2004-05/01

Manaaki Whenua
Landcare Research

Catchment channel characteristics and riverbed substrate assessment – a review and trial of a method of fine sediment assessment in the Motueka River

Prepared for

Stakeholders of the
Motueka Integrated Catchment Management Programme

Manaaki Whenua
Landcare Research

TDC Tasman District Council

CAWTHRON

June 2005

Catchment channel characteristics and riverbed substrate assessment – a review and trial of a method of fine sediment assessment in the Motueka River

Motueka Integrated Catchment Management (Motueka ICM) Programme Report Series

by

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Cover Photo: Fine sediment infilling pool following Easter 2005 storm - upper Motueka River at Gorge.

PREFACE

An ongoing report series, covering components of the Motueka Integrated Catchment Management (ICM) Programme, has been initiated in order to present preliminary research findings directly to key stakeholders. The intention is that the data, with brief interpretation, can be used by managers, environmental groups and users of resources to address specific questions that may require urgent attentin or may fall outside the scope of ICM research objectives.

We anticipate that providing access to environmental data will foster a collaborative problem-solving approach through the sharing of both ICM and privately collected information. Where appropriate, the information will also be presented to stakeholders through follow-up meetings designed to encourage feedback, discussion and coordination of research objectives.

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Glossary

The terms in this glossary are largely taken directly from the National Water-Quality Assessment (NAWQA) Program (Fitzpatrick et al. 1998).

Channel—The channel includes the thalweg and streambed. Bars formed by the movement of bedload are included as part of the channel. It is the deepest portion of a stream through which the main volume of water flows.

Cross section—A line of known horizontal and vertical elevation across a stream perpendicular to the flow. Measurements are taken along this line so that geomorphological characteristics of the section are measured.

Drainage basin—A part of the surface of the Earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water, including all tributary surface streams and bodies of impounded surface water.

Embeddedness—The degree to which gravel-sized and larger particles are surrounded or enclosed by finer-sized particles.

Floodplain—The relatively level area of land bordering a stream channel and inundated during moderate to severe floods. The level of the flood plain is generally about the stage of the 1- to 3-year flood.

Geomorphic channel units—Fluvial geomorphic descriptors of channel shape and stream velocity. Pools, riffles, and runs are three types of geomorphic channel units considered for NAWQA Program habitat sampling.

Habitat—In general, aquatic habitat includes all aspects of the physical (nonliving) environment where plants and animals live, although living components like aquatic macrophytes and riparian vegetation also are usually included. Measurements of habitat are typically made over a wider geographic scale than measurements of species distribution. It is used to divide reaches into physical units characterised by different plant and animal communities.

Non-wadeable—Sections of a stream where an investigator cannot wade from one end of the reach to the other, even though the reach may contain some parts that are wadeable.

Pool—Parts of the reach with low velocity, smooth water surface, commonly with water deeper than surrounding areas.

Reach—A length of stream that is chosen to represent a uniform set of physical, chemical, and biological conditions within a segment. It is the principal sampling unit for collecting physical, chemical, and biological data.

Riffle—A shallow part of the stream where water flows swiftly over completely or partially submerged obstructions to produce surface agitation (i.e. a broken water surface). They are generally composed of coarser sediment than other channel features, and often form a step in the bed and water surface profile.

Riparian—Pertaining to or located on the bank of a body of water, especially a stream or river.

Riparian zone—Area adjacent to a stream that is directly or indirectly affected by the stream. The biological community or physical features of this area are different or modified from the surrounding upland by its proximity to the river or stream.

Run—A relatively shallow part of a stream or river with moderate velocity and little or no surface turbulence. It often has an undulating but unbroken water surface.

Segment—A section of stream bounded by confluences or physical or chemical discontinuities, such as major waterfalls, landform features, significant changes in gradient, or point-source discharges. It is the principal unit for subdividing streams to characterise significant changes in physical character (and hence mixes of habitat types) within the stream system.

Sinuosity—The ratio of the channel length between two points on a channel to the straight-line distance between the same two points; a measure of meandering.

Stage—The height of a water surface above an established datum; same as gauge height.

Stream—The general term for a body of flowing water. Generally, this term is used to describe water flowing through a natural channel as opposed to a canal.

Streamflow—A general term for water that flows through a channel.

Terrace—An abandoned flood-plain surface that formed when the stream flowed at a higher level than at present. A terrace is a long, narrow, level or slightly inclined surface that is contained in a valley and bounded by steeper ascending or descending slopes, and it is always higher than the flood plain. A terrace may be inundated by floods larger than the 1- to 3-year flood.

Thalweg—The line formed by connecting points of minimum streambed elevation (deepest part of the channel) (Leopold et al., 1964).

Transect—A line across a stream perpendicular to the flow and along which measurements are taken, so that morphological and flow characteristics along the line are described from bank to bank. Unlike a cross section, no attempt is made to determine known elevation points along the line.

Wadeable—Sections of a stream where an investigator can wade from one end of the reach to the other, even though the reach may contain some pools that cannot be waded.

Part A Review of methods used for catchment channel characterisation and riverbed substrate assessment

Summary

There is little quantitative information on sediment composition in the Motueka River, or on trends in sediment composition. An increase in fine sediment has been implicated as a causal factor for changes in the trout population of the river. In order to assess the relationship between trout numbers and sediment characteristics, there is a need is to implement a set of simple, but reproducible, methods for characterising spatial and temporal patterns of bed sediment (or substrate) composition at the reach and habitat level. Ideally, the methods would:

- complement those used during routine drift dive assessments of trout numbers by Fish & Game in the Motueka River and its tributaries (for which information is required for ten 1-km long reaches of the river), and
- be used to identify slugs of fine sediment passing down the river, and determine their origin.

The Motueka River encompasses a wide range of channel form and water depth, and methods for sediment characterisation need to cover this range. A related issue is to provide some justification for the selection of drift dive reaches and the degree to which they represent the range of river and habitat types in the Motueka River catchment. This report describes:

- river and stream classification systems within a hierarchy of spatial scales;
- stream reach assessment methodologies, focusing on methods for substrate characterisation suitable for
    - determining the proportion of fine sediment in the river bed substrate,
    - use in both wadeable and non-wadeable reaches of the river;
    - quantitatively measuring spatial patterns and temporal change.

Most of the techniques reviewed are best suited to streams and rivers smaller than the main stem of the Motueka River and its major tributaries, because they are often only partially-wadeable.

Commonly used river/stream classification systems use some form of hierarchical spatial scale in which the specific attributes of a stream are assessed from the largest spatial scale down to the smallest (e.g., segment, reach, habitat) since stream morphology varies in response to variation in controlling factors (e.g., geology, climate, catchment size). A segment is the fundamental unit with a uniform set of physical, chemical, and biological stream conditions. However, it is normally too long for effective collection of field data and a smaller reach (with a consistent association of geomorphic channel units) is used to represent conditions within the segment. There is a strong association between physical characteristics and biological habitat, and the reach provides the basic sampling unit for habitat characterisation. At the habitat scale pools, riffles and runs are the key classes. Understanding the large scale variation and river/stream characteristics is fundamental to selecting representative stream segments and reaches for detailed study, and for extrapolating results.

The most commonly used classification systems in the USA are morphometric and geomorphically based:

- Rosgen (1994, 1996) distinguishes nine major channel types (based on channel pattern, entrenchment ratio, width-to-depth ratio, sinuosity, and slope) with different mixes of habitat types and stream stability, which are further subdivided according to bed material type. Classes use a non-intuitive alphanumeric code.
- Montgomery and Buffington (1993) proposed a geomorphic-based classification based on a 4-level hierarchy: major landform types (geomorphic provinces), valley morphology and sediment infill (segment), sequences of channel bedforms (reach), individual bedforms (geomorphic

channel units). The classes use common fluvial geomorphology terminology. A similar system is used by the US Geological Survey's National Water-Quality Assessment Programme (NAWQA).

Recently NIWA has developed river classification frameworks for New Zealand:

- the River Environment Classification: a broad scale 'controlling factor' classification with 6 levels based on climate, source of flow, geology, land cover, river network position, and valley landform. It is not designed to be used at habitat scale.
- The River Ecosystem Management Framework developed for application to river management at more detailed scales. Channel morphology (cascade, step-pool, plane cobble/gravel bed, riffle-pool, semi-braided gravel bed river, braided gravel bed river, entrenched, freely meandering, tidal, channelised) is introduced at the lowest level. It remains a broad-scale classification and does not deal with the habitat scale.

Substrate characterisation is a key component of habitat surveys. Methods for sampling substrate can be divided into:

- surface sampling including facies mapping, visual estimates, pebble counts and photographic methods. This approach samples a pre-selected number of surface particles from a pre-defined sampling area and data collection is generally completely field-based.
- subsurface sampling including shovel sampling, core sampling, and freeze-core sampling. This approach samples a pre-selected sediment volume from a pre-defined sedimentary layer (depth) and requires removal of a sediment sample for analysis.

Surface sampling is generally more common and is appropriate for the main stem of the Motueka River where the water is quite deep and fast flowing, and it is suitable for determining the amount of fine sediment on the river bed. Other methods of substrate characterisation include assessment of embeddedness, riffle stability index, relative bed stability index, and the volume of fine sediment in pools (V*).

A sampling scheme needs to be developed based on:

- spatial scale. For the drift dive reaches we need to determine substrate composition over ten 1-km-long reaches of river bed; to determine spatial and temporal trends in composition over the whole catchment the spatial scale is even larger.
- degree of spatial homogeneity or heterogeneity of particle-size patterns. This will typically include a number of different channel geomorphic units and composition will be determined by the pattern of GCUs. At the whole catchment scale several different stream classes occur and these will have different patterns of GCUs and substrate composition.
- desired sampling precision. In much of the main stem of the Motueka, the proportion of fine sediment is low (<10%) and determining spatial patterns of substrate composition will require measurements that have a high precision. Where slugs of fine sediment are passing down the river covering a high proportion of the bed (perhaps up to 50%), then the sampling precision can be lower.
- applicability to characterising changes in the proportion of fine sediment.

Repetitive mapping of habitat classes, combined with facies mapping, is rapid, and would provide information on the stability of habitat through time and broad scale composition patterns. However, by itself it is not likely to provide a sufficiently precise and repeatable measure to determine exactly what drives spatial and temporal variation in trout abundance. The broad pattern of pools, runs and riffles can probably be mapped from the digital orthophotos of the Motueka taken in 2000, and field checking would indicate the stability of these features over a 4-year period. The influence of variation in substrate characteristics on longitudinal patterns of trout abundance in the drift dive reaches will not be understood by characterising substrate alone. Without characterising the full range of habitat characteristics (e.g., water depth and velocity, cover, temperature, food supply, etc) it will not be possible to determine how significant the influence of substrate variation is compared to other habitat characteristics. It will be a large task to quantitatively characterise substrate in the 10 drift dive reaches of the main stem of the Motueka, most of which have a low proportion of fine sediment. It would be even more demanding to undertake this every time trout numbers are counted by drift diving.

A key question in characterising the fine sediment component of the surface substrate, is whether it is necessary to characterise all habitat components (i.e. pools, runs and riffles) or whether to adopt a stratified approach. Characterisation should be targeted at runs and pools since it unlikely that fine sediment will be deposited in riffles in the main stem. Runs may be the habitat class that is most influenced by changing sediment delivery. Pools may well always contain a relatively high proportion of fine sediment and comprise a small proportion of the river in the main stem.

The Wolman pebble count is by far the most widely used and accepted technique for quantitative substrate characterisation. However, it is problematic to use in deeper, swifter water where it is difficult to select clasts without bias towards larger clasts and it has limitations for assessing the proportion of fine sediment. For these conditions other techniques will be more suited. Bunte and Abt (2001a) suggest that for areas with large amounts of fine gravel and sand the best approach is to combine a Wolman pebble count with areal sampling. To minimise field time for areal sampling photographic techniques could be used . Alternatively the lead rope technique could be used with estimates of the proportion of different grain size classes, rather than just the dominant size class, where the proportion of fines is low. It would also be worth carrying out a pilot study in some pools to assess whether V* (the amount of fine sediment in pools) might provide a useful index of fine sediment trends.

Where the proportion of fine sediment is high (e.g., determining if slugs of fine sediment are passing down the river and greatly elevating fine sediment levels), it is more appropriate to use an approach that makes frequent but low precision estimates of the proportion of fine sediment. Visual estimates of sediment composition could provide estimates within ±10%, which will be adequate where the proportion of fine sediment rises from <10% to >30%. Monitoring sites could be established in the main stem at all main confluences and in the lower reaches of contributing tributaries, and assessments made at least annually and perhaps more often. Such an approach would identify slugs of fine sediment, provide information on their rate of movement through the river system, and identify which tributary(s) they originated from. A more quantitative approach could be developed using a combination of pebble counts and photographic techniques. The latter will require construction of a device for photographing stream beds, able to be deployed in a range of water depth and take good quality photos for image analysis. Alternatively a waterproof camera could be used with a frame to maintain a consistent height of the camera above the stream bed.

A rigorous approach to the selection of sample sites should be based on river segment and reach characterisation, to ensure study sites are representative (or in the case of the drift dive sites to assess how much of the river they represent) and to allow extrapolation of results within the Motueka and to other rivers. Similarly, a rigorous approach to required sample numbers should be based on degree of spatial heterogeneity and required sampling precision.

A1 Introduction

Defining the sources and fluxes of sediment, and its impacts on aquatic ecosystems, has been recognised as a key issue in the Motueka catchment since the inception of the Integrated Catchment Management programme (Dunne and Likens 2000). Key research questions raised by stakeholders and other scientists within the ICM programme have included:

1. What is the total sediment delivery to Tasman Bay?
2. What are the major influences on sediment supply and dynamics and to what extent can sediment supply be altered by land management practices?
3. What is the appropriate management for gravel extraction rates and sources and what impact does gravel extraction have on river bed levels and sediment composition?
4. How does river and stream bed composition vary spatially and temporally and what are the key drivers for this variation?
5. What have the direct and indirect impacts of sediment on freshwater and marine aquatic ecosystems been?

The first three questions are being addressed by work to provide information on sediment yield, dynamics and sources (Basher and Hicks 2003, Basher et al. 2003), and by analysis of historical river cross-section data (Sriboonlue and Basher 2003). The last two questions relate specifically to the impacts of sediment on aquatic organisms in the Motueka river system and have been key drivers for much of the sediment research.

Between 1994 and 1996 there was a significant decline in the numbers and biomass of trout in the Motueka River in the reach, near Woodstock, that has been regularly drift-dived (Fig. 1). A similar decline also occurred in the Wangapeka and Riwaka Rivers. Many believe this decline was caused by fine sediment degrading trout habitat in the river either by coarse sand clogging pore space on the beds of streams and rivers and infilling pools, changing both the quality of habitats and also the frequency distribution of these habitats, or by fine sediment clogging pore space on the river bed. However, there is no quantitative data to support this contention nor is it clear whether the observed decline in trout numbers is by a direct effect on adult or juvenile trout habitat (including the spawning habitat) or whether it is an indirect effect on trout food (invertebrate) habitat and abundance. Similarly, drift dive surveys of 10 reaches in the main stem of the Motueka below the Stanley Brook show variation in trout numbers between these reaches (Fig. 2), and it is thought that variation in sediment composition may be one of the causes of this variation (R. Young pers. comm. 2004).

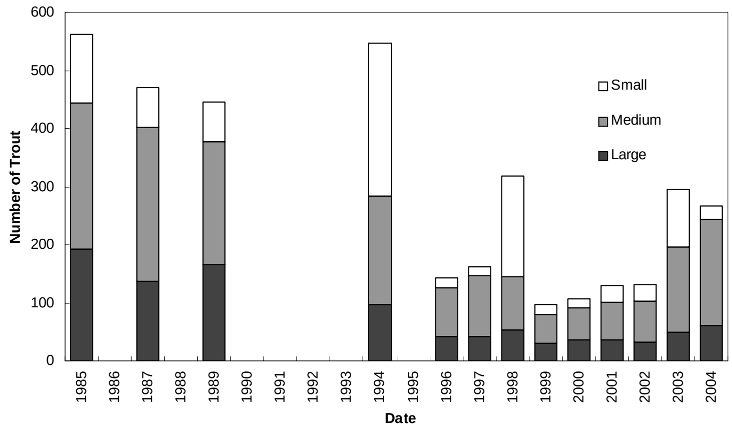

Fig. 1 Changes in trout numbers recorded by drift dives at Woodstock between 1985 and 2004

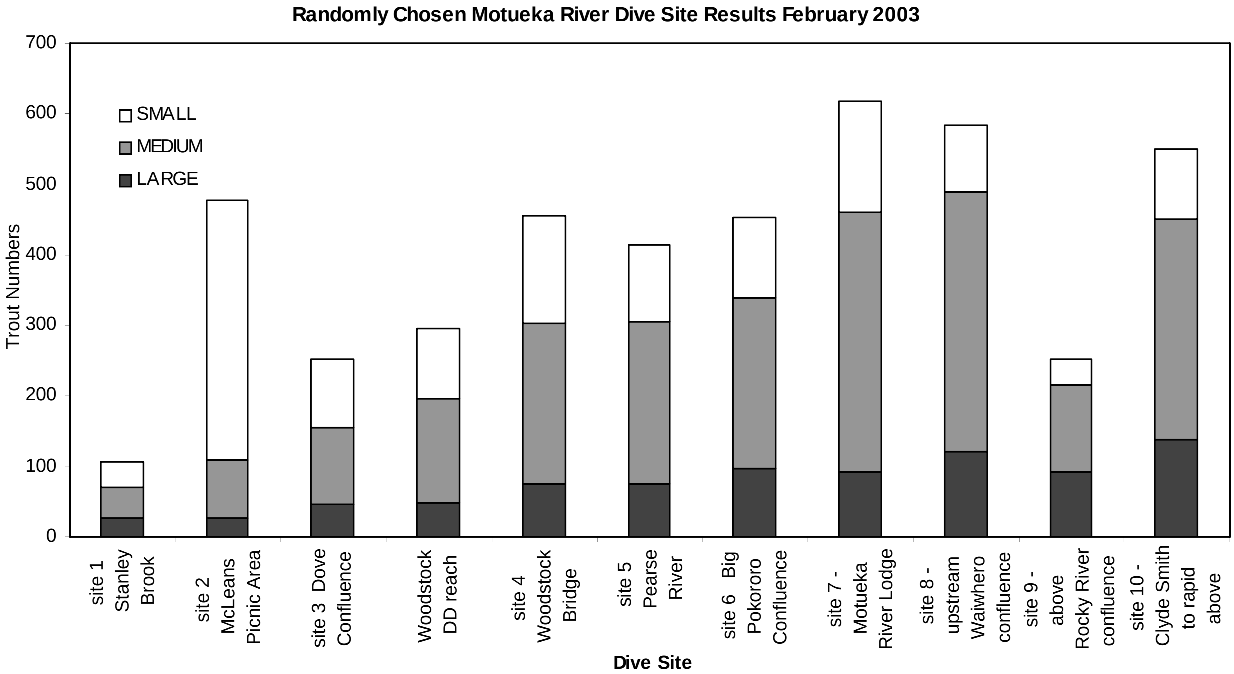

Fig. 2 Variation in trout numbers recorded by drift dives between the Stanley Brook and the Shaggery River

There is little quantitative information on sediment composition in the Motueka River, apart from the brief description of lithological variation given in Waterhouse (1996). There has been no previous work in the Motueka River on the relationship between trout numbers and sediment characteristics, or on changes to sediment composition that correlate with trout population changes. Therefore there is a need to find a set of simple, but reproducible, methods for characterising bed sediment (or substrate) composition at the reach and habitat level in order to assess the relationship between trout numbers and sediment characteristics, and trends in sediment composition through time. Ideally, the methods would complement those used as part of routine drift dive assessments of trout numbers by Fish & Game in the Motueka River and its tributaries. A wider, but related, issue is to provide some justification for the selection of drift dive reaches and the degree to which they represent the range of river and habitat types in the Motueka River catchment. Because of the perception that fine sediment has caused habitat changes, the emphasis of this report is on methods for characterising the proportion of fine sediment on the river bed.

The Motueka River encompasses a wide range of channel form and water depth, and methods for sediment characterisation need to cover this range. In particular methods suitable for both wadeable and non-wadeable parts of the river need to be developed. Edsall et al. (1997) draw a distinction between the different techniques that are appropriate in large, medium and small streams (or rivers):

- small streams are wadeable anywhere and traditional survey approaches are appropriate;
- at the first point a stream is not wadeable it becomes a medium-sized stream or river and traditional survey approaches will only work in some parts of the river;
- large rivers are non-wadeable and specialised remote sensing techniques are needed.

The Motueka River system dominantly comprises small and medium sized streams, although this is flow-dependent, and the lower reaches could be regarded as a large (non-wadeable) river. The main stem above the Wangapeka confluence is of a size that it has a mixture of both wadeable and non-wadeable reaches and this varies depending on discharge; the main stem below the Wangapeka confluence is mostly non-wadeable although at low flows some areas are wadeable; tributary valleys include both wadeable (e.g., Dove River) and non-wadeable (e.g., Wangapeka River) streams

This report reviews techniques for characterising stream systems within their landscape setting, and habitat types within those stream systems. It provides background to the selection of methods commonly used for habitat assessment in streams and rivers and recommends an approach for reach and substrate characterisation in the Motueka River catchment. Several key documents and approaches were reviewed (Mosley 1982, Meador et al. 1993, Fitzpatrick et al. 1998, Kauffman et al. 1999, Bain and Stevenson 1999, Lazorchak et al. 1998, 2000, Bunte and Abt 2001a, Biggs et al. 2002, Kondolf et al. 2003), a literature search was carried out to determine usage and limitations of commonly used techniques, and some preliminary field testing was undertaken. Habitat assessment can involve quite detailed assessment at a range of levels, and is governed by both the objectives of the study in question and the resources available. The current study's focus is on reach and habitat scales with specific emphasis on assessment of the physical characteristics of the riverbed substrate. However, because river and substrate characteristics at the reach and habitat scale are a function of the hierarchical structure and dynamics of the whole catchment an overview of river classification systems is provided.

The specific objectives of this report are to:

1. Describe river and stream classification systems within a hierarchy of spatial scales;
2. Describe stream reach assessment methodologies, focusing on methods for substrate characterisation suitable for determining the proportion of fines in the river substrate;
3. Recommend an approach to substrate characterisation for the Motueka River suitable for characterising spatial patterns of sediment characterisation and able to quantitatively measure temporal change.

A2 Background

A stable stream reach is one in dynamic equilibrium. Over a time frame of several years, sediment size and sediment transport rates into a reach are similar to those exiting the reach. When sediment supply into a reach exceeds transport capacity, some sediment is deposited within the reach. Accelerated deposition is typically accompanied by a textural change of the bed material (Lisle 1982). If the imbalance persists, channels may widen; pools may shorten, become shallower, and transform into runs; and general aggradation of the bed surface may occur (Lisle 1982). Of these responses, substrate change, defined as a change in the relative abundance of particles of different sizes on the streambed, was found by Lisle et al. (1993) to be the only hydraulic variable that responded consistently to changes in sediment load. To test the notion that the Motueka River is being impacted by increases in sediment deposition, and that this is directly responsible for affecting trout populations, it is important that research focus on ways to measure or assess substrate composition and that these methods are repeatable both in time and space to ensure that trends can be established. It is worth noting that elevated sediment input may have a variety of direct and indirect impacts on the aquatic ecosystem (Fig. 3).

Any approach aimed at understanding the impacts of sediment on fish and fish habitat in the Motueka River, needs to be based on a conceptual understanding of how stream systems are organized in space and how they change through time (Lotspeich and Platts 1982, Frissell et al. 1986). Different geomorphic processes control the form and development of catchments and streams (Wolman and Gerson 1978) both between, and within, different regions. In addition, geomorphic conditions may be different depending on the position of the stream within the hierarchy of the stream network. Therefore, researchers have recognized the importance of placing streams and stream habitats in a geographic, spatial hierarchy (Godfrey 1977, Lotspeich and Platts 1982, Bailey 1983, Frissell et al. 1986). Assessment of catchment

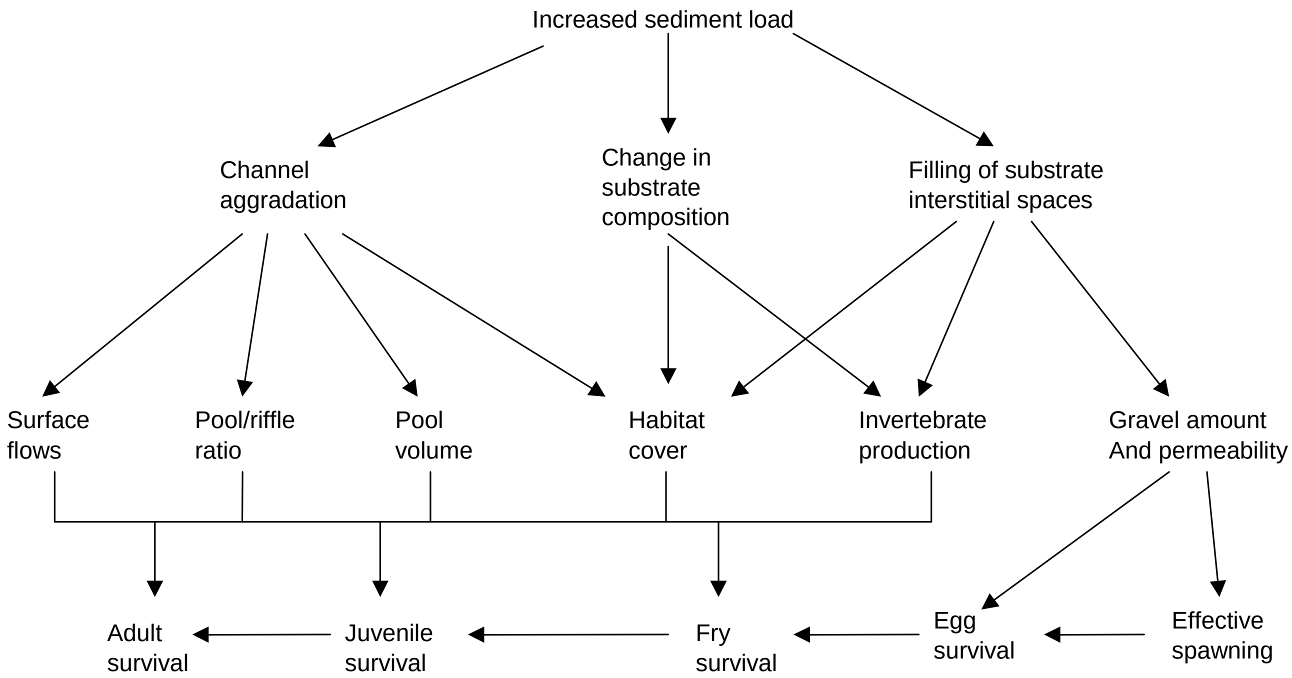

Fig. 3 Multiple impacts of increased sediment loads on trout and salmon populations (Reiser 1998).

and/or channel response to natural and anthropogenic environmental change thus requires a process-based landscape and channel classification that is capable of moving between a range of scales as well as having the flexibility to be used to address both single-issue and more complex multiple-issue questions.

Habitat is the basis of most aquatic impact assessments and resource inventories, many species management plans, mitigation planning, and environmental regulation (Bain and Stevenson 1999). Habitats are relatively stable through time, are easily defined in intuitive physical terms, and provide an identifiable unit for description and decision-making. Aquatic habitat is largely a product of the surrounding land and climate (Likens and Bormann 1974). Geology influences the shapes of drainage patterns, channel bed materials, and water chemistry. Soils influence infiltration rates, erosion potential, and vegetation types. Climate affects hydrologic, morphologic, and vegetational characteristics. Vegetation affects a number of factors, including water loss through evapotranspiration, runoff, and channel bank stability. Thus, the drainage basin (or catchment) serves as a fundamental ecosystem unit and an important basis from which to understand the characteristics of streams (Leopold et al. 1964, Schumm and Lichty 1965, Frissell et al., 1986, Gordon et al. 1992).

Catchments are the most common spatial units used by fisheries management agencies in aquatic habitat assessment activities and in framing guidelines for controls and remediation. Catchments accumulate the surface and subsurface flow of water up-gradient from a habitat assessment site. Consequently it is possible to document factors that could influence habitat quality, such as upstream pollution point sources and non-point source run off. The boundaries of a catchment are also used to explain biogeographic distributions of fish species and to enhance an understanding of the comparative biogeographic patterns in biological communities (Biggs et al. 1990, Quinn and Hickey 1990). The downstream transfer of water, sediment, nutrients, and organic material all influence the characteristics of stream habitats. It is therefore important to understand the geologic, hydrologic, morphologic, and vegetational setting of a stream in its catchment. Understanding catchment attributes aids interpretation of habitat conditions.

Numerous methods of analysing and reporting habitat conditions have been developed and habitat assessment approaches vary greatly. However, standardised sampling protocols are required to describe spatial and temporal trends. Techniques must be repeatable and sufficiently accurate and precise to detect change. The literature covers a wide range of assessment methodologies and tends to come from either a geomorphological perspective or a biological perspective. Both approaches have their merits. Channel classifications use similarities of form and function to impose order on a continuum of natural stream types or morphologies. Each channel classification system in common use has advantages and disadvantages in geological, engineering, and ecological applications (Kondolf 1995), and no single classification can satisfy all possible purposes, or include all possible channel types.

Evaluations of physical stream habitat frequently occur in lieu of monitoring biological conditions such as fish density or biomass because of the relative ease of collecting these data and the variability of biological systems (Platts et al. 1983). Often the outcomes of these surveys are used as evidence for compliance with regulations and laws. However, the use of stream attributes for monitoring has many critics (Roper et al. 2002). Common problems include different observers using the same protocol getting different results, inconsistent application of protocols, lack of consistent training, and difficulty in using stream attributes to detect change caused by management activity. At the root of each of these concerns is the variability associated with the measurement of an attribute and how it affects conclusions relative to that attribute (Roper et al. 2002).

Variability in the measurement of stream attributes can be divided into three sources: environmental heterogeneity, sampling variance, and measurement error. Roper et al. (2002) evaluated how variability in 13 common physical attributes affected their use in monitoring stream conditions where streams were subject to different management treatments. This study found that for 10 of the 13 attributes tested variability among streams accounted for >80% of total variation. Percent stable banks, percent fines, and percent pools had higher total variation and observer variation, resulting in a requirement for greater sample numbers. Roper et al. (2002) suggest three strategies for reducing variation: stratification of streams for sampling (using such factors as geology, catchment size, channel type, disturbance level), measuring attributes at permanent sites, and using analysis of covariance in comparisons of different sites.

Streambed sampling and analysis methods in gravel-bed rivers have received increasing attention over the last few years. While there are many approaches, a comprehensive compilation of these approaches was lacking until a report was published in 2001 – "Sampling surface and subsurface particle-size distributions in wadeable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring" (Bunte and Abt 2001a). This is a comprehensive review and readers wanting more detailed information are referred to it; however it is largely applicable to wadeable streams. While many stream studies tend to resort to so-called "standard methods", (e.g., the 100-particle Wolman (1954) pebble count), these methods are often not applicable to particular purposes. Finally, whatever methods are used, quality results rely on fieldwork being performed or closely guided by experienced personnel – "no guidelines can substitute for operator experience and training" (Bunte and Abt 2001a).

A3 Stream classification systems

A3.1 Introduction

Stream channels integrate watershed processes. Hillslope processes generate and deliver sediment to channels; fluvial processes transport and redistribute sediment through the channel network. Analysis of channel characteristics requires a catchment context because channel response to perturbation reflects this coupling of hillslope and fluvial processes. Montgomery and Buffington (1993) contend that the processes governing landscape form provide the most logical context for organising and classifying both landscapes and channel networks.

Two simple principles govern channel form and dynamics. First, conservation of mass dictates that both the water and sediment supplied to the upstream end of a channel reach must be either stored in the reach or discharged downstream. Second, the morphology and sediment transport dynamics of the channel reflect the style, magnitude, and frequency of both sediment and water input from outside the reach, and the ability of the channel to transmit these loads to downslope reaches. The sediment delivery, water discharge, and slope vary both systematically and locally throughout a drainage network. Consequently, channel morphology, sediment transport dynamics, and response potential reflect both local conditions and the context of the drainage network.

Gravel and cobble-bed rivers such as the Motueka River have a diversity of channel forms. Stream classifications describe the different cross-sectional shapes of the stream and the flood plain, the different morphological parts of a stream, the interactions between flow and sedimentation, and the resulting stream types. Implicit is an understanding that stream morphology, flow hydraulics and sedimentation processes respond to controlling agents such as flow regime, quantity and size of sediment supplied, and channel gradient.

The commonly used classification systems found in the literature all tend to use some form of hierarchical or nested spatial scale approach in which the specific attributes of a stream are assessed or organised in a rational or logical manner from the largest spatial scale down to the smallest (see Fig. 4 for an example).

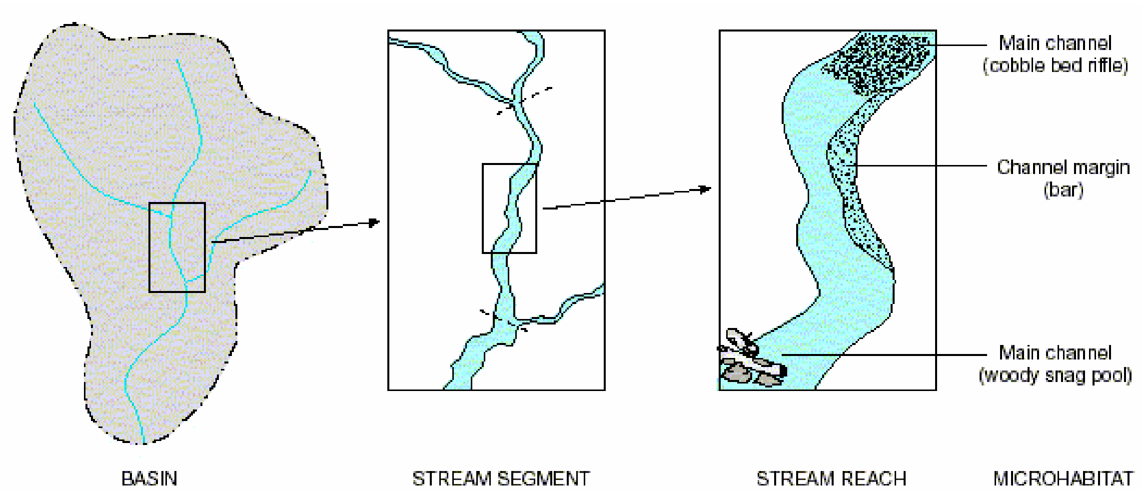

Fig. 4 Spatial hierarchy of basin, stream segment, stream reach, and microhabitat (after Frissell et al. 1986)

The focus of this report is on the stream reach to habitat scales (referred to as microhabitat in Fig. 4), but it should be remembered that consideration of larger scales is important, particularly when dealing with whole catchment studies where there are significant spatial differences in stream morphology in response to variation in controlling factors such as geology and climate. Understanding the larger scale variation is fundamental to selecting representative stream segments and reaches for detailed study.

Within the past couple of decades, the number of systems for habitat assessment and classification has increased substantially, and new ones are continually being published. Each assessment or classification scheme differs in goals, spatial scale, quantitativeness, the effort and time required, and applicability to different-sized streams. Some may be specifically designed to quantify fish habitat in wadeable streams while others are more focused on channel characteristics from a geomorphic perspective.

The main classification systems in common use are outlined below; the first two are currently those most often used in the USA.

A3.2 The Rosgen classification

A reach classification developed by Rosgen (1994) is based on valley and channel morphology and recognises 9 major (Fig. 5) and 42 minor channel types. The 9 major channel types are based on channel pattern (split into single thread and multiple channel patterns)[1], entrenchment ratio[2], width-to-depth ratio[3], sinuosity[4], and slope. :

- *Aa+*: steep, deeply entrenched, step-pool[5] headwater streams with low sinuosity
- *A*: steep, entrenched, cascading step-pool streams with moderate sinuosity
- *B*: moderately entrenched, moderate gradient, riffle-dominant with infrequent pools
- *C*: slightly entrenched, low gradient, meandering, point-bar, riffle-pool steams
- *D*: braided streams with very high width/depth ratio
- *DA*: anastomosing stream channels, wide floodplains and low width/depth ratio
- *E*: slightly entrenched, low gradient, meandering, riffle-pool streams with low width/depth ratio
- *F*: entrenched, low gradient, meandering, riffle-pool streams with high width/depth ratio
- *G*: entrenched, low gradient, meandering, riffle-pool streams with low width/depth ratio

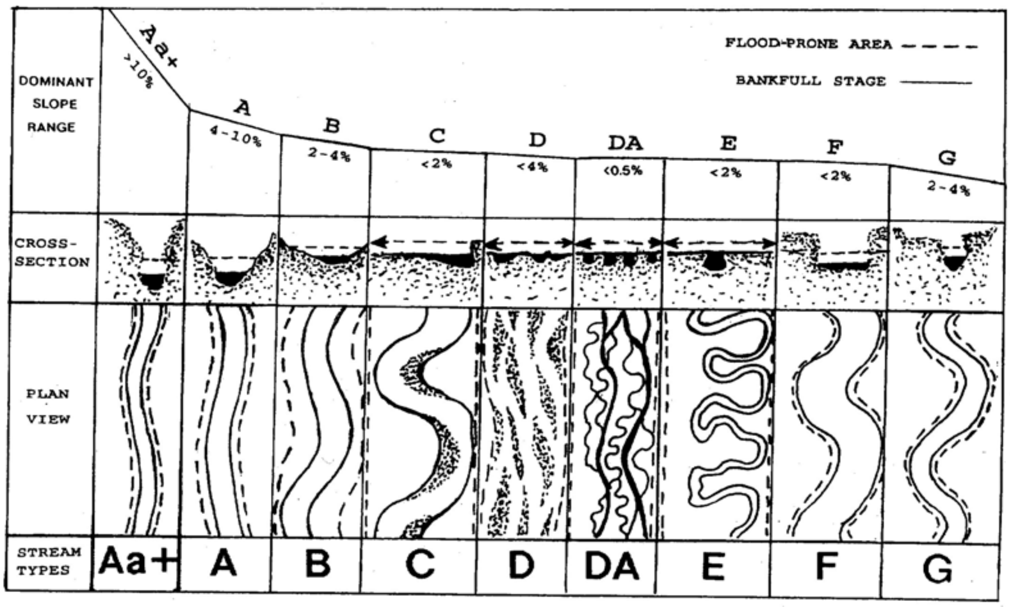

Fig. 5 The 9 major channel types, in longitudinal and plan view, of the Rosgen classification (from Rosgen 1996).

[1] Straight (A stream types), low sinuosity (B stream types), meandering (C, F, G stream types), tortuously meandering (E stream types), complex (multiple channel braided (D) and anastomosed DA stream types)).

[2] Entrenchment ratio - flood-prone width divided by bankfull width. Flood-prone width = water level at twice the maximum bankfull width.

[3] Width to depth ratio - bankfull channel width divided by bankfull mean depth.

[4] Sinuosity - ratio of the channel length between two points on a channel to the straight-line distance between the same two points; a measure of meandering.

[5] Step-pool - streams characterised by sequences of low-gradient pools separated by high-gradient, bouldery steps.

Each type is recognised by quantitative criteria (entrenchment ratio, width-to-depth ratio, sinuosity, and slope) obtained by measurement in the field or from maps and air photos (Fig. 6). The major classes reflect different mixes of habitat types and stream stability (for example Types E and B tend to have stable banks while Types D, F and G tend to have unstable banks). Each of the seven major classes is further subdivided according to bed material type (bedrock, boulders, cobbles, gravel, sand, silt/clay).

The classification is described and illustrated in detail by Rosgen (1996), including applications to fish habitat assessment and river restoration. This stream classification technique can be used to classify the entire stream or a reach, and is geomorphically-based rather than process-based (Montgomery and Buffington 1998). The classification system has two hierarchical levels (the 9 major classes with subdivisions based on substrate) but it can be applied at 4 levels:

- Level 1: broad geomorphic characterisation
- Level II: detailed morphological description incorporating bed materials
- Level III: morphological description incorporating analysis of stream state or condition
- Level IV: validation of stream classification incorporating measurements of streamflow, sediment, bank and bed stability, etc.

This classification has been widely used either in total or in part, at one or more of the four levels (Bain and Stevenson 1999). However, it does not get down to the level of individual habitat types within stream channels, although the 9 major types incorporate different mixes of habitat types.

A3.3 The Montgomery and Buffington classification

Montgomery and Buffington (1993) proposed a geomorphically-based classification based on a hierarchy of spatial scales: geomorphic province, watershed, valley segment, channel reach, and channel unit. This system is relatively widespread and in use by a number of agencies. Each level of the hierarchy provides a framework for comparing channels at increasingly finer spatial scales:

- *geomorphic province*: regions with similar landforms that reflect comparable hydrologic, erosional and tectonic processes.
- *watershed*: whole drainage basins, or the area upstream of any defined point in the channel network.
- *valley segment*: portions of the drainage network with similar valley-scale morphologies and governing processes. These are subdivided, based on valley fill, sediment transport processes, channel transport capacity and sediment supply, into:
    - colluvial valleys (channelled or unchannelled valleys with colluvial valley fill, implying hillslope sediment supply is greater than transport capacity)
    - bedrock valleys (confined valleys without significant valley fill, implying transport capacity is greater than hillslope sediment supply)
    - alluvial valleys (channelled valleys with alluvial valley fill)
- *channel reach*: portions of the channel network with similar sequences of bedforms (or channel units). These are characterised as
    - colluvial reaches (headwater channels with ephemeral streams that also carry debris flows)
    - bedrock reaches (with little colluvial or alluvial valley fill)
    - free-formed alluvial reaches, subdivided into
        - cascade reaches (on steep slopes with longitudinally and laterally disorganised bed material, typically cobble and boulders confined by valley walls; flow follows a tortuous convergent and divergent path around individual large clasts)
        - step-pool reaches (large clasts organised into discrete channel spanning accumulations that form a series of steps separating pools containing finer bed material; alternating turbulent flow over the steps and tranquil flow in the pools)

        - plane-bed reaches (relatively featureless gravel/cobble bed streams lacking pools but may contain runs and a variety of riffles)
        - pool-riffle reaches (laterally oscillating sequence of bars, pools and riffles that causes flow convergence and scour on alternating banks of the channel)
        - dune-ripple reaches (unconfined, low gradient sand-bedded channels with mobile bedforms that change their character (plane-bed, ripples, sand waves, dunes, anti-dunes) as flow depth and velocity increase)

        These classes reflect decreasing stream gradient (Fig. 7).
    - forced alluvial reaches, subdivided into
        - step-pool reaches
        - pool-riffle reaches

(Forced alluvial reaches occur where obstructions, such as bedrock or large woody debris, affect the channel)

channel units: morphologically distinct bedforms within a channel reach. Distinctions between units are based on topography, grain size, flow depth and velocity. This includes pools, bars and shallows (riffles, rapids, cascades). These units have specific habitat characteristics, although they may vary with discharge. These units are often referred to as “geomorphic channel units” or GCU’s and are discussed in detail in the next section.

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Both the Rosgen and Montgomery-Buffington classification systems are morphometric and geomorphically based, and there are many points of commonality (for example, the three alluvial reach types step-pool, plane-bed, and pool-riffle in Montgomery-Buffington correspond to stream types A, B, and C in the Rosgen classification) – see Fig. 7. However, there are a number of significant differences. The Montgomery-Buffington classification is not based on quantitative measurements of stream characteristics like the Rosgen classification. It introduces bed material type at a high level in the hierarchy (valley segment level) compared to the Rosgen classification, and uses a colluvial/alluvial distinction rather than the bed material size distinction used by Rosgen. Rosgen uses a non-intuitive alphanumeric code while Montgomery-Buffington uses commonly known fluvial terminology.

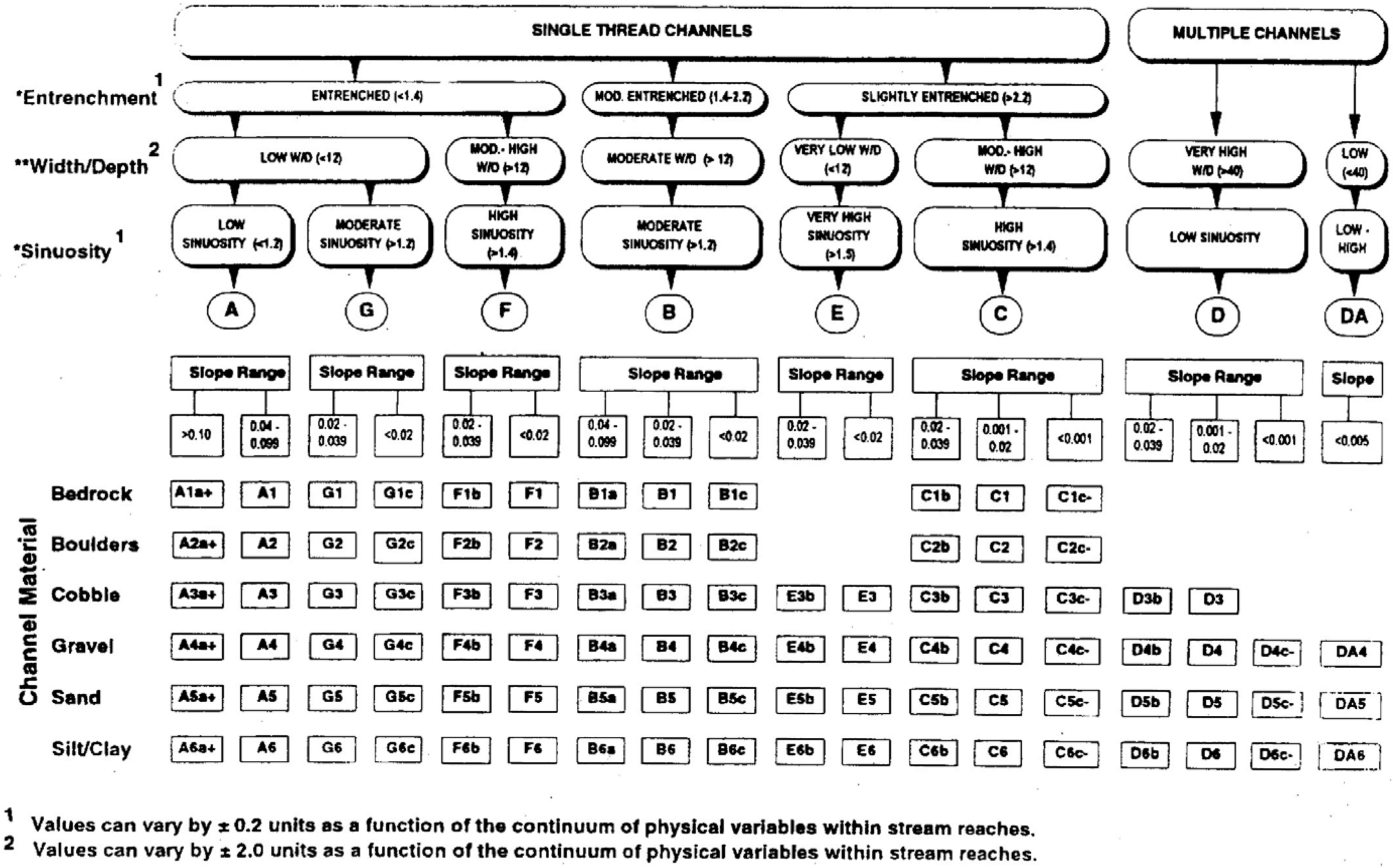


Fig. 6 Key for the classification of rivers using the Rosgen classification (from Rosgen 1996)

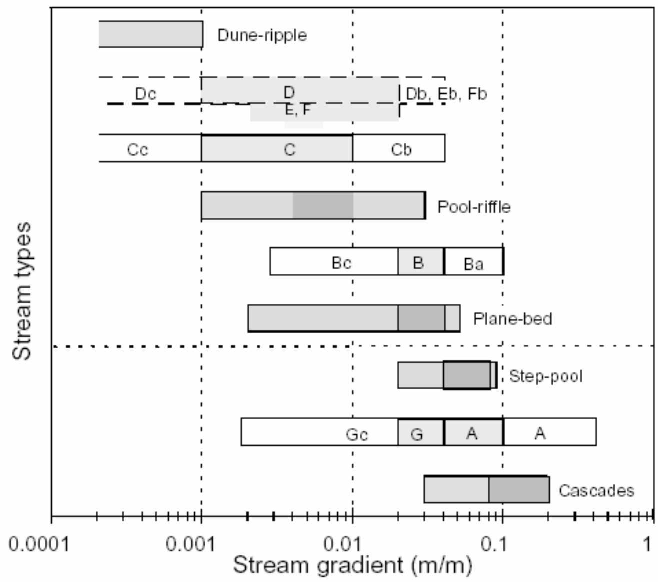


Fig. 7 Comparison of stream gradients in the Montgomery-Buffington (1993,1998), and the Rosgen (1994, 1996) classification. The Montgomery-Buffington stream types are pool-riffle, plane-bed, step-pool, and cascades. The light shading indicates the range of observed stream gradients, the dark shading indicates the mode. The letters refer to the Rosgen classification. Light shading indicates the main stream type, whereas subtypes with steeper or gentler stream gradients have no shading. Open-ended boxes indicate stream gradients given in terms of "larger than", or "smaller than" (from Bunte and Abt 2001a).

A3.4 The NAWQA habitat classification

The US Geological Survey's National Water-Quality Assessment Programme (NAWQA), while specifically designed to assess the status and trends in the US' water quality, has as one of its core activities, the characterisation of stream habitat. It has developed a protocol to deal with all aspects of habitat assessment (Fitzpatrick et al. 1998) and offers an alternative to a geomorphic-based approach while endeavouring to include those aspects of a geomorphic-based approach that are relevant to water quality assessment and site description.

NAWQA uses a modification of the spatially hierarchical approach proposed by Frissell et al. (1986) for describing environmental settings and evaluating stream habitat that included five spatial systems—stream, segment, reach, pool/riffle, and microhabitat. The modified approach used in the NAWQA Program consists of a framework that integrates habitat data at four spatial scales (Fig. 4):

- basin: whole drainage basin attributes.
- segment: length of stream that is relatively homogeneous in physical, chemical and biological properties.
- reach: defined by stream width, depth (wadeable or non-wadeable), geomorphology (type and distribution of geomorphic channel units, namely pools, riffles and runs) and local habitat disturbance.
- microhabitat: the individual geomorphic channel units.

This approach differs from the scheme proposed by Frissell et al. (1986) in that (1) the term "system" is not used, (2) basin is used to refer to stream system, and (3) the pool/riffle system is omitted as a separate scale to be evaluated because measurements are incorporated into the reach scale. The microhabitat scale has been found to provide insight to patterns of relations between biota and habitat at larger scales (Biggs et al. 1990).

Basin and segment data are collected using GIS, topographic maps, or aerial photographs, whereas reach data require site visits. The collection of a core part of the reach-scale data is based on the systematic placement of equally spaced transects with the distance between these transects depending upon stream width. This approach was adopted to maximize repeatability and precision of measurements while minimizing observer bias; it is based in part on results from a study of optimal transect spacing and sample size for fish habitat (Simonson et al., 1994). Sampling sites are chosen to be representative of a set of environmental conditions, and both basic fixed sites and synoptic sites are used. The basic fixed sites are permanently marked, measurements are repeated at different times and are comprehensive. At the synoptic sites one-off measurements of key parameters are made to answer specific questions.

The NAWQA protocol balances qualitative and quantitative measures of habitat. Qualitative measures of habitat are often advantageous because they reduce the amount of time needed to collect data at a site. However, qualitative measures often incorporate observer bias; thus, they may lack repeatability (Roper and Scarnecchia, 1995). Although quantitative measures may be more precise, they increase the amount of time needed to collect data. The NAWQA system does not include a strict hierarchical classification system but the habitat measurements made include many of the attributes used in the Rosgen and Montgomery-Buffington classifications (e.g., slope, sinuosity, dominant substrate).

A3.5 The River Styles framework

River Styles is an approach developed in Australia to provide a geomorphic template for river management (Brierly et al. 2002). It links river character with river behaviour and has been used as a basis for river management and restoration, mainly in New South Wales. A River Style is defined as “a river reach with a near-uniform assemblage of geomorphic units” (Brierly and Fryirs 2000). Its key features are that it is:

- open-ended and generic,
- process-based,
- catchment-based,
- hierarchically structured,
- set within the context of river evolution,
- directly linked to assessment of future behaviour.

At the highest level rivers are classified into 3 classes in terms of their valley setting (similar to Montgomery and Buffington), and then different criteria (such as floodplain extent and continuity, channel continuity and character, bed material texture) are used to further subdivide each of the major valley settings and define geomorphic units (Fig. 8). Application of this classification to coastal catchments in New South Wales is shown in Fig. 9. The classification framework has also been used for habitat assessment by assessing flow hydraulics and substrate character within geomorphic units, including measurements of velocity and roughness characteristics (Thomson et al. 2000).

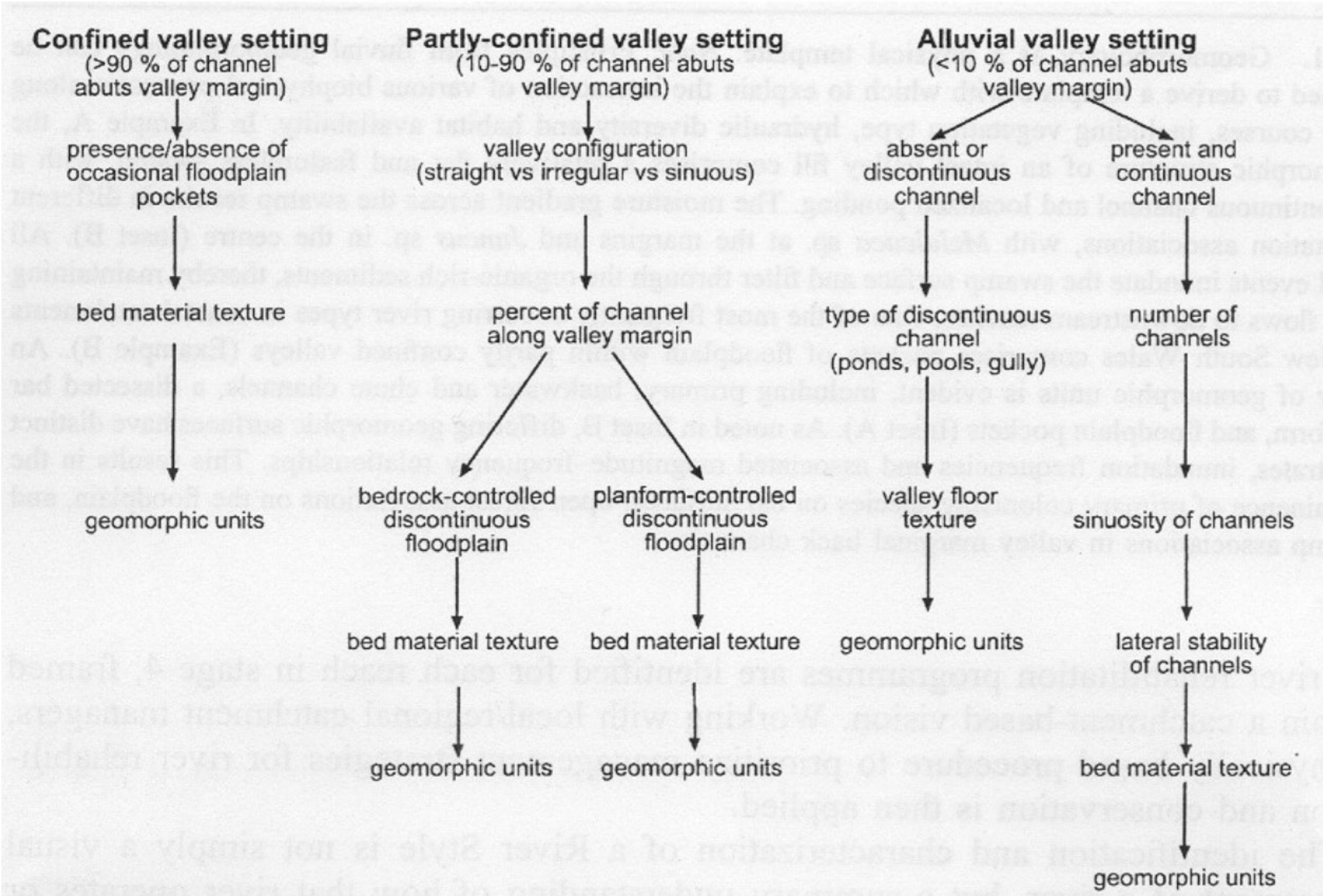


Fig. 8 Hierarchy of criteria used to identify River Styles (Brierly et al. 2002)

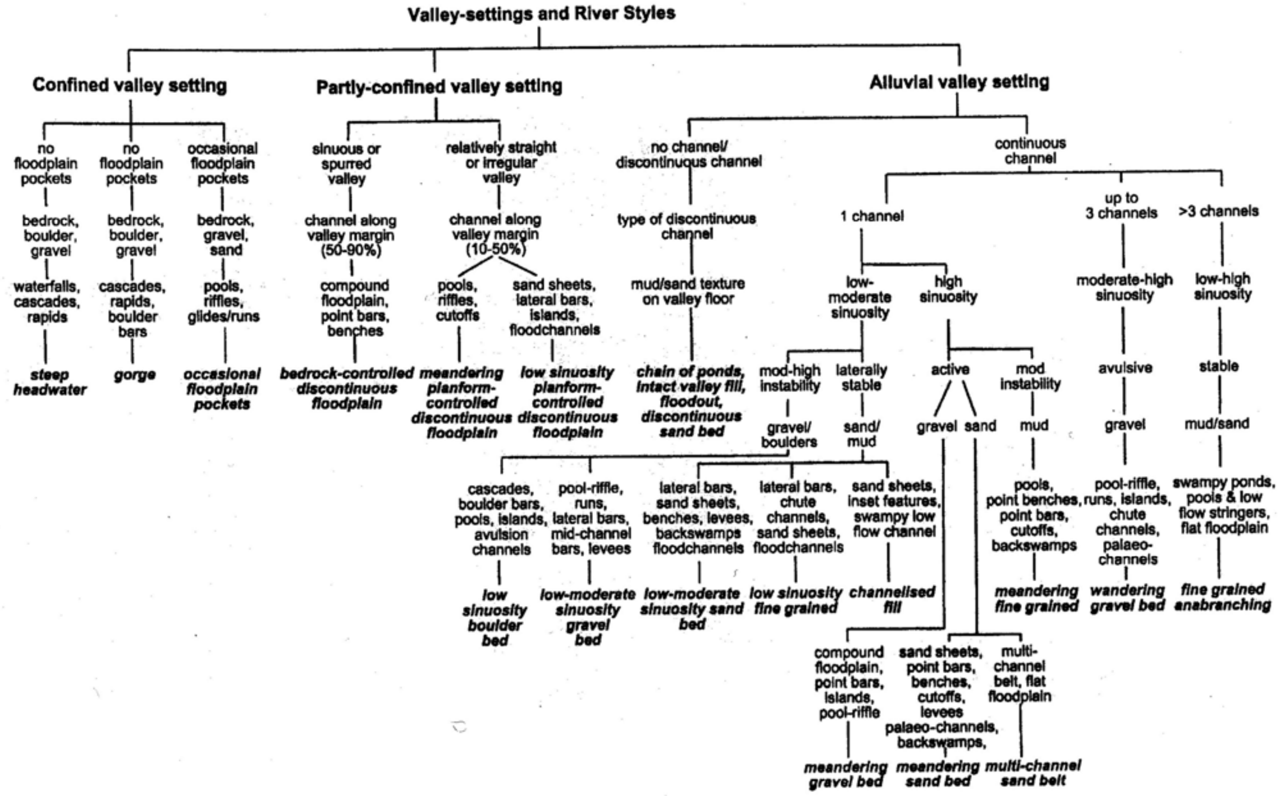


Fig. 9 Application of River Styles classification to coastal catchments in New South Wales (Brierly et al. 2002)

A3.6 River environment classification

River Environment Classification (REC) is a 'controlling factor' approach, developed by NIWA, that classifies and maps New Zealand's river environments at a range of spatial scales (Snelder et al. 2000). The Ministry for the Environment has supported the development of the REC as a tool for environmental management purposes and it has application to inventories of river resources, a spatial framework for effects assessment, policy development, developing monitoring programs and interpretation of monitoring data and state of environment reporting.

REC characterises river environments at six levels, the names of which reflect the controlling factors at that level and scale of enquiry:

- climate: distinguishes broad patterns in flow per unit area, seasonal behaviour of flow and water temperature, and broad differences in flood frequency. The classes are: warm extremely wet, warm wet, warm dry, cool extremely wet, cool wet, and cool dry.
- source of flow: subdivides the climate class on the basis of catchment dominant topography which affects flow regime and sediment supply. The classes are: mountain, hill, low elevation, and lake.
- geology: distinguishes different geological groupings that affect water chemistry, flow patterns and yield, and sediment supply. The classes are: alluvium, hard sedimentary, soft sedimentary, basic volcanic, acidic volcanic, and plutonic.

- land cover: distinguishes vegetation that affects flow variability (particularly low flow), sediment supply, water chemistry and channel sediments. The classes are: bare, indigenous forest, pasture, tussock, scrub, exotic forest, wetland, and urban.
- network position: the classes are low order, middle order, and high order.
- valley landform: the classes are high gradient, medium gradient, and low gradient.

This approach provides a broad overview of similarities and differences in river types and is more appropriate at the segment scale and larger. It is not designed to be used at habitat scale.

Subsequently the 'River Ecosystem Management Framework' has been developed for application to river management at more detailed scales (Snelder and Guest 2000). It uses a very similar hierarchical controlling factor approach, with the following modifications:

- climatic zones are redefined as geographical zones (northern North Island, western North Island, eastern North Island, northern South Island, western South Island, eastern South Island).
- additional 'source of flow' classes are introduced (glacial mountain, spring, wetland, regulated).
- geology classes are expanded to 13 classes.
- land cover classes are expanded to include all classes of the Land Cover Database.
- elevation (4 classes) and size (based on 7 classes of median flow range) are introduced as separate controlling factors, and network position and valley landform are not used.
- channel morphology is introduced as the lowest level in the hierarchy using the classes cascade, step-pool, plane cobble/gravel bed, riffle-pool, semi-braided gravel bed river, braided gravel bed river, entrenched, freely meandering, tidal, channelised.

This classification system is designed to be used at all scales

- at regional scale climate is the single controlling factor.
- at catchment scale source of flow, geology and land cover are used as controlling factors.
- at valley segment scale elevation size and channel morphology are used
- at reach scale additional factors are introduced as descriptors (water temperature, depth, velocity, riparian vegetation and cover).

A4 Channel reach classification and assessment

A segment (valley or stream) is the fundamental unit that represents a uniform set of physical, chemical, and biological conditions within a stream. However, its length is often more than several kilometres thus prohibiting effective collection of field data to characterise the whole segment. The reach is used as the principal sampling unit for collecting physical, chemical, and biological data to represent conditions within the segment. A reach is a length of channel that exhibits a consistent association of geomorphic channel units and is many channel widths long. Because there is a strong association between physical characteristics and biological habitat, the reach provides the basic sampling unit for habitat characterisation. Although the limits of individual reaches may be difficult to define, since river characteristics generally form a continuum, it is the most useful scale for determining the population dynamics and distribution of aquatic communities and for describing long-term effects of human activities on rivers and streams (Frissell et al., 1986). Generally, maps and aerial photographs can be used to identify segment and reach boundaries by estimating stream gradient, degree of valley confinement, channel meander patterns, and significant changes in the predominant rock type.

Much of the following is taken from the methods used in the USGS NAQWA program for characterising stream habitat (Fitzpatrick et al. 1998).

A4.1 Selection of a Reach

The selection of a reach depends on a combination of four criteria:

- stream width,
- stream depth (wadeable or non-wadeable),
- geomorphology (type and distribution of geomorphic channel units defined by bed form, water velocity, the presence of flow control features, and other physical attributes),
- local habitat disturbance.

In general, the reach length is determined by the spatial variability of stream morphology with the composition of GCU's in the reach reflecting the sequence of GCU's in the segment. Essentially two different approaches to determining reach length have been used:

- based on the recurring pattern of GCU's within the stream segment. Because some stream types have more complexity than others this requirement will dictate very different reach lengths (e.g., C-type streams have riffle-pool morphology and the reach length is determined by the spatial variability of this pattern; B-type streams have fairly featureless plane-bed morphology and the sampling length may be much shorter). Fitzpatrick et al. (1998) suggest the reach should include at least two examples of each GCU, with the proviso that only GCU's that exceed 50% of the channel width are considered. Rosgen (1996) suggests up to 4 examples of each GCU be included in the reach length. As a minimum at least one example of each GCU must be included in the reach length.
- based on a multiple of the channel width. Fitzpatrick et al. (1998) suggest the reach length be determined by multiplying the mean wetted channel width (MCW) by 20. The width is multiplied by 20 because, in meandering streams, 20 times the channel width typically encompasses at least one complete meander wavelength (Leopold et al., 1964) and ensures that all habitat types are represented within the reach. Rosgen (1996) proposes the reach length be 20-30 times bankfull channel width.

A minimum reach length is necessary to ensure the collection of representative samples of biological communities and for habitat characterisation, and a maximum reach length is needed to prevent unnecessary sampling. Meador et al. (1993) suggest minimum and maximum reach lengths for wadeable streams of 150 and 300 m (or 500 m for streams >30 m wide), respectively, and for non-wadeable streams recommended minimum and maximum reach lengths are 500 and 1,000 m. In practice most investigators ensure that both criteria are met (both the GCU pattern criteria and the width:length criteria).

If the representative reach selected must be located near a bridge or other man-made alteration, it should be located upstream from the structure in order to minimize its influence on habitat. When compelling reasons dictate that the reach must be downstream from a bridge or other feature, then the reach must be established far enough downstream from the bridge to avoid local hydraulic effects, such as scour holes and over-widened channels.

A4.2 Reach classification

The type and distribution of GCU's (also often called habitat types by biologists, or macrohabitat by Bain and Stevenson 1999) are the primary factors used to select a reach for detailed measurement and characterisation. The development of specific sequences of GCU's is a fundamental stream process (Ying 1971, Beschta and Platts 1986), and identification of GCU's is important because it classifies stream habitat at a spatial scale relevant to most biota in streams (Frissell et al. 1986). Three types of GCU's are considered when selecting a reach—pools, riffles, and runs (Fig. 10). From an in-stream perspective in large, non-wadeable rivers, inside meander bends (convex side of a meander bend), outside meander bends (concave side of a meander bend), crossovers (areas carrying the greatest water volume between two river bends), and possibly forewater and backwater side habitats may be as important as pools, riffles, and runs as geomorphic units.

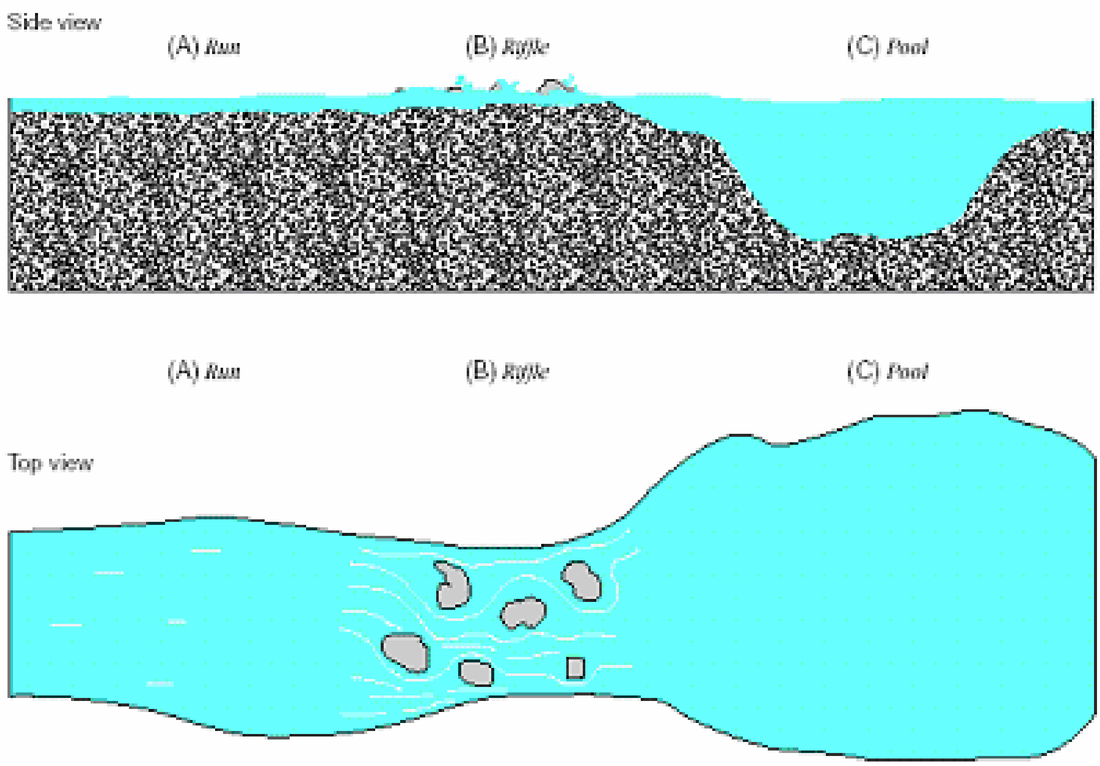


Fig. 10 Diagram of the three main geomorphic channel units (after Bisson et al. 1982)

The key features, and subdivisions, of each of the 3 key GCU's are listed below:

- *Pools* are areas of the channel with deeper water, lower velocity and finer bed material than surrounding areas, with little surface turbulence (Fig. 10 and 11). Pools can form downstream from depositional bars, in backwater areas around boulders or woody debris, or in trenches or chutes. Eddies may be present. Pools can also form behind channel blockages, such as log-jams, where water is impounded. Because a pool can form from a variety of hydraulic processes, there are many different types of pools (Bisson et al., 1982; McCain et al., 1990). Plunge pools form at the base of a nickpoint or channel obstruction that creates a hydraulic drop. Lateral scour pools form beside a bank or against a partial channel obstruction.
- *Riffles* are relatively shallow areas of the channel where water flows swiftly over completely or partially submerged obstructions to produce a turbulent, broken water surface (Fig. 10 and 12). Usually, riffles have relatively coarser substrates than pools and runs and occur in straight lengths of the stream. At higher water during floods, a riffle can look like a run. Riffles can be subdivided into low-gradient riffles, rapids, and cascades (Bisson et al., 1982). Low-gradient riffles have a gradient less than 0.04 m/m, are shallow with moderate velocities, moderate turbulence, and gravel to cobble substrates. Rapids have gradients greater than 0.04 m/m with fast velocity, significant turbulence, and typically boulder substrate. Cascades have very steep gradients and are distinguished from rapids by having alternating small waterfalls and shallow pools, usually with bedrock or boulder substrate. Riffles represent concentrations of larger residual particles in stream channels (Church and Jones 1982) and therefore offer the greatest contrast between residual particles and those that are mobile. Kappesser (2002) suggests riffles offer logical sites to determine changes in channel substrate composition in small to medium, wadeable mountain

streams. However, they are not suitable in large, lowland rivers where fine material is unlikely to be deposited in riffles.

- *Runs* are intermediate areas between pools and riffles with moderate water depth, little or no surface turbulence (i.e., the water surface is not broken) and a flat or undulating water surface (Fig. 10, 11 and 13). Velocities can be high or low, but the key feature is little apparent surface turbulence. The term "glide" also has been applied to runs (Bisson et al. 1982). Runs typically are found in the transition zone between riffles and pools and in low-gradient reaches with no flow obstructions. Typical substrate in runs ranges from cobble to sand. Runs may become riffles during low-flows or droughts. In large, lowland rivers this is where fine material is likely to be deposited.

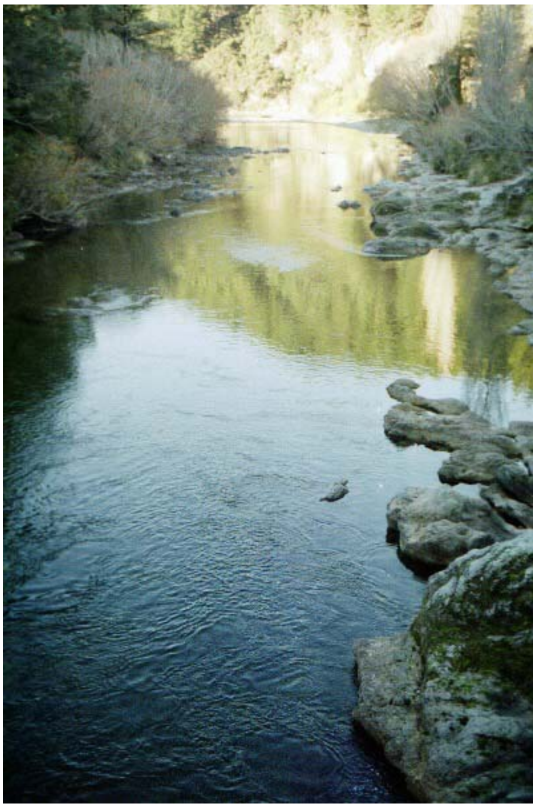


Fig. 11 Motueka River showing a run in the foreground with a pool downstream.

Fig. 12 Motueka River showing a reach dominated by riffles.

Fig. 13 Motueka River showing a run in foreground with a riffle downstream.

Further subdivisions or classes of these 3 main GCU's have been made by some authors. Bain and Stevenson (1999) outline 3 hierarchical systems that have been used to classify GCU's, which each distinguish and organise habitat classes differently and use slightly different terminology (Hawkins et al. 1993, Flosi and Reynolds 1994, Armantrout 1996). They are all hierarchical and each have 3 or 4 hierarchical levels. They do have a common approach of distinguishing fast water from slow water (pools) at the highest level of the hierarchy, and then turbulent water (equivalent to riffles) is distinguished from non-turbulent water (equivalent to runs) – see Figs. 14 and 15). This level of detail is not required for this investigation of the Motueka River.

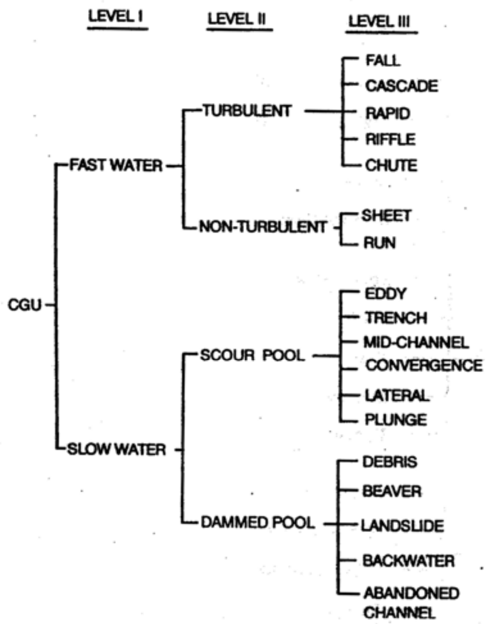


Fig. 14 The Hawkins habitat classification system (Hawkins et al. 1993)

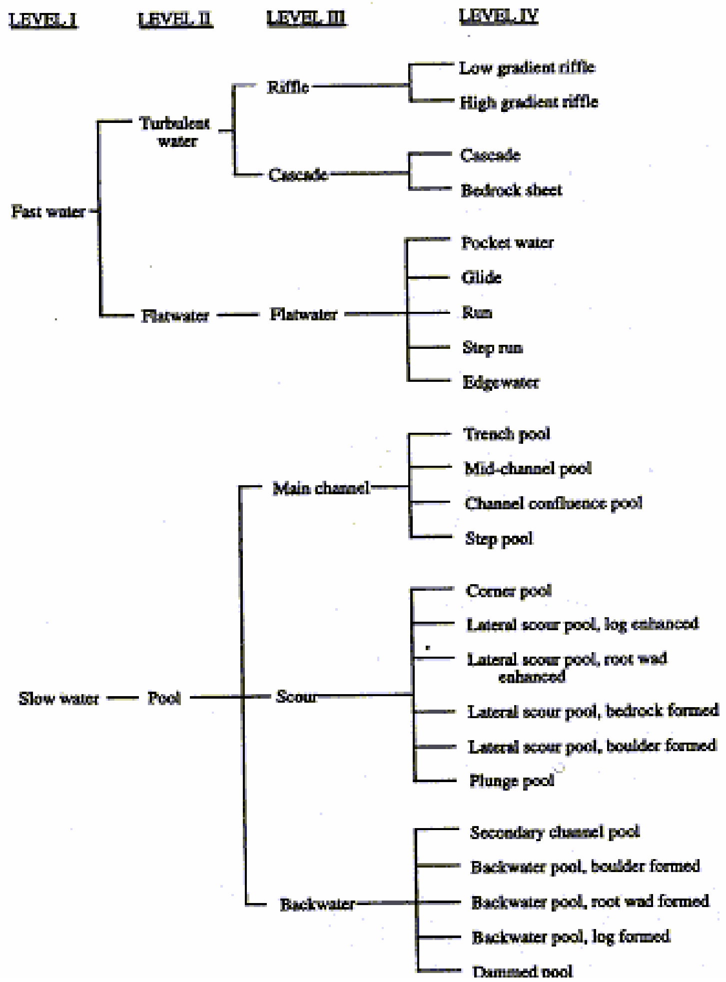


Fig. 15 The Flosi and Reynolds (1994) habitat classification system

Identification of pools, runs, and riffles has long been regarded as a problem, both because the criteria for distinguishing them have never been clearly defined, and because their character may change with flow (e.g., Jowett 1993). Many researchers have simply identified these features without stating the criteria by which they were identified. Criteria of bed morphology (e.g., bed material size, bed topography) or hydraulics (e.g., water surface slope, ranges of water depth and velocity, Froude number[6], water surface characteristics) have both been used. Visual assessments of habitat type and physical measurements at 1112 sample points on one gravel-bed river in New Zealand were used by Jowett (1993) to develop an objective method for distinguishing pool, run, and riffle habitats. Velocity/depth ratio, Froude number, and slope were the best determinants of habitat type with velocity/depth ratio and Froude number showing the most significant differences between habitat types:

- pool habitats had velocity/depth ratios of less than 1.24, Froude numbers less than 0.18
- riffles had velocity/depth ratios of more than 3.20 and Froude numbers in excess of 0.41, and
- run habitats had intermediate values.

Riffle habitats were characterised by slopes greater than 0.0099 and run and pool habitats by lesser slopes. Jowett (1993) notes that the value of the numbers may vary with stream or river, but the distinguishing criteria are likely to apply on all rivers.

Bain and Stevenson (1999) suggest two quantitative techniques for identifying GCU's:

- the 'channel feature and dimension' technique using measurements of wetted width, slope, depth, velocity, turbulence, and dominant substrate to identify areas which have clearly different physical characteristics
- the 'bed form differencing' technique using detailed survey of the stream bed, and a user-specified criterion of elevation change between bed forms, to identify pools and riffles.

Both the Jowett (1993) and Bain and Stevenson (1999) approaches require detailed field measurements at the reach scale, rather than a simple visual assessment. Again this level of detail is not required for investigation of the main stem of the Motueka River, which has a relatively simple pattern of GCU's, but could be useful in a wider survey of all channel types within the Motueka.

Habitat unit classification, based on identification of GCU's, has been suggested (e.g., Hawkins et al. 1993, USDA Forest Service 1996) as a technique for monitoring the response of streams to disturbance, using such measures as the pool/riffle ratio or percent pools. However a critical evaluation by Poole et al. (1997) suggests the following problems with this approach

- because identification of GCU's is subjective, observer bias seriously compromises repeatability and precision
- important changes are not always reflected in changes in habitat unit frequency or characteristics
- classification data are nominal which limits statistical analysis

Poole et al. (1997) recommend monitoring focus on direct, repeatable, cost-efficient and quantitative measures of selected physical components to complement monitoring of biological components of stream ecosystems.

A4.3 Reach characterisation

An assessment of channel dimensions and characteristics provides the finest level of resolution at which a stream reach can be related to the whole stream segment and to the entire watershed. Data from channel assessments are typically compiled to develop a detailed description of habitat unit dimensions, channel form and plan, discharge, substrate, bank condition, and riparian vegetation - see Fitzpatrick et al. 1998 for a detailed description of the methods used to characterise steam habitat in the NAWQA program. Typically methods incorporate cross-sectional and longitudinal profile surveys as a basis for this level of

[6] Ratio of the inertia force to the gravity force, a value <1 indicates tranquil flow, a value >1 indicates turbulent flow. Calculated as $Fr = V_m/\sqrt{(gY)}$, where V_m is mean water velocity, g = acceleration due to gravity, Y = depth of flow.

assessment. The objective of a stream reach survey is to deduce the representation of the stream as accurately as possible, without actually sampling it in its entirety. Therefore, it is critical that sites are selected that are representative of the stream segment.

The reach surveys should be conducted at typical low flow conditions when habitat features are most evident. The NAWQA program recommends that at a minimum the following measurements are included at the reach scale: segment characteristics such as boundary locations, length, elevation, sinuosity, and gradient; discharge; water surface gradient; wetted channel width and bankfull channel width; water depth and velocity; reach length; channel modifications; geomorphic channel units including a map of the type, distribution, and length of each GCU and other important features (see Fig. 16).

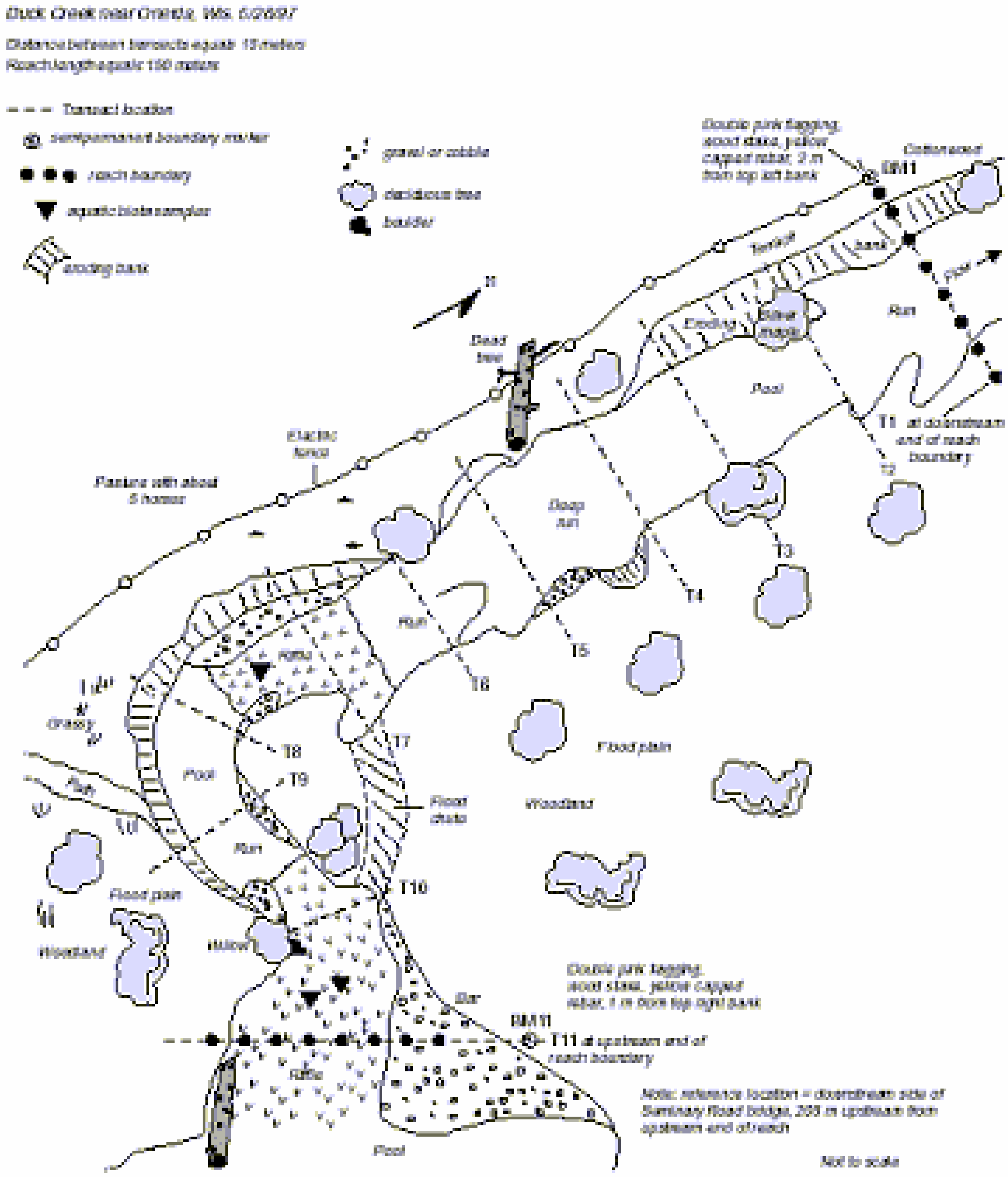


Fig. 16 Example of a diagrammatic stream map showing transect locations, reach boundaries and other important stream characteristics

Quantitative sampling within a reach is normally done along transects. NAWQA recommend 11 equidistant transects along a reach, perpendicular to streamflow direction, to collect data on channel, bank, and riparian characteristics, with the proviso that if this sampling strategy misses important GCU's then information on these may be recorded separately. Information collected along transects by NAQWA includes:

- GCU (habitat type)
- wetted channel width
- bankfull channel width
- depth and velocity of the water
- channel features (e.g., bars, shelves, islands)
- riparian vegetation characteristics and land use
- bank characteristics (height, angle, substrate, vegetation cover, erosion)
- bed substrate and embeddedness. These measures are discussed in detail in the next section.

A sampling scheme must be developed that is appropriate to the objectives of the study, and must address the following issues (Bunte and Abt 2001a): spatial scale, spatial homogeneity or heterogeneity, desired sampling precision or tolerable error, and practical constraints to sampling. The 3 main types of sampling schemes are

- unstratified sampling (same sampling pattern for the whole reach, ignoring GCU's)
- stratified sampling (a different sampling pattern for each GCU)
- spatially focused sampling (focused on GCU's of specific interest, and ignoring others)

Detailed discussion of sampling strategies (including methods for determining the number of sampling points, minimum sampling point spacing, minimum sampling area, selection of particles, measurement of particle sizes, sampling bias) is included in Bain and Stevenson (1999) and Bunte and Abt (2001a).

A5 Substrate

Substrate refers to the bed material of a water body (including the floodplain), and it is almost always documented in habitat surveys. There are three reasons for measuring substrate:

- the composition of the substrate determines the roughness of stream channels, and roughness has a large influence on channel hydraulics (water depth, width and velocity) and hence stream habitat.
- substrate provides the micro-habitat conditions needed by many fish and invertebrate species (including cover and spawning habitat).
- substrate provides indications to local and watershed influences on stream habitat quality. Catchment disturbance often alters runoff and sedimentation rates, and these processes are often reflected in the size composition of the substrate

The goal of substrate characterisation may to describe the dominant type(s) of bed material, the variability in the mixture of material that makes up the substrate, and/or to provide data for measuring change in substrate composition. In many biological studies the assessment is done visually rather than by detailed measurement e.g., IFIM[7] surveys (Bovee 1986, Jowett 1996) and the United States Environmental Protection Agency Environmental Monitoring and Assessment Program procedures described by Kaufmann and Robison (1998). However it can be difficult to accurately and consistently describe substrate composition using visual assessment techniques (Kondolf 2000, Hudson et al. 2003).

Methods for sampling substrate can be divided into (Kondolf et al. 2003):

[7] IFIM – instream flow incremental methodology. A method for evaluating incremental differences in instream habitat as flow changes

- surface sampling including facies mapping, visual estimates, pebble counts and photographic methods. This approach samples a pre-selected number of surface particles from a pre-defined sampling area.
- subsurface sampling including shovel sampling, core sampling, and freeze-core sampling. This approach samples a pre-selected sediment volume from a pre-defined sedimentary layer (depth).

The two different approaches give different types of data. The study objective determines whether to sample the surface sediment or a particular sedimentary layer, although other factors may impose practical constraints (e.g., the ability to wade the stream or river, accessibility of the site, the nature of the bed material).

Surface sediment can only be sampled using surface sampling techniques. Bed-material layers (Fig. 17), such as the armour, subarmour, and subsurface layer, which may be infilled and censored, have a specific thickness, and can therefore only be sampled by taking a subsurface (volumetric) sample. The latter require a sample to be removed from the bed and may be taken using a variety of samplers, including shovels, mesh bag scoops, grab samplers, pipe samplers, and barrel samplers, or by taking freeze-cores or resin cores). The Quorer (Quinn et al. 1997), was developed by NIWA to characterise the amount of fine sediment on New Zealand stream beds. However, its use is constrained by depth (<30 cm), velocity (<0.5 m/s), and it does not work in streambeds dominated by boulders or bedrock. This technique would not be suitable for the main stem of the Motueka but might be useful in smaller streams, such as spawning streams.

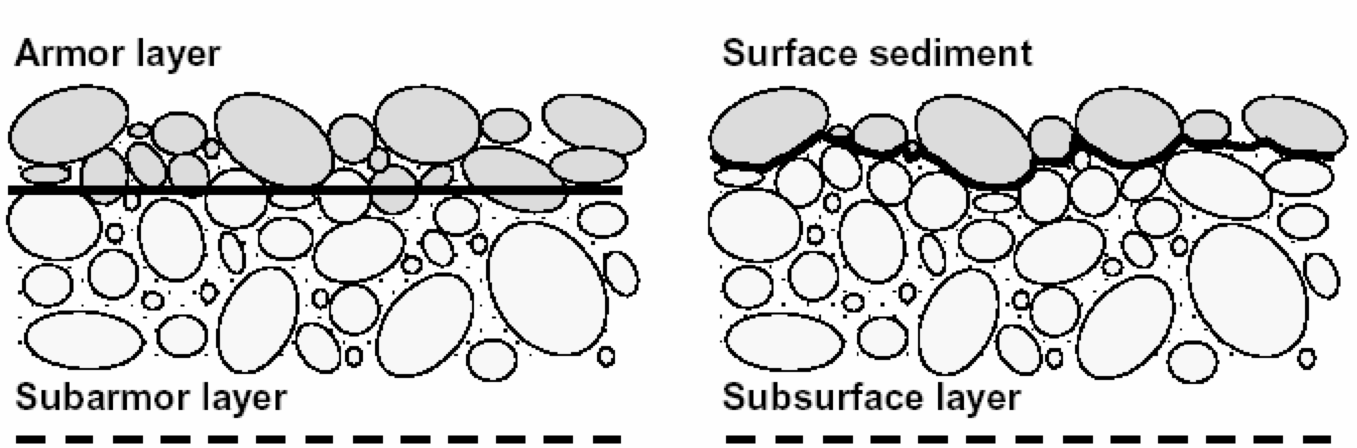


Fig. 17 Stratigraphy of an armoured bed distinguishing between armour layer, subarmour layer, surface sediment, and subsurface layer (after Bunte and Abt 2001a).

Surface sampling is generally more common and is probably the only practical technique for the main stem of the Motueka River where the water is quite deep and fast flowing, and it is suitable for determining the amount of fine sediment on the river bed.

A5.1 Techniques for quantifying surface composition

Surface sampling collects bed-surface particles that are exposed on top of the streambed whether the bed is dry or submerged. The vertical extent of the surface sediment is equal to the diameter of one particle, i.e., the particle that is exposed on the surface at any given point (Fig. 17). Although most surface particles are easy to identify, problems arise when small particles are surrounded by large particles, and when particles are partially exposed only, or partially hidden under neighbouring particles (e.g., when the surface is imbricated or clustered). At some point the question arises as to how much of a particle needs to be actually visible at the surface to qualify as a surface particle.

Facies mapping and visual estimates are the simplest means of describing surface composition (Kondolf et al. 2003). Facies mapping identifies distinct variations in grain size and/or sedimentary structure, representing local depositional environments. It captures reach-wide variation in particle size and avoids small-scale variability. Visual estimates (generally along transects or at many points in a reach) can also be used to estimate the dominant particle size or percentages in different broad size classes. Both these approaches are limited in their accuracy and reproducibility, are not well suited for statistical analysis, but are commonly used because they are rapid.

Bain and Stevenson (1999) distinguish three quantitative approaches to surface sediment characterisation:

- assessment of dominant composition: observations of the dominant size class at each sampling point are used to give the overall frequency of size classes and the variability of composition.
- assessment of size-frequency distribution: measurements of individual particles are used to assess the overall frequency of size classes and the variability of composition.
- assessment of structure: the degree to which larger particles are surrounded by smaller particles is usually assessed as embeddedness.

In all these sampling methods substrate composition may be determined either from measurements of size of individual clasts (mm scale) or by the frequency of size classes of particles (boulders, cobbles, pebbles, gravel, sand, silt, clay). The size of a particle can be determined in three different categories: the actual (intermediate) b-axis length (mm scale), the particle-size diameter class (intermediate axis recorded usually using the Wentworth scale in 0.5Ø classes), and the nominal diameter (used to assess the diameter of an equivalent sphere where mass of the particle is important). The three approaches are used for different purposes with the first two suitable for determining habitat characteristics. During field studies, gravel particle sizes are best determined with templates, calipers or rulers. Templates are commonly used because they provide higher accuracy than measurements with rulers, and using templates reduces variability between different operators. A template, also called a gravelometer, is a thin aluminum or plastic plate with several sieve-sized square-holes. The holes usually correspond to the sizes of standard 0.5Ø -increment sieve sets, ranging from 2 mm (-2 Ø), and to 362 mm (-8.5 Ø). The operator picks up a particle and pushes the particle through various holes. The aim is to determine a particle's sieve diameter either in terms of "not passing or larger than" the hole of a given size (equivalent to the sieve size on which a particle would be retained), or in terms of "passing or smaller than" the hole of a given size (equivalent to the sieve size that the particle would pass). Any particle smaller than 2 mm on the intermediate axis is recorded as < 2 mm.

For assessment of composition, observations of dominant size class at each sampling point are used to assess the overall frequency of size classes and the variability of composition (Bain and Stevenson 1999). This technique uses a lead core rope or chain (1-m or 2-m long) with 10 cm sections painted in contrasting colours. For each location on the bottom of the stream, dominant substrate class in contact with each coloured section of rope is recorded. Dominant substrate size class is usually recorded (boulder, cobble ,pebble, gravel, sand, silt and clay), although where this may undersample the fine component the proportion of different size classes can be recorded (R.Young, pers. comm. 2004). This procedure is repeated at predetermined intervals across the study site. The mean of all substrate observations is calculated to estimate the average dominant substrate size, the dominant substrate for the entire site, and the standard deviation. This technique is simple, straightforward and rapid to conduct.

The frequency distribution of the size of surface sediment can be obtained by three methods (Bunte and Abt 2001a):

- pebble counts: (line counts) a preset number of surface particles are selected and hand-picked at even-spaced increments along straight or zig-zag transects that may be parallel and span a relatively large sampling area (≈ 100 m2). Sampling techniques in use include heel-to-toe walks, and systematic sampling along even-spaced marks along a measuring tape. The main differences between these two methods are summarized in Table 1. This technique is commonly known as the Wolman pebble count (Wolman 1954) and is probably the most widely used method for substrate characterisation. Differences between heel-to-toe sampling and systematic sampling along a measuring tape are summarized in Table 1.
- grid counts: particles are selected at a preset number of even-spaced grid points that span a relatively small sampling area (≈ 1-10 m2). Grid counts performed in the field hand-pick particles under a grid. A grid consisting of elastic bands stretched over a rigid frame (allowing grid spacing to be altered according to substrate size) is described by Bunte and Abt (2001b) and was specifically designed for underwater use. Alternatively grid counts may be conducted using photographs on which grids can be superimposed for later analysis. Photographing a sediment surface takes very little field time per sample, but analyzing the photographs requires a relatively large amount of laboratory time.
- areal samples: measure all surface particles contained within a small preset area (≈ 0.1 -1 m2) of the streambed, using manual hand picking of all clasts or adhesives to ensure that small particles are included representatively in the sample. This technique tends to be time-consuming in the field and requires laboratory time for sieve analysis. Areal samples are suitable for gravel sediment that contains a relatively large amount of sand and fine gravel, because areal samples, which focus on a small sampling area, are capable of including these fines, whereas pebble counts and grid counts may under-represent them. Photographic techniques have also been used for quantifying areal sediment composition (e.g. Adams 1979, Ibbeken and Schleyer 1986, Boyero 2003, Whitman et al. 2003) and applied to both coarse (>2 mm) and fine (<2 mm) fractions.

The three methods differ in several points including the spacing between sampled particles, the size of the sampling area covered, suitability for small and large particle sizes, field time vs. lab time, and the comparability of sampling results. These factors should be taken into account when selecting a sampling method. Comparison between pebble counts, grid counts, and areal samples are summarised in Table 2.

Table 1 Overview of differences between heel-to-toe sampling and systematic sampling along a measuring tape and potential operator bias and variability in poorly sorted gravel and cobble-bed streams (from Bunte and Abt 2001a).

	Heel-to-toe steps	**Systematic sampling along a tape**
Step spacing:	1 - 2 paces (0.3 - 0.6 m), regardless of bed material size	1 - 2 times the D_{max} particle size, in accordance with bed material size
Particle selection on dry surfaces:	Blind touch at the tip of the boot	Visual correspondence with even-spaced marks on measuring tape
Possible improvements:	Keep finger straight to avoid touching neighboring particles	Use pin or awl for more precise identification of particle to select
Particle selection under water:	Blind touch at the tip of the boot	Visual correspondence with even-spaced marks on a measuring tape as best as possible; otherwise blind touch
Sampling path:	Along an imaginary line at operator's discretion	Along a tape, strictly predetermined
Possibility for operator bias:		
- against fines	Higher	Lower
- against cobbles & boulders	Higher	Lower
Variability between:		
- samples	Higher	Lower
- operators	Higher	Lower

Table 2 Comparison between pebble counts, grid counts, and areal samples (from Bunte and Abt 2001a)

Pebble counts	**Grid counts**	**Areal samples**
Sample a *preset number* of particles in wide and approximately even-spaced increments of at least D_{max} size	Sample a *preset number* of particles under a grid of approximately D_{max} size	Sample *all* surface particles within a small *predefined* sampling area
Cover a large sampling area	Sample several small areas within a reach or cover small areas of homogeneous sediment (facies patch)	Focus on point locations and require several samples to be taken within the sampling area
Suitable for gravel and cobbles, not for sand	Suitable for gravel, not for sand	Suitable for sand to medium gravel not for coarse gravel or cobbles
Long field time, no lab time	*Hand-picking*: long field time no lab time; *Photographs*: short field time, long lab time	Both field time and lab time
Sampled particle sizes comparable and combinable with particle sizes from grid counts and volumetric samples	Sampled particle sizes comparable and combinable with particle sizes from pebble counts and volumetric samples	Sampled particle sizes not directly comparable and combinable with particle sizes from pebble or grid counts, or volumetric samples

Evaluation of the Wolman pebble count procedure has supported its use as a rapid method for quantitative substrate analysis, that is superior to visual characterisation (e.g., Kondolf and Li 1992, Bevenger and King 1995). Pebble counts can be performed on dry beds as well as on inundated beds, as long as the streams are wadeable. Pebble counts take between 0.5 and 2 hours per sample, depending on the number of particles to be collected and the difficulty involved in dislodging particles from the bed; however, no further laboratory time is needed. It is probably the most widely used quantitative method of assessing substrate composition. The technique yields particle size data that can be used to compute frequency distributions, summary statistics, and parameters used for hydraulic analyses. The key to accuracy of this technique is location of representative sampling sites and unbiased selection of particles, particularly for fine particles. Marcus et al. (1995) and Kondolf (1997) and others discuss limitations of the Wolman pebble count technique including sampling error and sampling bias.

Pebble counts usually focus on mid-sized and large particles, with some authors suggesting it has limited ability to represent the fine component of bed material because of the difficulty in identifying and handling small clasts (e.g., Bunte and Abt 2001a). However, pebble counts have been used successfully to characterise trends in fine sediment composition (e.g., King 1993, Potyondy and Hardy 1994, Bevenger and King 1995), particularly where a rigorous procedure is used to ensure unbiased particle selection (using pre-set sampling intervals and a pointer to identify the particle to be measured) and to characterise particle size (using a gravelometer). Wolman (1954) suggested that particles between 2 and 4 mm are the smallest that can be handled in the field. However Rice and Church (1998) suggest that only particles larger than 8 mm can be recovered without bias. At least 60 to 100 particles are needed to consistently estimate either population means or medians. Using the bootstrap technique, Rice and Church (1998) determined absolute percentile standard errors across the entire distribution of sizes. They suggest, as a general guideline, additional gains in precision are not sufficient to warrant the field effort in collecting samples of more than 400 clasts. Other authors have suggested hybrid techniques to address difficulties of using the pebble count technique to characterise the fine fraction. Fripp and Diplas (1993) used a pebble count to characterise the >10 mm fraction and the fine fraction was sampled using clay in a piston sampler to lift a sample from the riverbed.

The number of samples required to characterise the distribution of particle sizes on a stream bed is a compromise between sampling precision and sampling effort. As the number of particles collected increases, the precision with which the bed material can be described increases. A very detailed description of sampling design strategies, estimating minimum sample numbers, and sampling errors can be found in Bunte and Abt (2001a).

Photographic techniques have also been used for both areal (photosieving) and grid sampling (e.g. Adams 1979, Ibbeken and Schleyer 1986, Bunte and Abt 2001a, Boyero 2003, Whitman et al. 2003) and applied to both coarse (>2 mm) and fine (<2 mm) fractions. The sediment surface is photographed usually using some form of stand to maintain a uniform distance above the stream bed, and in deeper water a Plexiglass-bottomed device is used to obtain clear images. The images can then be analysed manually or scanned for image analysis. The images are superimposed with a grid for grid sampling, or all particle diameters are measured for areal sampling. Since each image only covers a small area (up to c.1 m^2) these techniques are typically applied to characterising small reaches of rivers. Results are quantitative and reproducible, but are not directly comparable with other techniques such as Wolman pebble counts (Whitman et al. 2003). In non-wadeable streams an underwater camera is required. Bunte and Abt (2001a) suggest photographic techniques are best suited to streams with a negligible amount of fine sediment because of bias against fine particles (due to photo resolution, and shadowing effects), unless photos are taken from a close distance. However, other authors have successfully used photographic techniques to determine the proportion of sand on the river bed (e.g., Boyero 2003, Whitman et al. 2003). Photographic techniques have been applied at larger scales by elevating the camera up to 30 m above a river, using a crane or balloon, to provide coverage of larger areas (e.g., Church et al. 1998, Kozlowski and Ergenzinger 1999). However, it is impossible to see small particles and difficult to see underwater particles unless the water is very shallow and clear.

Carbonneau et al. (2004) describe an approach to automated catchment-scale mapping of surface grain size using digital image processing of centimetre-resolution digital imagery. Images with a scale of 1:350 and 1:1200 (giving pixel sizes of 3 and 10 cm respectively) were taken from a helicopter to map the median particle size (D_{50}) of the dry, exposed gravels in an 80 km study reach. While this approach provides catchment scale mapping of substrate it was only applied to the dry areas of riverbed and estimated a single grain size parameter (D_{50}). Carbonneau et al. (2004) suggest the technique might be applicable to the wetted area of the channel but that the quality and resolution of the grain size estimates would be reduced.

Multispectral video has been applied to automatically map habitat features, subaqueous sediment type, water depth for fisheries research in the United States (Hardy et al. 1994, Crowther et al. 1995, Hardy and Shoemaker 1995, Panja et al. 1995). Data collection involves synchronous recording of imagery from three video cameras and a radiometer, combined with use of a GPS to obtain positional data. Images are digitised, corrected for colour differences and registered. The images can be classified by both automatic classification procedures and manual digitising, and classifications verified by ground truthing. Crowther et al. (1995) used this approach to distinguish 7 mesoscale hydraulic features (deep run, shallow run, deep pool, turbulent, exposed sand, bank, vegetation, shadow) and 7 sediment classes (cobble/gravel, fine sediment/silt, turbulent, sand, bank, vegetation, and shadow). This type of technology is expensive and still largely experimental.

Embeddedness is a substrate attribute reflecting the degree to which large particles are surrounded or covered by fine sediment such as sand, silt, or clay, and provides an alternative approach to assessing the fine sediment composition on a river bed (Fig. 18). A variety of specific definitions have been used (see Sylte and Fishenich 2002), reflecting the techniques that have been used to measure embeddedness, including:

- the degree that larger particles are surrounded or covered by fine sediment (defined variously as smaller than sand-size or <6.3 mm)
- the distance from the top of the rocks on the bed surface down to the top of the layer of fines in which the cobbles are embedded
- the position of a large particle relative to the plane of the bed when that particle is partially buried in fine sediment.

Embeddedness assessment is usually conducted after substrate sizes have been described in qualitative or quantitative terms. A five class embeddedness rating system is commonly used (Table 3) and assessments made for each representative habitat (riffle, run, pool). If the site is being assessed with transects, embeddedness can be recorded for midstream or thalweg locations on each transect. The technique is simple to conduct in dry stream beds or shallow water, although the visual assessment of embeddedness is not highly accurate as the classes of embeddedness are generally rather broad. Alternative methods of measuring embeddedness have been developed which are more quantitative (briefly described in Table 3), but which require intensive sampling effort and are difficult to apply in deeper water.

Current research has suggested less reliance on embeddedness and more on substrate size fraction estimates for substrate characterisation (Sylte and Fishenich 2002). In New Zealand, embeddedness has been found to be less reliable as an indicator of the amounts of fine sediment on the bed of the stream (Ian Jowett pers comm.).

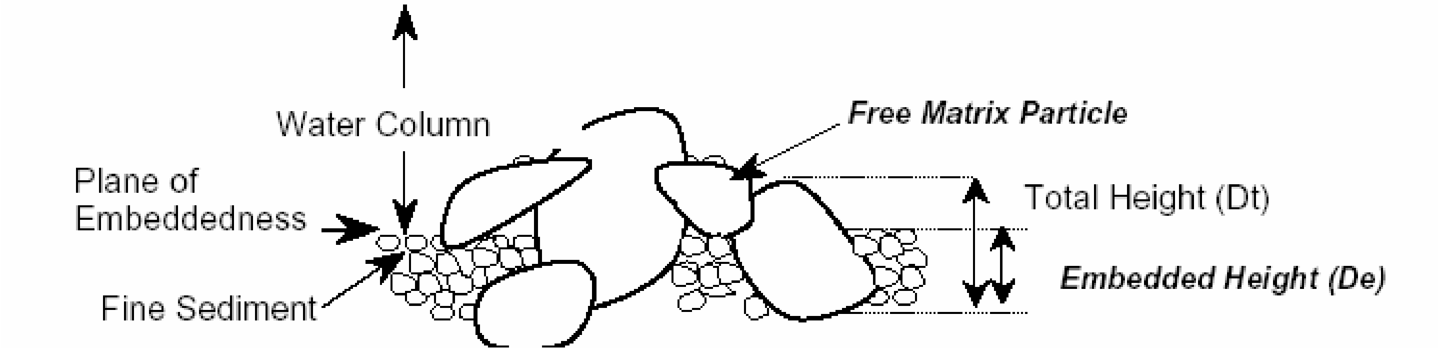


Figure 18 Schematic representation of embeddedness (from Sylte and Frischenich 2002).

Table 3 Embeddedness rating for gravel, cobble, and boulder particles (Platts et al. 1983)

RATING	RATING DESCRIPTION
5	< 5 percent of surface covered by fine sediment
4	5 to 25 percent of surface covered by fine sediment
3	25 to 50 percent of surface covered by fine sediment
2	50 to 75 percent of their surface covered by fine sediment
1	> 75 percent of surface covered by fine sediment

Table 4 Summary of embeddedness methods (Sylte and Fischenich 2002)

METHOD	MODE	SAMPLE NO.	SAMPLE LOCATION	DESCRIPTION
Platts/Bain	Visual	General sample design guidance; no specifics for embeddedness	Thalweg or mid-channel (Bain and Stevenson 1999)	Embeddedness Classes of 0-5, 5-25, 25-50, 50-75, 75-100
EPA EMAP	Visual	55	Five estimates at 11 cross-sections	10-cm sampling area at 0, 25, 50, 75, 100 percent of cross-sectional width
Burns	Measured	100-400 individual particles, depending on desired standard deviation from the mean	Specific fish habitat criteria	Random 60-cm hoop toss; specific depth and velocity criteria, hoops tossed until sample particle number is attained
BSK (Burns, Skille, and King)	Measured	Typically, 20 random hoops. Recommend statistically determined sample size. Three hoops per transect typically result in ≅100 individuals sampled per transect	Typically, transects spanning bank-to-bank for a reach length of ≅ 20 times the average stream width	Skille and King (1989) modified Burns (1984). Focused on stream-related questions, improved statistics by averaging individuals within the hoop and then averaging for the transect
USFWS	Measured	20 measurements per site	Minimum of 1 run and riffle per site, specific depth and velocity criteria wading parallel to shoreline	Measures depth to embeddedness (DTE) (protrusion); 20 DTE are divided by median rock width for that site, then averaged for the reach
USGS NAWQA	Visual	5 gravel-to boulder-sized substrates are examined at three transects	Not specified	Percentage (nearest 10 percent) of embedded depth per particle is averaged

Pool tail embeddedness has also been used as a simple, subjective means of evaluating salmonid spawning habitat quality in the field (California Department of Fish and Game 1998). Pool tail crests are assessed visually to determine to what degree potential spawning gravels are embedded. Categories are <25%, 25-50%, 50-75% and greater than 75% gravel embedded. Less than 25% gravel embedded is regarded as suitable for salmonid spawning. A fifth category is used to describe pool tails otherwise unsuitable for spawning (log, plank, rock, concrete sill, bedrock sheet, etc.). High embeddedness is generally caused by an excessive supply of sediment to the stream. The method is somewhat reliable for showing differences in habitat conditions among streams surveyed by the same observers, and much less reliable for strictly classifying habitat conditions or showing differences among streams surveyed by different observers.

A5.2 Other measures relevant to assessing fine sediment composition

A5.2.1 Riffle stability index

Assessment of the mobile percentile of particles on a riffle was developed by Kappesser (2002) as a method, termed the "riffle stability index" (RSI), for measuring the response of streams to increases in sediment supply. The basis of the technique is that riffles that have received excessive sediment from upstream will have a higher proportion of smaller mobile particles than riffles in streams that are in dynamic equilibrium. The principal premise is that riffle bed material is a mixture of smaller mobile materials that can move from one riffle to the next during frequent flood flow events and larger residual particles that do not move, or move only slightly and stay within the same riffle, for frequent flood flow events. As a riffle is increasingly loaded with sediment from upstream, textural shifts occur because of the relative increase in the mobile component of the bed. Thus the mobile percentile in stable systems is distinctly different from that in systems that have received excessive sediment from upstream. The mobile percentile (which is what the RSI measures) is a useful expression of the relative degree of textural shift in the riffle. By extrapolation, sedimentation of a reach can be estimated, and the condition of the catchment above this reach may be inferred (Kappesser 2002). The technique can be applied by comparative measurements in catchments subject to different management treatments, or to assess increases in sediment supply by measuring RSI changes through time. Kappesser (2002) suggests this index correlates well with other measures of physical habitat and results of fish habitat surveys. Note that it has only been applied to a limited number channel types (Rosgen B and Fb) where increases in gravel size bedload are depositing in riffles .

The method requires information on the size of the largest bedload particles mobile during frequent flood events, obtained by characterisation of point or lateral bars which are formed from the coarsest fraction of the bedload (Leopold, 1992,1994). Riffles that are representative of the stream segment and reach are selected. Wolman pebble counts (>200 particles measured) are made on at least 3 riffles in a reach, and a cumulative particle size distribution curve calculated. On a nearby bar the dominant largest size of particles is identified, the diameter of 10–30 of these particles is measured and the geometric mean size of these particles calculated. The percentile of the cumulative particle size distribution (from the riffle) corresponding to the mean of dominant large particle sizes (from the bar) is the RSI (Fig. 19). RSI values above 85 and approaching 100 are indicative of riffles that are loading increasingly with excess sediment; values between 70-85 suggest that the riffle is somewhat loaded with sediment; values less than 70 are indicative of watersheds in good condition.

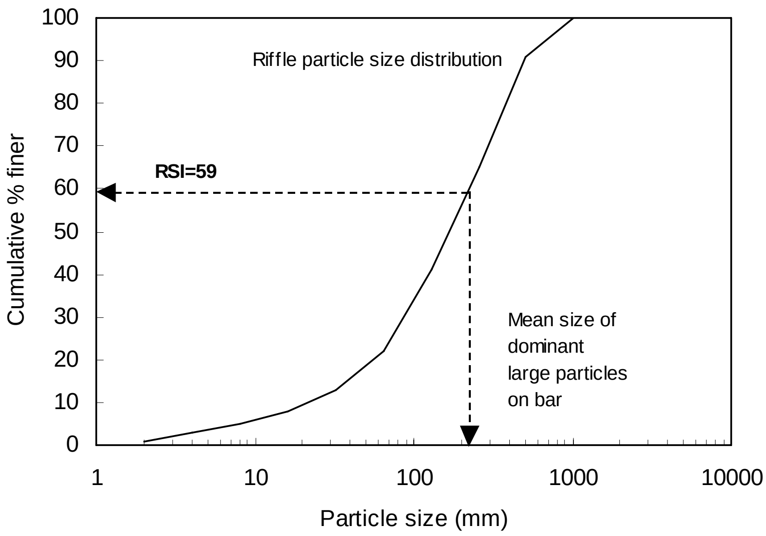


Fig. 19 Example of the calculation of riffle stability index

A5.2.2 Relative bed stability (RBS)

Kaufman et al. (1999) use a similar technique to estimate relative bed stability. They compare the median particle size (D_{50}) of bed material with the largest particle that is mobile during bankfull flow (D_{cbf}):

$$RBS = D_{50} / D_{cbf}$$

A Wolman pebble count on the riffle is used to obtain the median particle size (D_{50}), and the diameter of the largest mobile particles (D_{cbf}) is obtained from the mean diameter of a sample from a point bar.

Kappesser (2002) compares the RSI and the D_{50}/D_{cbf} and found that log D_{50}/D_{cbf} regressed against RSI showed departure from the regression line above RSI=70. He concluded that riffles depicted by points with RSI greater than 70 had strong bimodal distributions, with one mode being sand and the other cobble or small boulders. Further these channels could be described as highly embedded. They probably were indicative of channels that had been smothered by sand from upstream. Kappesser (2002) further concluded that RSI was more sensitive in watersheds underlain by competent rocks that decompose to produce gravels. The log D_{50}/D_{cbf} metric is more sensitive in watersheds with incompetent rocks that decompose to sand or very fine gravel sizes. Both metrics can be generated from the same field data, however.

A5.2.3 Volume of fine sediment in pools (V*)

During waning flood flows in gravel-bed streams, fine-grained bedload (sand and fine gravel) is commonly winnowed from riffles and deposited in pools, where it mantles an underlying coarse layer. As fine sediment load increases, more fine sediment fills the pools and their depth reduces. The fraction of pools filled by fine sediment can be quantified using a method developed by the U.S. Forest Service Redwood Sciences Laboratory to provide an index of fine sediment supply in streams (Lisle and Hilton 1992).

The volume of fine sediment in pools can be measured by probing with a metal rod to the underlying coarse layer. The proportion of the residual water volume in a pool (below the riffle crest) that is filled by fine sediment is used to define V*, the fraction of the pool volume filled by fine sediment (Fig 20):

$$V^* = V_f / (V_f + V_r)$$

where V_f = fine sediment volume

V_r = residual pool volume (equivalent to pool volume without the fine sediment)

To measure fine sediment volume and residual pool volume a tape measure is run up the middle of the pool, with perpendicular transects selected along the entire length of the pool. A stainless steel probe is used to measure the depth of fine sediment along the transects across the pool and the water depth. The transect data are combined to provide a whole pool value of fine sediment volume and residual pool volume. The mean value for a reach can be calculated as the weighted average of the V*'s for all the pools in a reach.

Ten pools, a valid sample, can be measured by a trained crew in just one day, yielding statistically rich data. Lisle and Hilton (1992) used 15–50 soundings along 4–8 transects in each pool, while Lisle and Hilton (1999) measured 8–24 pools in each reach. Like RSI this parameter can be applied to assess the effect of comparative management treatments on sediment supply in different catchments, or to monitor trends in individual reaches. V* is a useful monitoring tool for determining if fine sediment is increasing or decreasing in response to land management or restoration efforts. Lisle and Hilton (1992, 1999) note that:

- in the steams they studied fine material in pools is typically replaced several times per year
- the technique measures the active component of channel stored sediment, independent on any arbitrary definition of the size of fine sediment.
- weathered granitic rocks supplied much of this fine sediment
- V* should not be used in steep, confined reaches (such as Rosgen A channel types) but rather should be used in reaches with milder gradients (Rosgen B2, B3, or C channel types), and has only been applied to small to moderate sized stream channels.
- different amounts of pressure on the probe may result in penetration of the bed to several depths. This may indicate multiple armor layers from previous disturbance regimes, such as early logging.

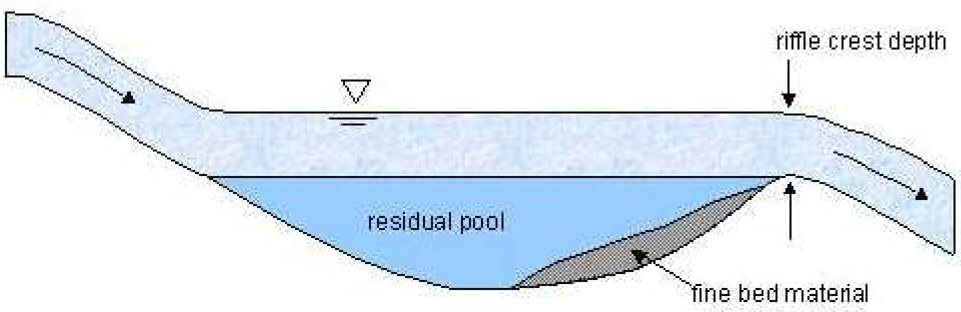


Fig. 20 Diagrammatic illustration of fine material in a residual pool (after Lisle and Hilton 1999).

A5.3 Techniques for assessing substrate composition in non-wadeable rivers

The techniques described above have generally been applied to wadeable rivers. There is little information in the literature describing techniques used in non-wadeable rivers. For example, the NAWQA methodology (Fitzpatrick et al. 1998) suggests that while transects be established as for wadeable streams substrate composition data is not collected unless there is a specific requirement for this information. If it is required, it is collected using a sediment coring device and analysed in the laboratory. Kaufmann (2000) describes field methods for non-wadeable streams used by the Environmental

Protection Agency in the United States. Bed substrate is determined visually or using a pole drag technique from a boat to "feel" the dominant substrate in slowly flowing portions of the river.

Edsall et al. (1997) list the quantitative techniques used in non-wadeable rivers by the NAWQA program. The emphasis is on remote sensing techniques that can be used where traditional ground-based survey approaches are ineffective or impossible to apply. The techniques described typically include a primary data collection device to collect store and process the data, GPS and/or total station to provide location and elevation information, and use of GIS to process and display the data collected in the field. The primary data collection devices that are used for substrate characterisation are:

- side-scan sonar (SSS) surveys are conducted by towing a sensor (towfish) behind a boat, mapping swaths of riverbed and preparing a mosaic of the swaths. It can be used to map dominant substrate class types, including sand, with resolution depending on towing speed, swath width, and sonar frequency. Some ground truthing of output is required. It can only be used in water >2–3 m deep.
- RoxAnn (RA) uses acoustic data from any single-beam echo sounder source to discriminate substrate types. First and second echos provide an index of substrate roughness and hardness respectively, which can be combined into a classification. The classification requires ground truthing to derive the relationship between classes and substrate types. It can be used in water that is 1–5 m deep.
- remotely operated underwater video camera (ROUVC) systems, including drop camera systems (that photograph small areas of the bed from a stationary boat) and towed systems (that record images of the riverbed while being towed). Image analysis is required to provide quantitative data on substrate composition.

All these approaches tend to be relatively expensive (US$60,000–100,000 for SSS, US$60,000 for RA, and US$15,000–40,000 for ROUVC), and have limitations in shallow water. They are better suited to large, deep rivers that are suitable for boats, and for lakes. NIWA has developed the Benthic Ecology Video Information System (http://www.niwa.co.nz/rc/instruments/bevis) for rapid, cost-effective seafloor habitat surveys. It uses colour and B&W video cameras, mounted on a frame with runners, that is pulled along the seafloor. Use of differential GPS and a video overlay which displays time, depth, heading and GPS coordinates directly onto the video screen enables highly accurate georeferencing of the video data. It can also be combined with SSS to survey large areas of seafloor habitat in an efficient and cost-effective way.

Use of these techniques would provide detailed quantitative data but they are too expensive and time-consuming for routine application and most of them are designed to be used from large boats in deeper water than the Motueka River.

A6 Recommendations

There are many different approaches to classifying and characterising rivers at different scales, although most approaches have some similarities between them. The exact set of procedures chosen for a particular study is dependent on the specific question(s) being addressed, available resources, and the precision required to answer the specific question(s) being addressed. And most importantly they must be repeatable at the same precision. Most of the techniques reviewed in this document are generally best suited to streams and rivers smaller than the main stem of the Motueka River and its major tributaries.

Bunte and Abt (2001a) suggest the appropriate sampling scheme is determined by:

- spatial scale. For the drift dive reaches we need to determine substrate composition over ten 1-km-long reaches of river bed. To determine spatial and temporal trends in composition over the whole catchment the spatial scale is even larger.
- degree of spatial homogeneity or heterogeneity of particle-size patterns. The drift dive reaches include several different geomorphic channel units and composition will be determined by the pattern of GCUs. At the whole catchment scale several different stream classes occur and these will have different patterns of GCUs and substrate composition.
- desired sampling precision or tolerable error. In much of the main stem of the Motueka at least, the proportion of fine sediment is low (<10%) and determining spatial patterns of substrate composition will require measurements that have a high precision. Where slugs of fine sediment are passing down the river covering a high proportion of the bed (perhaps up to 50%), then the sampling precision can be lower.
- practical restrictions imposed by keeping the sampled area or volume manageable.
- the specifics of a given study. The key question we are trying to answer concerns changes in fine sediment on the bed of the main stem of the river and its relationship to trout numbers, therefore the techniques we choose must be suitable for this parameter.

Trout numbers are related to habitat (for both trout and trout food) and therefore a key requirement is to define the habitat characteristics of the river. The impact of fine sediment needs to be viewed in the wider context of how habitat varies in space and changes through time. Repetitive mapping of habitat classes is rapid, would provide information on the stability of habitat through time, and is fundamental to understanding broad scale patterns of trout abundance, although by itself it is not likely to provide a sufficiently precise and repeatable measure to determine exactly what drives spatial and temporal variation in trout abundance (Poole et al. 1997). It is however, an essential component of defining the habitat characteristics of the river. The broad pattern of pools, runs and riffles can probably be mapped from the digital orthophotos of the Motueka taken in 2000, and field checking would indicate the stability of these features over a 4-year period. Similarly, the influence of variation in substrate characteristics on longitudinal patterns of trout abundance (Fig. 2) will not be understood by characterising substrate alone. Without characterising the full range of habitat characteristics (e.g., water depth and velocity, cover, temperature, food supply, etc) it will not be possible to determine how significant the influence of substrate variation is compared to other habitat characteristics. It will be a large task to quantitatively characterise substrate in the 10 drift dive reaches of the main stem of the Motueka, most of which have a low proportion of fine sediment. It would be even more demanding to undertake this every time trout numbers are counted by drift diving.

A key question in characterising the fine sediment component of the surface substrate, is whether it is necessary to characterise all habitat components (i.e. pools, runs and riffles) or whether to adopt a stratified approach. In large part this determines the techniques that are appropriate. Techniques that can be easily applied in small tributaries (e.g., Wolman pebble counts) will be difficult to apply in the deep fast-flowing water of the main stem or major tributaries, particularly in riffles. However, it is unlikely that significant amounts of fines would be deposited in riffles because of frequent flushing flows down the main stem, and it is probably better to target characterisation at pools and runs. Pools may well always contain a relatively high proportion of fine sediment and runs may be the habitat class that is most influenced by changing sediment delivery. In addition pools comprise a small proportion of the river, particularly in the main stem where some of the drift dive reaches contain no pools, and would require a boat for undertaking substrate characterisation. Runs are likely to be the key habitat class to characterise. However, it would be worth carrying out a pilot study in some pools to assess whether V* (the amount of fine sediment in pools) might provide a useful index of fine sediment trends.

The Wolman pebble count is by far the most widely used and accepted technique for quantitative substrate characterisation. It can provide accurate and precise estimates of substrate characteristics particularly if a rigorous approach is used to the selection of study reaches, determining transect numbers and spacing in relation to habitat classes, and to selecting and measuring clasts. While there is some debate in the literature on its application to characterising the proportion of fine sediment it has been successfully used for this purpose. It would be the most suitable technique in the main stem above the Wangapeka and in smaller tributaries. However it is problematic to use in deeper, swifter water where it is difficult to select clasts without bias towards larger clasts. For these conditions other techniques will be more suited. Bunte and Abt (2001a) suggest that for areas with large amounts of fine gravel and sand the best approach is to combine a Wolman pebble count with areal sampling. To minimise field time for areal sampling, photographic techniques could be used, although this will require a waterproof digital camera and might also require software for digital image analysis. This is the approach that is being used in a current study of the Wairau River (H. Hudson pers. comm. 2003). However, Bunte and Abt (2001a) suggest that photographic techniques using image analysis are not suitable where there is a significant proportion of fine sediment which is difficult to recognise digitally. Alternatively the lead rope technique could be used with estimates of the proportion of different grain size classes, rather than just the dominant size class, where the proportion of fines is low.

Where the proportion of fine sediment is high (e.g., determining if slugs of fine sediment are passing down the river and greatly elevating fine sediment levels), it is probably more appropriate to use an approach that makes frequent but low precision estimates of the proportion of fine sediment. Visual estimates of sediment composition could provide estimates within ±10%, which will be adequate where the proportion of fine sediment rises from <10% to >30%. Monitoring sites could be established in the main stem at all confluences and in the lower reaches contributing tributaries, and assessments made at least annually and perhaps more often. Such an approach would identify slugs of fine sediment, provide information on their rate of movement through the river system, and identify which tributary(s) they originated from. Kauffman et al. (1999) note that while measurements are more precise than visual estimates, carefully designed visual estimation procedures can be nearly as precise as measurements, particularly where visual estimates are based on measurable characteristics. A more quantitative approach could be developed using a combination of pebble counts and photographic techniques. The latter will require construction of a device for photographing stream beds, able to be deployed in a range of water depth and take good quality photos for image analysis. Alternatively a waterproof camera could be used with a frame to maintain a consistent height of the camera above the stream bed.

A rigorous approach to the selection of sample sites should be based on river segment and reach characterisation, to ensure study sites are representative (or in the case of the drift dive sites to assess how much of the river they represent) and to allow extrapolation of results within the Motueka and to other rivers. Similarly, a rigorous approach to required sample numbers should be based on degree of spatial heterogeneity and required sampling precision.

Part B Results from a reconnaissance survey of the Motueka River

B1 Introduction

Over the 2004/05 summer a reconnaisance survey was undertaken to characterise patterns of fine sediment abundance in the Motueka River. During this survey the use of Wolman pebble counts and a visual assessment technique were trialed over a wide range of sites in the main stem of the Motueka River and all the major tributaries. Two issues became clear very quickly:

- in the main stem and the larger tributaries there are limited areas where the river is wadeable and it is only the runs that are practical to sample. In riffles the water velocity was often too fast to be able to wade the river, and it was often dificult to see the river bed. In pools the water was frequently too deep to wade and it was often impossible to see the bottom. However, it is likely that the runs are the areas where fine sediment will be deposited (as well as pools) and therefore data collection was restricted to this CGU for practical reasons.
- Wolman pebble counts were impractical to apply to measurement of the proportion of fine sediment in deeper and/or swift water. It was impossible to obtain an unbiased sample of individual small grains either using a random walk technique or using a pointer to determine sample location along line transects. Therefore we abandoned Wolman pebble counts in favour of a visual assessment technique.

Our results from the survey, and observations during recent drift dives, suggest that a technique that provides relatively low precision estimates of the proportion of fine sediment but is simple and rapid to undertake will be suitable for determining if slugs of fine sediment are passing down the river.

B2 Methods

Sampling sites were chosen to provide

- wide geographic coverage of the catchment;
- a range of geology, topography, catchment size and channel/sediment characteristics;
- characterisation of as many drift dive sites as possible;
- characterisation of sites where invertebrate or water quality sampling has previously been carried out (Roger Young pers. comm. 2005).

The list of sites is shown in Table 5. Nine sites were in the main stem of the Motueka River , from Motueka gorge to downstream of the Rocky River. All of the major west bank tributaries draining steep, high rainfall, basement rock terrain were sampled, and most of the major east bank tributaries draining Moutere gravel terrain were sampled. Some of the east bank tributaries could not be sampled because extensive algae cover made it impossible to see the bed of some streams.

Table 5 List of sites sampled in the Motueka River

Site	Grid reference[1] Start	Finish	Previous sampling[2]	Number of transects	Observations/transect	N
Motueka River d/s Rocky River	**2505420/6007775**	2505302/6007269	DD10	5	20	100
Motueka River d/s Pokororo River	2500557/6002074	2500304/6001958	DD7	5	20	100
Motueka River d/s Pearse River	2494363/5997429	2494382/5997682	DD5	4	20	80
Motueka River at Woodstock	2495008/5994085	2495162/5994729	DD # *	8	20	160
Motueka River d/s Stanley Brook	2494044/5989881	2494551/5990510	DD1	10	20	200
Motueka River d/s Wangapeka River	2492188/5986903	2492021/5987233	# *	5	20	100
Motueka River u/s Wangapeka River	2492182/5986351	2492608/5985998	DD # *	10	10	100
Motueka River d/s Motupiko confluence	2495231/5978501	2496450/5976090		22	10	220
Motueka at Gorge	2502131/5953211	2502681/5952772	# *	10	10	100
Rocky River	2503331/6005575	2503090/6005837		34	3	102
Herring Stm	2501619/6004654	2501475/6004151		35	3	105
Big Pokororo River	2498985/6001417	2499002/6001316	#	10	10	100
Little Pokororo River	2497552/6001654	2497858/6001548		34	3	102
Graham Stm	2496083/5999499	2496039/5999423	# *	10	10	100
Pearse River	2494183/5997117	2494285/5997171	DD # *	11	10	110
Baton River u/s of ford	2493165/5992167	2493472/5992249	DD # *	9	10	90
Clarke River	2486169/5987145	2485796/5986811		14	5	70
Wangapeka River u/s Motueka	2491036/5986221	2491781/5986274	DD # *	10	10	100
Dart River	2480658/5976191	2480715/5975362	#	10	10	100
Rolling River	2474911/5973464	2474527/5973145	#	10	10	100
Sherry River at Blue Rock	2487961/5980715	2487649/5980144	# *	20	5	100
Tadmor River at Glenrae bridge	**2493623/5981474**	2493729/5981612		19	5	95
Motupiko River at Quinneys Bush	2494352/5970900	2494951/5972226	DD # *	20	5	100
Stanley Brook	2494146/5989548	2494162/5989861	# *	20	5	100
Riwaka at Moss Bush	2503597/6017585	2504253/6017250		20	5	100

[1] Grid reference given as Easting and Northing [2] Sediment sampling was not always at exactly the same location as previous water quality and invertebrate sampling DD drift dive site * water quality site # invertebrate sampling site N total number of observations

Table 6 Results of fine sediment assessment at sites in Motueka catchment. The table shows the proportion of observations recorded in each % fines class

	Fine sediment class (%)						
Site	<1	1-5	5-10	10-20	20-50	50-100	Average % fines
Motueka River d/s Rocky River	44	36	12	8	0	0	3.4
Motueka River d/s Pokororo River	56	19	7	9	7	2	6.7
Motueka River d/s Pearse River	49	20	10	8	13	1	8.0
Motueka River at Woodstock	58	20	9	7	4	1	5.1
Motueka River d/s Stanley Brook	59	28	6	8	1	0	2.9
Motueka River d/s Wangapeka River	31	40	11	12	5	1	6.5
Motueka River u/s Wangapeka River	48	23	13	6	3	7	9.1
Motueka River d/s Motupiko confluence	40	32	14	9	6	0	5.6
Motueka at Gorge	18	34	24	13	6	5	10.7
Rocky River	2	8	11	23	36	21	32.6
Herring Stm	1	5	8	20	30	36	41.2
Big Pokororo River	12	50	23	12	3	0	6.1
Little Pokororo River	12	29	20	20	11	9	15.7
Graham Stm	7	45	29	15	2	2	8.0
Pearse River	35	31	16	12	5	2	7.1
Baton River u/s of ford	16	32	17	19	12	4	12.7
Clarke River	50	31	10	9	0	0	3.2
Wangapeka River u/s Motueka	41	34	12	9	3	1	5.3
Dart River	21	20	23	27	8	1	10.0
Rolling River	70	23	6	0	1	0	1.8
Sherry River at Blue Rock	19	9	24	16	18	14	21.4
Tadmor River at Glenrae bridge	97	2	0	1	0	0	0.7
Motupiko River at Quinneys Bush	76	19	1	2	1	1	2.4
Stanley Brook	59	33	6	1	0	1	2.6
Riwaka at Moss Bush	34	34	21	6	4	1	5.8
All sites	46	28	11	9	5	2	5.9

Fig. 21 Variation in amount of fine sediment at sites in the Motueka catchment

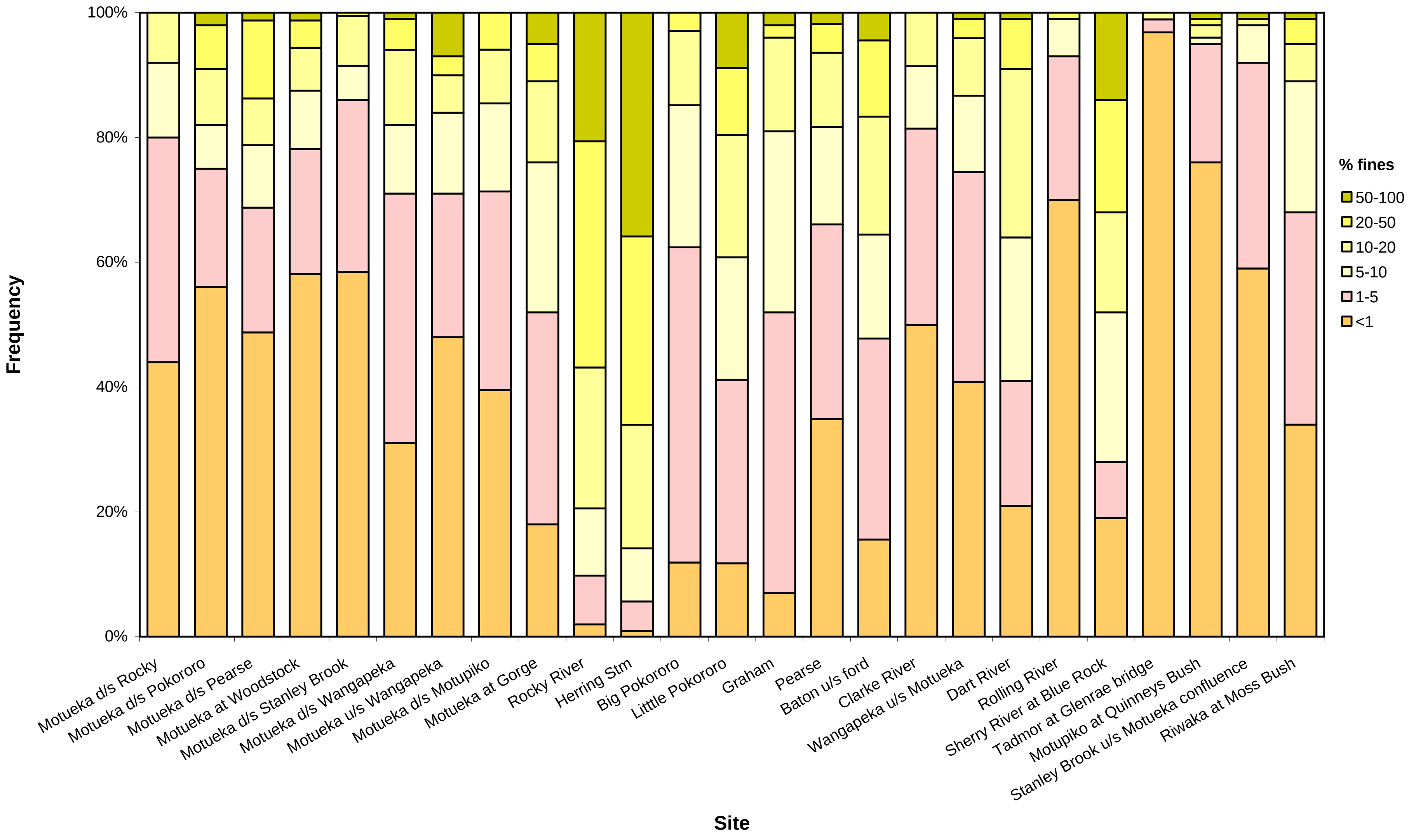
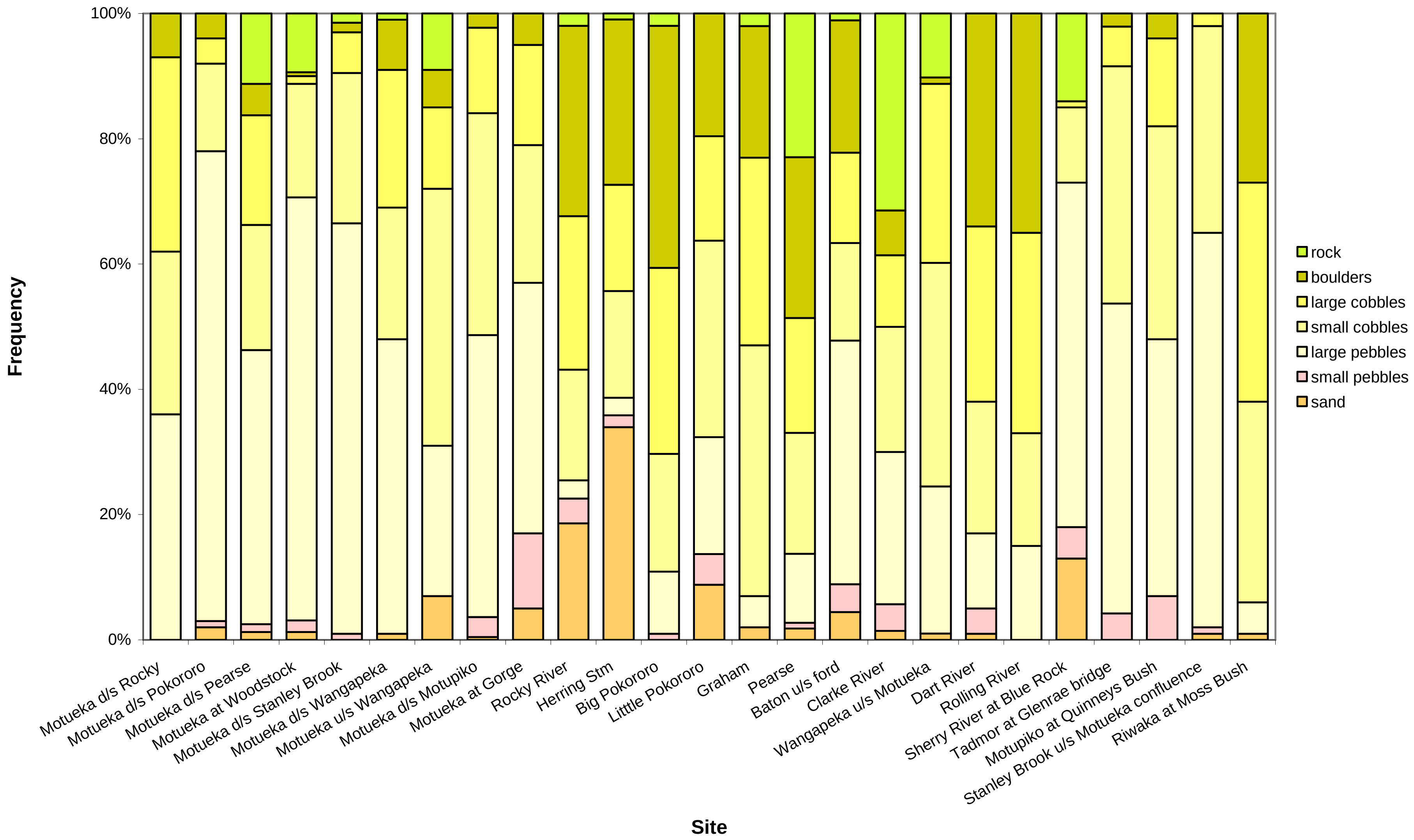


Fig. 22 Variation in dominant particle size at sites in the Motueka catchment



At each site study reaches were defined from the pattern of channel geomorphic units (CGU). This ranged from a single long run at some sites in the main stem, to a large number of runs in the smaller tributaries. Within each reach a visual assessment of the proportion of fine sediment and dominant particle size was made along line transects. A comparator chart was used to assess the fine sediment proportion and a gravelometer to determine the dominant particle size. The area in which the proportion of fine sediment was assessed was approximately standardised as equivalent to the area of the gravelometer (0.38 by 0.21 m or 0.08 m^2). The number of transects and number of observation points per transect varied according to stream width, ranging from 5 transects with 20 observation points per transect in the main stem to 34 transects with 3 points per transect in smaller tributaries (Table 5). Along each transect observation points were spaced approximately equidistantly across the stream so that spacing varied according to stream width. The entire width of the stream was sampled along each transect. The start point of each transect was determined accurately by GPS (±1m) allowing repeat measurements to be made at the same location in future. The aim was to collect at least 100 observations at each site, and this was achieved at most sites (Table 5). While the technique would allow statistical comparison between sites the primary aim is to repeat the survey in the future and determine whether the proportion of fine sediment has changed at individual sites.

At each observation point we recorded:

- the proportion of fine sediment using class intervals of <1%, 1–5%, 5–10%, 10–20%, 20–50%, and>50%. These class intervals were chosen to allow the use of percentage area charts and they approximately match visual embeddedness assessment classes. They provide more detail where the percentage of fine sediment is low (most of the Motueka River), and less detail where the percentage of fine sediment is high;
- dominant particle size using class intervals of bedrock, boulder (>256 mm), large cobble (128-256 mm), small cobble (64-128 mm), coarse gravel (8-64 mm), fine gravel (2-8 mm), and fines (<2 mm).

Data was recorded directly into a datalogger connected to a GPS (Trimble GeoXT). All sampling was done under base flow conditions (at Woodstock the flow ranged between 10 and 20 cumecs) and only the wetted area of the channel was characterised.

From the raw data the frequency of occurrence of each % fines and dominant particle size class was calculated at each site. This was converted to the % frequency based on the total number of observations at each site to allow comparison between the sites, since total observation numbers varied (Table 5). An average % fines was calculated for each site based on the midpoint of each % fines class and weighted by the proportion of observations recorded in each class. While this statistic does not provide an accurate estimate of the average % fines (because of the range included within each class) it does provide a simple basis for comparison between the sites.

B3 Results

At most sites the proportion of fine sediment was very low with c.75% of all observations recorded at all the sites having <5% fine sediment and only 7% having >20% fines (see Table 6 and Fig. 21). At most sites the spread of values recorded was strongly skewed towards <1% and 1–5% fine sediment. The average % fines ranged from 41% at Herring Stream to 0.7% at the Tadmor.

There were a small number of sites that had greatly elevated amounts of fine sediment compared to this dominant pattern of a low proportion of fine sediment. Most notable were two small west bank tributaries (Herring Stream and Rocky River) where >50% of observations were in the 20–50% and 50–100% fines classes, and the average % fines was 30–40%. Jackson (1995) notes that in 1995 the Herring had "a stable bouldery bed with little sand-sized material obvious", suggesting that the sediment composition on the bed has changed in the last 10 years. The Sherry and Little Pokororo Rivers also had moderately high levels of fines (20–30% of observations in the 20–50 and 50–100% fines classes, and an average % fines of 15–20%). At all these sites the fine sediment was dominated by coarse sand derived from Separation Point granite. These four sites had the most fine sediment by whatever measure was used (average % fines, frequency of observations in 50–100% or 20–100% fines classes)

A number of sites had moderately high levels of fine sediment. The Baton and Dart River sites had c.10–15% of observations in the 20–50 and 50–100% fines classes, as did a number of the main stem sites (Motueka downstream of the Pearse, Motueka at Gorge, Motueka upstream of the Wangapeka, and Motueka downstream of the Pokororo). At these sites the average % fines was 7–13%.

These results suggest that fine sediment is being generated from both the west bank tributaries and the upper Motueka River, although the nature of the fine sediment from the two sources differs considerably (white coarse granite sand from the west bank tributaries, finer darker sand from the upper Motueka). It is interesting to note that at the main stem site downstream of the Pearse very high amounts of sand were observed during the 2004 drift dive (although not quantitatively measured the average % fines was probably well in excess of 20%), indicative of a slug of sand in this part of the river. It appears that much of this sand has already moved out of this site and and it was not detected at either of the sites downstream of here, perhaps suggesting that it is dispersing from this site rather than translating downstream.

There was little distinctive pattern in the dominant particle size. Many of the main stem sites were dominated by large pebbles and small cobbles, as were the tributaries draining Moutere gravels. By contrast the west bank tributaries, including the smaller west bank tributaries, had a greater proportion of small cobble to boulder size particles.

The survey method has proved to be an efficient and effective method of providing semi-quantitative data on the spatial variation in the proportion of fine sediment on the river bed. To gather 100 measurements at each site took between 1 and 4 hours, depending on factors such as how long the reach was, how difficult the river was to wade, how variable the amount of fine sediment was, how quickly the position of each transect could be established by GPS (often amongst overhanging tree cover on the river bank). The survey of 25 sites took 30 person-days (a team of 2 for 5 days and a team of 4 for 5 days). Now that the survey technique has been developed it would take less time to repeat the measurements at the same set of sites. It does not require highly skilled personnel or expensive equipment. Data was collected only where the river was wadeable, but in very slow runs water up to neck-deep was sampled using a snorkel to see through the water surface. Other limitations to where data could be collected were an uneven water surface which, in deeper water, made it impossible to see the river bed. The presence of high levels of organic debris made it impossible to see the river bed in some of the east bank tributaries.

The data is suitable for quantitative statistical analysis. While it could be used to determine if differences between sites are statistically significant, the primary aim was to develop a technique that could be used to determine if there are temporal trends at individual sites. The survey will be repeated at least annually to determine trends at the sites, or after significant flood events to identify the generation of slugs of fine sediment in the river system and their rate and mode of movement downstream. It was intended that, using the GPS-derived location of each transect, remeasurement would be undertaken at exactly the same locations. However this approach has been compromised by the large flood in the Motupiko and upper Motueka Rivers on 25 March. In the upper Motueka River at least some of the runs in which transects were located have been transformed into riffles. At these locations the transects will need to be relocated to the nearest run. To assess whether transect location had a major impact on the results, further analysis of the data from the sites where large numbers of observations were made (Motueka River at Woodstock, Motueka River d/s Stanley Brook, Motueka River d/s Motupiko confluence) was undertaken. The data was resampled by taking results from every second transect, or by randomly selecting transects, and the analysis repeated. The results from this analysis were statistically indistinguishable from the results reported in Table 6, suggesting that transect location within a run does not significantly affect the results. However it was observed during the survey that the proportion of fine sediment sometimes varied systematically across transects. Commonly there was a higher proportion of fine sediment in the shallower, slower flowing water near the stream edge than in the deeper, swifter water in the middle of the stream. Therefore it is important that observations extend across the full width of streams.

B4 Conclusions

The visual assessment technique has provided a semi-quantitative overview of the variation in the amount of fine sediment in one channel geomorphic unit (runs) in the Motueka River. It has identified differences in the amount of fine sediment in sites in the main stem and Motueka River tributaries and identified two small west bank tributaries as having very high levels of fine sediment compared to all other streams in the catchment.

The results from the survey show that this technique provides semi-quantitative estimates of the proportion of fine sediment and is rapid and simple to undertake. One of the biggest constraints to sampling in the Motueka River is the inability to be able to wade many parts of the river, particularly in the main stem and larger tributaries. Data collection has been limited to runs, but it is likely that these areas of the river will be impacted by slugs of fine sediment. Visual assessment of the proportion of fine sediment, derived from a large number of individual observations, will be suitable for determining if slugs of fine sediment are passing down the river, so long as they result in a change in the proportion of fine sediment by at least one class interval. Repeat surveys will allow identification of which tributaries slugs of fine sediment originate in, and how quickly they move through the river system.

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