cm in diameter and greater than 1m in length	
Thomson et al. 2001		The number of pieces of multiple and single logs per hydraulic unit	Visual count	
Kaufmann 2000		Tally large woody debris in littoral plot and in bankfull channel	Visually classify to size and length categories	USEPA 2004

Barbour et al. 1999		1. Density of LWD 2. RBP: epifaunal substrate/ available cover	1. Visual estimates (see section 5.1.8) 2. Visual estimates of cover/ substrate available for fish and other colonisation; includes snags, logs, undercut banks, cobble	
Ladson et al. 1999	Y	Density and origin of coarse woody debris	Rating whether the LWD situation is ideal i.e., some indigenous species, never been de-snagged or have the streamside vegetation cleared	
Extent and type of in-stream bars				
Kaufmann and Robison1998, USEPA 2004		Width of exposed mid-channel bars.	Measure width of exposed bars while measuring wetted width (Table 7-2 and 7-7)	
Munné et al. 2003		Width of islands in the river	Classify if width of the total area of the islands is either > or < 5 m	
Parsons et al. 2002b		% of streambed area which is a bar of any type	Visually estimate the % streambed area that protrudes to form a bar of any type. Record the dominant sediment particle size of the bars	
Davies et al. 2000	Y	RBP: part of sediment deposition	Uses presence of islands and point-bars as evidence of sediment deposition, scores depend on increase in bar formation or not	Barabour 1999
Kaufmann 2000		Mid-channel bar width	Measure while measuring wetted width, using a laser rangefinder and surveyor's rod	
Barbour et al. 1999	Y	RBP: part of sediment deposition	Uses presence of islands and point-bars as evidence of sediment deposition, scores depend on increase in bar formation or not	
Raven et al. 1998	Y	Recorded in 'channel features' and in 'point bars'	Each 'natural' channel feature (i.e. exposed bedrock, boulders, unvegetated mid-channel bar, vegetated mid-channel bar, mature island) recorded scores 1; if it occurs at two to three spot-checks, it scores 2; if it occurs at four or more spot-checks, it scores 3 Point bars: add together the total number of unvegetated and vegetated point bars recorded	
Instream fish cover (areal cover of each type of vegetation)				
Kaufmann and Robison1998, USEPA 2004		The types and amount of instream fish cover	Visual estimate the areal cover of each type (table 7-10)	

Parsons et al. 2002b	Y	1. RBP: Epifaunal substrate/ available cover assessment 2. Extent of bank-trailing vegetation	1. Estimate % of substrate favourable for epifaunal colonisation and fish cover 2. Visually estimate occurrence and density of trailing bank vegetation in one of the four categories: nil, slight, moderate, extensive	Barbour 1999
Bjorkland et al. 2001	Y	The amount of types of cover available as fish habitat	Observe and number of different habitat and cover types with the assessed area, i.e. deep pools, logs, overhanging vegetation, thick roots	
Davies et al. 2000	Y	1. RBP: Epifaunal substrate/ available cover assessment 2. Edge bank vegetation	1. Estimates % substrate favourable for epifaunal colonisation and fish cover 2. Estimate to one of four categories	Barbour 1999
Kaufmann 2000		Areal cover class of fish concealment and other features	Visual estimate or measurement by sounding pole	
Barbour et al. 1999	Y	1. RBP: Epifaunal substrate/ available cover assessment	1. Estimates % of substrate favourable for epifaunal colonisation and fish over	
Raven et al. 1998	Y	Associated features of trees	Overhanging boughs, exposed bankside roots, underwater tree roots, coarse woody debris and fallen trees each score 1 if present; extensive exposed bankside roots and underwater tree roots each score 2; extensive coarse woody debris scores 3; extensive fallen trees score 5	
Bank stability				
McMurtrie and Suren 2006		Stability of upper and lower stream bank	Binary categorisation: stable or unstable	
Parsons et al. 2002b		Factors that contribute to bank erosion and stability	Indicate the presence of one or more of factors that may negatively influence the stability of either bank (bow waves from boats; cattle, sheep or horse access to the channel; mining)	
Roper et al. 2002		% of a reach with stable banks	Plot is stable is there was no sign of erosion, slumps or fractures; divide number of plots with stable banks by the total number of plots	
Davies et al. 2000	Y	RBP: measures whether the stream banks are eroded or considered unstable	Score for each side, estimate area of bank affected	Barbour 1999
Barbour et al. 1999	Y	RBP: measures whether the stream banks are eroded or considered unstable	Score for each side, estimate area of bank affected	

Ladson et al. 1999	Y	Bank stability by looking at erosion factors	Rating based on signs of erosion and damage to bank structure and vegetation	
Petersen 1992	Y	Stream-bank structure	Judge whether the banks are stable, held firm by grasses and roots or unstable with loose soil and easily disturbed	
Bank angle				
Frappier and Eckert 2007		Mean bank angle (degrees)		USEPA 2004
McMurtrie and Suren 2006		Estimate angle of each section of bank on both TRS and TLS	Assessed as one of four possible groupings e.g., 0-22, 22-45, 45-68, 68-90 degrees	
Kaufmann and Robison 1998, USEPA 2004		Bank angle	Clinometer measurement of left bank	
Parsons et al. 2002b		Bank slope	Choose one of five categories that represents the predominant slope of the bank e.g., vertical slope 80-90°, steep slope 60-80°	
Roper et al. 2002		Average bank angle	Measured by laying a depth rod along the bank at right angle to the flow, a clinometer was placed along the depth rod and angle recorded to nearest degree	
Thomson et al. 2001		Angle of bank recorded in degrees		
Kaufmann 2000		Angle of bank in one of four categories	Visually estimate the bank angle (undercut, vertical, steep, gradual), as defined on the field form; bank angle from the wetted channel margin to bankfull channel margin	
Canopy tree cover/shading over the stream				
Frappier and Eckert 2007		Mean canopy cover %		USEPA 2004
McMurtrie and Suren 2006		Estimation of the amount of trees that extend over the streambed	Estimate % how much of the sky is blocked by canopy tree cover; measured for each side of the channel.	
Kaufmann and Robison1998, USEPA 2004		Quantifying the riparian canopy cover over the stream	Measured using a Convex Spherical Densiometer, model B (Lemmon, 1957) (Table 7-8)	
Parsons et al. 2002b		Amount of light that reaches the channel	Visually estimate % of stream area shaded by riparian vegetation when the sun is directly overhead	
Bjorkland et al. 2001	Y	The portion of the water surface area that is shaded	Estimating areas with no shade, poor shade, and shade, assuming sun is directly overhead and vegetation is in full leaf	

Thomson et al. 2001		Proportion of total stream area shaded by riparian vegetation		
Davies et al. 2000		Shading of the reach	One of five categories (not given)	
Kaufmann 2000		Riparian canopy cover	Determined using a Convex Spherical Densiometer, model B (Lemmon, 1957) (Fig 6-7, Table 6-8)	
Areal cover class at canopy, understory and ground level				
Frappier and Eckert 2007		Mean riparian cover of large trees, small trees, shrubs, tall herbs, short herbs, 'bare ground'		
Kaufmann and Robison1998, USEPA 2004		Semi-quantitative evaluation of the type and amount of various types of riparian vegetation	Determine the dominant vegetation type and estimate areal cover for each level/layer	
Munné et al. 2003	Y	Assessing the structural complexity	Total % cover of the trees; score may be increased by the presence of shrubs, low-lying vegetation, helophytes or other channel vegetation	
Parsons et al. 2002b		% cover of different riparian components	Visually estimate % area of the riparian zone that is covered by: trees >10m in height, trees < 10m in height, shrubs, grasses ferns and sedges	
Davies et al. 2000		% of trees > 10m, % of trees <10m, % of shrubs and vines, % of grasses, ferns and sedges	Visual estimates	
Kaufmann 2000		Characterizing riparian vegetation structure and composition	Estimate areal cover class and type of riparian vegetation in canopy, mid-layer and ground cover	USEPA 2004
Barbour et al. 1999	Y	RBP: the amount of native vegetation on the stream bank, at all levels	% cover of the bank and riparian zone by native vegetation including trees, understory shrubs etc	
Ladson et al. 1999	Y	Structural intactness of streamside vegetation	Comparison of overstorey, understorey and groundcover density with that existing under natural conditions	
Petersen 1992	Y	Width of riparian zone from stream edge to field	Ratings, with top score for >30 m	
Width of riparian zone				
Parsons et al. 2002b		Width of the riparian zone on the left and right banks separately (see glossary)	Measure distances with a tape measure at a number of sites, until estimates can be made with accuracy	
Bjorkland et al. 2001	Y	Width and regeneration of the riparian zone	Looking for natural vegetation on both sides, with understory trees/ shrubs and regenerating bush	
Davies et al. 2000		Riparian width (m)		

Barbour et al. 1999	Y	RBP: riparian vegetative zone width	Width of the riparian zone in metres, and estimation of how much human activities have impacted the zone	
Ladson et al. 1999	Y	Width of the streamside vegetation	Ratings for width of vegetation in relation to channel width are provided (Table 6)	
Raven et al. 1998	Y	Tree positioning	Score 1 if trees are isolated/ scattered; score 2 if regularly-spaced or occasional clumps; score 3 if semi-continuous or continuous	
Catchment and local land use type e.g., cropping, forestry, native forest, urban				
Kaufmann and Robison1998, USEPA 2004		Determine what the local (channel, bank, riparian) human influences are and their proximity to the stream	A list of influences is provided and a set of proximity classes.	
Parsons et al. 2002b		Local activities that may be impacting on stream habitat	Indicate activities or potential impacts are present at the sampling site. Include brief description of each selected impact	
Bjorkland et al. 2001		Land use within the drainage area	Given 5 options of land use, estimate what % of the drainage area each of them covers	
Kaufmann 2000		Evaluate the presence/ absence and the proximity of 11 categories of human influences outlined in Table 6-11	A list of influences is provided and a set of proximity classes	USEPA 2004
Barbour et al. 1999		Predominant surrounding land use type	Record the dominant use e.g., forest, field/pasture, residential	
Raven et al. 1998	Y	Land use within 50 m	Score only broadleaf woodland (or native pinewood), moorland/heath, and wetland	
Channelisation or dredging/channel modification				
Munné et al. 2003	Y	How much the flow has been altered	Remove points depending on how much the channel is modified and constrained	
Parsons et al. 2002b		Human induced changes to the channel	Indicate the presence of channel modifications corresponding to one or more of the given categories, e.g., natural, straightened, reinforced, channelised in the past	
Bjorkland et al. 2001	Y	Condition of the channel	Look for signs of channelisation or straightening, downcutting, dikes or levees	
Davies et al. 2000	Y	RBP: Channel alteration	Look for artificial embankments, riprap, and other forms of artificial bank stabilisation, as well as straightening	Barbour 1999

Table 2. New Zealand publications illustrating the link between selected habitat parameters and stream macroinvertebrate and fish communities.

Parameter	Notes	Macroinvertebrates	Fish
Channel or stream (wetted) width		Davies-Colley 1997	Jowett et al. 1996; Jowett and Richardson 2003; Baker and Smith 2007
Channel or stream depth		Jowett et al. 1991	Jowett 1998; Chadderton and Allibone 2000; Bonnett and Sykes 2002; Rowe and Smith 2003; Baker and Smith 2007
Water velocity		Jowett and Richardson 1990, Jowett et al. 1991; Collier 1993	Jowett et al. 1996; Bonnett and Sykes 2002; Whitehead et al. 2002; Rowe and Smith 2003;
Thalweg profile			Mossop and Bradford 2006 (overseas); Hayes et al. 2007
Stream discharge & flow regime		Quinn and Hickey 1990b; Jowett and Duncan 1990; Jowett 2000; Greenwood and McIntosh 2008	McIntosh 2000; Kirstensen and Closs 2008
Organic substrate composition		Rounick and Winterbourn 1983; Collier et al. 1998; Death 2000; Reeves et al. 2004, McIntosh et al. 2005	
Inorganic substrate sizes/composition	substrate stability	Quinn & Hickey 1990a,b; Jowett et al. 1991; Death and Winterbourn 1995; Townsend and Scarsbrook 1997; Collier et al. 1998	McDowall 1990; Jowett and Richardson 1996; McIntosh 2000
Sinuosity		Suren 2000	
Silt coverage/fine substrate		Quinn & Hickey 1990a,b; Ryan 1991; Jowett et al. 1991; Suren and Jowett 2001; Usio and Townsend 2000	Ryan 1991; Jowett and Boustead 2001; Richardson and Jowett 2002; Jowett and Richardson 2003
Water flow type (r, r, p, g, freefall, chute, chaotic etc)		Pridmore and Roper 1985	Jowett and Richardson 1996; Chadderton and Allibone 2000; Jowett and Richardson 2003
LWD (number, size, total volume and distribution of wood)		Quinn et al. 1997; Collier et al. 1998	Rowe and Smith 2003; Baker and Smith 2007
Instream fish cover (areal cover of each type e.g., macrophytes, overhanging veg)			Jowett et al. 1996; Rowe 2000; Bonnett and Sykes 2002; Whitehead et al. 2002; Rowe and Smith 2003
Bank stability	via effects on sedimentation	Suren 2000; Quinn 2000; Reeves et al. 2004	Jowett et al. 1996; Rowe et al. 2000
Bank undercut			Jowett et al. 1996
Bank vegetation coverage/overhang		Collier and Scarsbrook 2000	Rowe and Smith 2003

Parameter	Notes	Macroinvertebrates	Fish
Canopy tree cover/ shading over the stream		Quinn et al. 1997; Quinn 2000	Bonnett and Sykes 2002; Eikaas et al. 2005a,b; Baker and Smith 2007
Width of riparian zone	riparian generally	Collier and Scarsbrook 2000; Reeves et al. 2004; Eivers 2006	McDowall 1990; Jowett et al. 1996; Hicks 1997; Rowe et al. 2002; Eikaas et al. 2005a,b
Areal cover class at canopy, understory and ground level			
Native vs exotic vegetation		Parkyn and Winterbourn 1997	See below
Catchment and local land use type e.g., cropping, forestry, native forest, urban		Quinn & Hickey 1990a; Harding et al 1995; Quinn et al. 1997; Harding et al. 1999; Quinn 2000	Hanchet 1990; Minns 1995; Jowett et al. 1996: Rowe et al. 1999; Jowett and Richardson 2003; Eikaas et al. 2005b
Channelisation or dredging/channel modification		Quinn et al. 1992; Suren 2000	David et al. 2002
Fish obstructions/ artificial barriers			McDowall 1996, 1998; Chadderton and Allibone 2000; Rowe et al. 2000; Rowe and Smith 2003
Altitude/distance from ocean			Jowett and Richardson 1996; Joy et al. 2000; Jowett and Richardson 2003; Eikaas et al 2006

Appendix 3 Ruler method for measuring velocity

If you do not have a velocity meter or it is not functioning properly a crude velocity measurement can be used in faster water. The "Ruler Method" is described here by Doug Craig (University of Alberta), also see Drost (1963).

The method works on simple physics, water at rest has a certain potential energy measured by its depth (sometimes referred to as the 'head'), the deeper the water the more energy it will have. The potential energy is that caused by gravity trying to pull it down to sea level. That energy of a volume of water is in its totality usually referred to as the 'specific energy'. On a slope and the water begins to flow, there is now some kinetic energy, plus the remaining potential energy, but since the specific energy at that time and place is the same (that is, no work has been done to extract any energy) the depth of the water must decrease. This what you see when water flows over a rock and accelerates, the water level drops – more velocity, less depth. Similarly, dimples in the top of flowing water are where a vortex is spinning (high velocity), and the depth must decrease.

So, there is a relationship between the head of water and velocity, thus if you stop the water flowing (as with a ruler) the kinetic energy (velocity) must convert back into potential energy, or head, and hence you get a bow wave of height that is a head of water of potential energy equivalent to the kinetic energy that was there.

Take the depth measurement (d_1) with the water running along the width of the ruler - ignore any little bow wave on the edge (Fig. 1).

Then do it again (d_2) with the ruler turned crossways to the flow.

Record both measurements. The flow will be variable and the depths on your ruler will fluctuate. However, your eye is very good at estimating the mean of that variation, so depending on what you want to do with the velocity estimate, you either record the mean, or the extremes, the later will give you better idea of what the range is. The following formula enables you to calculate velocity;

$$\text{Velocity } (v) = \sqrt{2g(d_2 - d_1)}$$

v = cm/s
g = 980cm/sec^2
d = depth measurements in cm.

At about 20cm/s the height difference is about 2mm only and that is lower limit of the usability of this method. At higher velocities about 1 m/s the bow wave is getting extreme. Obviously this method is has some inherent inaccuracies, however it has been shown to proved numbers within 10% of flow meter readings.

Appendix 4

P1 - Site characterization field sheet

Site	Site code		Site name			GPS	N -	
	Assessor		Date				E -	
Channel & Bank	Wetted channel width	m	Vegetated bank width	m	Site length	m	* Channel & bank notes	
	Channel shape	Artificially channelised	Straight	Weakly sinuous	Strongly sinuous			
	Flow conditions	Low flow	Base flow	High flow				
	Flow types present	Riffle/rapid ☐	Run ☐	Pool ☐	Other ☐			
	Lower bank height	L – m	R – m	Upper bank height	L – m	R – m		
	Bank stability	Stable	Mostly stable	Highly unstable	Bank undercut	Yes/No		
	Bank cover	Soil ☐	Stony ☐	Grass ☐	Tussock ☐	Shrubs ☐	Trees ☐	Artificial ☐
In-stream	Stream bed substrate	Clay/mud ☐	Silt/sand ☐	Gravel ☐	Cobble ☐	Boulder ☐	Bedrock☐	Artificial ☐
	Bed stability	Highly stable	Moderately stable	Highly unstable			* In-stream notes	
	Macrophytes	Submerged ☐	Marginal ☐	Emergent ☐				
	Periphyton	None visible	Sparse	Common	Abundant	Dominating		
	Wood	Absent	Sparse	Common	Abundant	Dominating		
	Moss	Absent	Sparse	Common	Abundant	Dominating		
	Leaves	Absent	Sparse	Common	Abundant	Dominating		
	Shading	Open	Partial	Heavily shaded	Overhanging vegetation	Yes/No		
Riparian & Catchment	Riparian width	L – m	R – m	Stock access	L – Yes/No	R – Yes/No	* Riparian & catchment notes	
	Stock damage	None	Minor	Moderate	High			
	Problem plants	Yes/No	Photo taken – Yes/No		Type(s)			
	Riparian cover	Soil ☐	Rock/ gravel ☐	Grass ☐	Tussock ☐	Wetland plants ☐		
		Ferns ☐	Shrubs ☐	Native trees ☐	Deciduous exotic ☐	Conifers☐	Other ☐	
	Adjacent land use	Conservation/ reserve ☐	Short grazed ☐	Long ungrazed ☐	Production forest ☐	Dairy cattle ☐	Beef cattle ☐	Sheep ☐
		Crop ☐	Horticulture ☐	Deer ☐	Horse ☐	Urban ☐	Road ☐	Other ☐
	Catchment land use	Native forest ☐	Plantation forest ☐	Farming ☐	Urban ☐	Industry ☐	Mining ☐	Other ☐

P1 - Site characterization field sheet (continued)

Cross section diagram of site (*include shape of floodplain, riparian vegetation, and channel shape*)

Plan diagram of site (*include significant land marks, access points, N direction, direction of stream flow, location of roads, rough scale*)

Additional notes:

Directions to find site (*include landowner contact details, precise details of site location*)

Site photos – Upstream ☐ Downstream ☐

P2b field form

Site code		Site name	
Assessor		Date	

Reach assessment

Wetted width (m)		
Site length (m)		
	Easting	Northing
GPS reach start		
GPS reach end		

Pool	Max depth (m)	Sediment depth (m)	Crest depth (m)
1			
2			
3			

Floodplain shape	

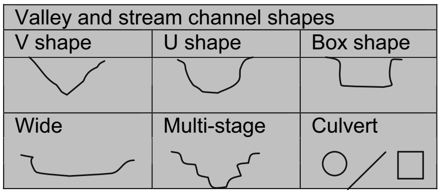
Meso-habitat length (m)					
Rapid	Run	Riffle	Pool	Backwater	Other

Cross sections

	Run	Riffle	Pool
Bankfull channel shape			
Wetted width channel			

Bank undercut (m)			

Valley and stream channel shapes



Run	LBF	LB$_1$	LB$_2$	LB$_3$	WE	1	2	3	4	5	6	7	8	9	10	WE	RB$_3$	RB$_2$	RB$_1$	RBF
Offset (m)																				
Depth (m)																				
Velocity	0	0	0	0	0											0	0	0	0	0
LBF = left bank full, LB = left bank (for bank offsets record distance between ground and transect line in depth row) WE = water's edge																				

Plan diagram of site *(include significant land marks, access points, N direction, direction of stream flow, location of roads, rough scale)*

Notes/comments

P2c field form

		Riffle	Run	Pool
Bed substrate	% Concrete/artificial			
	% Bedrock (>4000mm)			
	% Boulder (256– 4000mm)			
	% Cobble (64 - 255 mm)			
	% Gravel (2 – 63 mm)			
	% Silt, sand, mud (< 2 mm)			
	% embeddedness			
	Substrate compactness			
	% Deposition & scouring			
Organic matter	% Macrophytes			
	% Moss			
	% Algae			
	% Woody debris & leaf packs			
Fish habit	% Obstructions to flow			
	% Bank cover			

P2d field form

Attributes	L	R	Scores 1	Scores 2	Scores 3	Scores 4	Scores 5
Shading of water			Little or no shading	10-25% shading	25-50%	50-80%	>80%
Buffer width			<1 m	1-5 m	5-15 m	15-30 m	>30 m
Buffer intactness			Buffer absent	50-99% gaps	20-50% gaps	1-20% gaps	Completely intact
Vegetation comp. of buffer and/or adjacent land to 30 m from streambank	**Buffer** **Adjacent**	**Buffer** **land**	Short grazed pasture grasses to stream edge, or impervious surfaces	Exotic weedy shrubs Gorse, blackberry, broom, or mainly high grasses or low native shrubs 0.3-2 m	Deciduous tree dominated; native shrub dom. (2-5 m); or plantation with <25% cover of >5 m trees; or tussock where natural	Regen. native forest or woodlot evergreens with >25% cover sub-canopy (>5 m) trees but <10% canopy trees (>12 m)	Maturing native forest including >10% cover canopy trees (>12 m); or native wetland or natural tussock veg.
Bank stability			Very low: uncohesive sediments & few roots & >40% recently eroded	Low: uncohesive sediments & few roots/ low veg. cover & >15-40% recently eroded	Moderate: stabilized by geology (e.g. cobbles), veg cover &/or roots & >5-15% recently eroded	High: stabilized by geology (e.g. bedrock), veg. cover &/or roots; & 1-5% recently eroded	Very high: stabilized by geology (e.g. bedrock), veg. cover &/or roots; <1% recently eroded
Livestock access			High: unfenced and unmanaged with active livestock use	Moderate: some livestock access	Limited: Unfenced but with low stocking, bridges, troughs, natural deterrents	Very limited: Temporary fencing of all livestock or naturally v limited access	None: Permanent fencing or no livestock
Riparian soil denitrification potential			Soils dry/firm underfoot <u>or</u> moist-wet but frequent tile drains bypass riparian soils (≥3 per 100 m)	1-30% streambank soils moist but firm <u>or</u> moist-wet with infrequent bypass drains (1-2 per 100 m)	≥30% streambank soils moist but firm underfoot. No drains.	1-30% streambank soils water-logged, soft underfoot with black soil. No drains.	≥30% of streambanks water-logged, surface moist/fluid underfoot. No drains.
Land slope 0-30 m from stream bank			>35°	>20 - 35°	>10 - 20°	>5 -10°	0 - 5°
Groundcover of buffer and/or adjacent land to 30 m from streambank	**Buffer** **Adjacent**	**Buffer** **Land**	Bare	Short/regularly grazed pasture (<3 cm)	Pasture grass/ tussock with bare flow paths or 2-3 cm tree litter layer	Moderate density grass or dense (>3 cm) tree litter layer	High density long grass
Soil drainage			Impervious (e.g. sealed) or extensively pugged and/or compacted soil	Low permeability (e.g. high clay content) or moderately pugged/compacted soil	Low-moderate permeability (e.g. silt / loam) and not pugged/compacted	Mod-high permeability (e.g. sandy loam) & not pugged/compacted	Very high permeability (e.g. pumice / sand) & not pugged/compacted
Rills / Channels			Frequent rills (> 9 per 100 m) or larger channels carry most runoff	Common rills (4-9 per 100 m) or 1-2 larger channels carry some runoff	Infrequent rills (2-3 per 100 m) and no larger channels	Rare rills (1 per 100 m) and no larger channels	None

P3b field form

Site code		Site name	
Assessor		Date	

Reach assessment

Wetted width (m)		
Reach length (m)		
	Easting	Northing
Reach start		
Reach end		

Pool	Maximum depth(m)	Sediment depth (m)	Crest depth (m)
1			
2			
3			
4			
5			
6			

Meso-habitat length (m)					
Rapid	Run	Riffle	Pool	Backwater	Other

Plan diagram of the site (include significant land marks, access points, N direction, direction of stream flow, location of roads, rough scale)

Notes/comments

Cross sections

Run	Location$^+$									Water depth below staff gauge										
	LBF	LB_1	LB_2	LB_3	WE	1	2	3	4	5	6	7	8	9	10	WE	RB_3	RB_2	RB_1	RBF
Offset (m)																				
Depth (m)																				
Velocity	0	0	0	0	0											0	0	0	0	0
$^+$ 'head', 'middle' or 'tail' of run LBF = left bank full, LB = left bank (for bank offsets record distance between ground and transect line in depth row), WE = water's edge																				
Run	Location$^+$									Water depth below staff gauge										
	LBF	LB_1	LB_2	LB_3	WE	1	2	3	4	5	6	7	8	9	10	WE	RB_3	RB_2	RB_1	RBF
Offset (m)																				
Depth (m)																				
Velocity	0	0	0	0	0											0	0	0	0	0
Run	Location$^+$									Water depth below staff gauge										
	LBF	LB_1	LB_2	LB_3	WE	1	2	3	4	5	6	7	8	9	10	WE	RB_3	RB_2	RB_1	RBF
Offset (m)																				
Depth (m)																				
Velocity	0	0	0	0	0											0	0	0	0	0

Riffle	Location$^+$									Water depth below staff gauge										
	LBF	LB$_1$	LB$_2$	LB$_3$	WE	1	2	3	4	5	6	7	8	9	10	WE	RB$_3$	RB$_2$	RB$_1$	RBF
Offset (m)																				
Depth (m)																				
$^+$ ‘head’, ‘middle’ or ‘tail’ of run																				
Riffle	Location$^+$									Water depth below staff gauge										
	LBF	LB$_1$	LB$_2$	LB$_3$	WE	1	2	3	4	5	6	7	8	9	10	WE	RB$_3$	RB$_2$	RB$_1$	RBF
Offset (m)																				
Depth (m)																				
Riffle	Location$^+$									Water depth below staff gauge										
	LBF	LB$_1$	LB$_2$	LB$_3$	WE	1	2	3	4	5	6	7	8	9	10	WE	RB$_3$	RB$_2$	RB$_1$	RBF
Offset (m)																				
Depth (m)																				

Pool	Location$^+$									Water depth below staff gauge										
	LBF	LB$_1$	LB$_2$	LB$_3$	WE	1	2	3	4	5	6	7	8	9	10	WE	RB$_3$	RB$_2$	RB$_1$	RBF
Offset (m)																				
Depth (m)																				

$^+$ ‘head’, ‘middle’ or ‘tail’ of run
LBF = left bank full, LB = left bank (for bank offsets record distance between ground and transect line in depth row), WE = water’s edge

Pool	Location$^+$									Water depth below staff gauge										
	LBF	LB$_1$	LB$_2$	LB$_3$	WE	1	2	3	4	5	6	7	8	9	10	WE	RB$_3$	RB$_2$	RB$_1$	RBF
Offset (m)																				
Depth (m)																				

Pool	Location$^+$									Water depth below staff gauge										
	LBF	LB$_1$	LB$_2$	LB$_3$	WE	1	2	3	4	5	6	7	8	9	10	WE	RB$_3$	RB$_2$	RB$_1$	RBF
Offset (m)																				
Depth (m)																				

P3c field form

Site name		Site code	
Assessor		Date	

Riffle 1	Cross-section	Wetted width (m)									
		1	2	3	4	5	6	7	8	9	10
	Substrate size										
	Embeddedness										
	Compactness										
	Depositional & scouring (cm)										
	Macrophytes (cm)										
	Algae (cm)										
	Leaf packs (cm)										
	Woody debris (cm)										
	Large boulders & log jams (count)										
	Bank cover (m)	Left bank					Right bank				

Riffle 2	Cross-section	Wetted width (m)									
		1	2	3	4	5	6	7	8	9	10
	Substrate size										
	Embeddedness										
	Compactness										
	Depositional & scouring (cm)										
	Macrophytes (cm)										
	Algae (cm)										
	Leaf packs (cm)										
	Woody debris (cm)										
	Large boulders & log jams (count)										
	Bank cover (m)	Left bank					Right bank				

Run 1	Cross-section	Wetted width (m)									
		1	2	3	4	5	6	7	8	9	10
	Substrate size										
	Embeddedness										
	Compactness										
	Depositional & scouring (cm)										
	Macrophytes (cm)										
	Algae (cm)										
	Leaf packs (cm)										
	Woody debris (cm)										
	Large boulders & log jams (count)										
	Bank cover (m)	Left bank					Right bank				

Run 2	Cross-section	Wetted width (m)									
		1	2	3	4	5	6	7	8	9	10
	Substrate size										
	Embeddedness										
	Compactness										
	Depositional & scouring (cm)										
	Macrophytes (cm)										
	Algae (cm)										
	Leaf packs (cm)										
	Woody debris (cm)										
	Large boulders & log jams (count)										
	Bank cover (m)	Left bank					Right bank				

Pool 1	Cross-section	Wetted width (m)									
		1	2	3	4	5	6	7	8	9	10
	Substrate size										
	Embeddedness										
	Compactness										
	Depositional & scouring (cm)										
	Macrophytes (cm)										
	Algae (cm)										
	Leaf packs (cm)										
	Woody debris (cm)										
	Large boulders & log jams (count)										
	Bank cover (m)	Left bank					Right bank				

Pool 2	Cross-section	Wetted width (m)									
		1	2	3	4	5	6	7	8	9	10
	Substrate size										
	Embeddedness										
	Compactness										
	Depositional & scouring (cm)										
	Macrophytes (cm)										
	Algae (cm)										
	Leaf packs (cm)										
	Woody debris (cm)										
	Large boulders & log jams (count)										
	Bank cover (m)	Left bank					Right bank				

P3d field form

Site name		Site code	
Assessor		Date	

	Buffer width (m)		Land slope		Distance to stopbank (m)		Distance to floodplain (m)	
Cross-section	LB	RB	LB	RB	LB	RB	LB	RB
1								
2								
3								
4								
5								

Riparian vegetation	Distance from LB (m)				Distance from RB (m)			
Cross-section 1	0.5	3	7.5	20	0.5	3	7.5	20
Native vegetation	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Veg tier height								
0 - 0.3 m								
0.3 - 1.9 m								
2.0 - 4.9 m Shrubs								
5 - 12 m Subcanopy								
>12 m Canopy								
Cross-section 2								
Native vegetation	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Veg tier height								
0 - 0.3 m								
0.3 - 1.9 m								
2.0 - 4.9 m Shrubs								
5 - 12 m Subcanopy								
Cross-section 3								
Native vegetation	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Veg tier height								
0 - 0.3 m								
0.3 - 1.9 m								
2.0 - 4.9 m Shrubs								
5 - 12 m Subcanopy								
Cross-section 4								
Native vegetation	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Veg tier height								
0 - 0.3 m								
0.3 - 1.9 m								
2.0 - 4.9 m Shrubs								
5 - 12 m Subcanopy								
Cross-section 5								
Native vegetation	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Veg tier height								
0 - 0.3 m								
0.3 - 1.9 m								
2.0 - 4.9 m Shrubs								
5 - 12 m Subcanopy								
>12 m Canopy								

	Left bank	Right bank
Gaps in buffer		
Wetland soils		
Stable undercuts		
Livestock access		
Bank slumping		
Raw bank		
Rills/Channels		
Drains (count)		

Shading of water				

Notes

Index

Stream Habitat
Assessment Protocols

This self-contained guide provides a set of practical, cost-effective and standardised protocols for the assessment of physical habitat in New Zealand waterways. It is intended that the information provided will allow practitioners to measure the current state of stream habitat using accurate and specific variables that allow for the identification of spatial and temporal trends in habitat condition.

Often when you visit a stream or river for the first time your impression of that stream is based on the visual clues about its surrounding landscape and how the stream looks. These visual impressions are in effect an assessment of the physical condition of the stream. Although we may not think of it in that context, what we are doing is picking up cues about the condition of riparian zone, the presence of human engineering structures, the current and recent of flow conditions and the morphology of the stream bed.

Historically, much of the focus of stream assessments have been on measuring water quality and collecting ecological information about algae, invertebrate and fish communities. Frequently, less emphasis has been placed on collecting hydrological, riparian or stream morphology data. Increasing pressures to extract water from our streams and rivers has meant that understanding the relationship between flow levels and stream communities have become more important. Similarly, greater demands for stream restoration and effective riparian management have occurred as our understanding of the importance of riparian and habitat conditions in maintaining the structure and function of healthy streams has increased. As a result, there has been an increasing need for better and more consistent tools to characterize and quantify stream habitat. These protocols are an attempt to fulfill that need.

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