River and channel morphology: Technical Report prepared for Horizons Regional Council

Measuring and monitoring channel morphology

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Cover Photo:
Tapuaeroa River, East Cape

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FOREWORD

As part of a review of the Fluvial Research Programme, Horizons Regional Council have engaged experts in the field of fluvial geomorphology to produce a report answering several key questions related to channel morphology and linkages with instream habitat diversity in Rivers of the Manawatu-Wanganui Region. This report is aimed at introducing concepts of the importance of morphological diversity in the Region's rivers to the planning framework (to be used in the development of Horizons second generation Regional Plan – the One Plan).

This expert advice has been used in the development of permitted activity baselines for activities in the beds of rivers and lakes which may influence the channel morphology and to address the cumulative impacts of these activities over time and space.

Monitoring recommendations within this report provide guidance for the management of cumulative reductions in channel morphological diversity over time. Regional implementation of the monitoring of channel morphology is planned for introduction in the 2007/08 financial year through the newly reviewed Fluvial Research Programme. The monitoring will be conducted in line with recommendations from this report.

Kate McArthur
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CONTENTS

1. Introduction

This technical report is drafted in response to a Horizons workshop convened on 16 November 2006 as part of a process to provide information on river channel morphology to the new regional plan (One Plan). This part of the report provides answers from a fluvial geomorphology perspective to key questions posed in the project brief. These questions are outlined in section 2. The Report documents material presented at the workshop to address measurement and monitoring of channel morphology (section 3). This is also informed by material drawn from discussion during the day. This provides a basis for a series of responses to the key questions posed (section 4).

2. Questions

- Are there any reasonably pragmatic and simple methods of measuring and defining quality of channel morphology, and thereby habitat heterogeneity, that Horizons could use?
- What are some monitoring recommendations for maintaining good channel morphology and enhancing poor channel sinuosity (both on a habitat and river length scale)?
- How can these recommendations be utilized for policy development (down to a level of detail to develop plan rules) and for resource consent conditions to address any adverse impacts from river engineering works such as major channel diversions or bed lowering/ instream gravel excavation?
- How can Horizons address cumulative impacts on river sinuosity and instream morphology over time? (We would like to introduce some degree of cumulative assessment into our policy framework around the beds of rivers).
- What different engineering methods can be applied to minimise environmental footprints or to actively participate in habitat enhancement (please provide examples that may be applied to the Horizons Region)?

3. Measurement and monitoring of channel morphology

3.1 Channel morphology defined and characterised

Alluvial rivers, which include gravel-bedded and sand-bedded rivers, typify rivers within the Horizons region. The principal morphological components in alluvial rivers are bars, riffles, pools and runs. Bars are the principal bedform arising from deposition within the active channel. They may be classified according to their morphology into a range of types (Figure 1). Riffles, pools and runs represent topographic highs, lows and intermediate zones respectively within the wetted channel. Wetted channel morphology is intrinsically linked with barforms, e.g. riffle crossings may form as the thalweg flows from side to side in a straight channel across alternate lateral / diagonal bars (Figure 2). Pools and riffles should be considered together as a continuous bedform, i.e. as a pool-riffle unit / sequence. Pools and riffles do not tend to occur in isolation. Table 1 provides a summary of channel morphology linked to channel continuum categories which are common in New Zealand (braided, wandering and meandering).

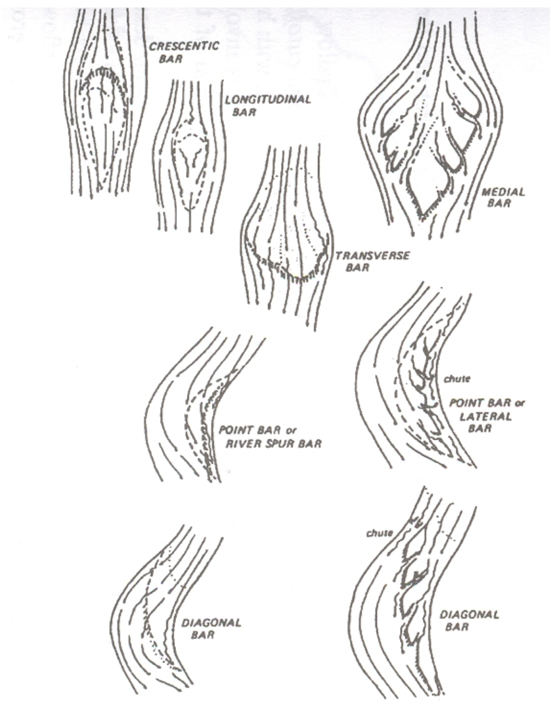


Figure 1: Types of channel bars based on Church and Jones (1982) classification. *Source:* Fig. 9.6 Thorne *et al* (1997).

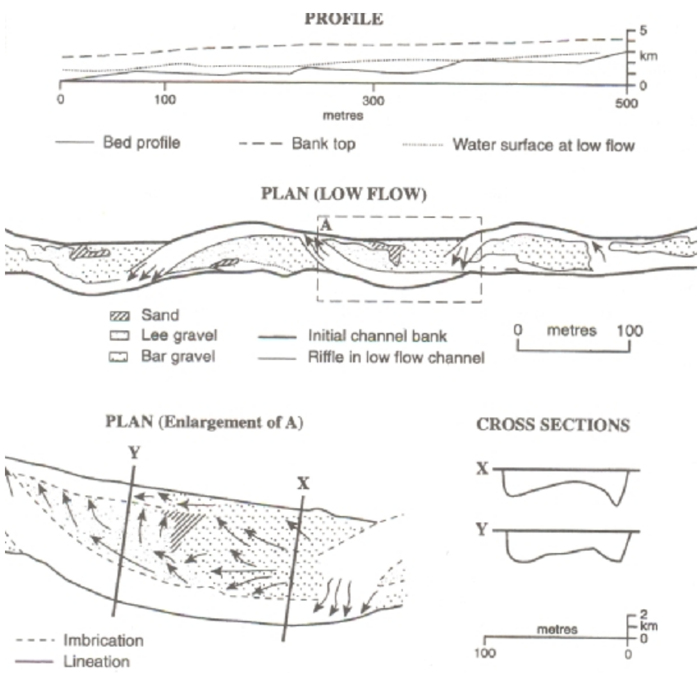


Figure 2: Formation of asymmetrical pools, alternate bars and riffle crossings in a straight alluvial channel (after Richards 1982). *Source:* Fig. 7.7 Thorne *et al* (1997).

Table 1: Channel morphology: linkages with sinuosity.

Morphological Unit	Braided Planform	Wandering Planform	Meandering Planform
Point bar	×	✓	✓
Lateral bar	✓	✓	✓
Diagonal bar	✓	✓	✓
Medial bar	✓	✓	×
Transverse bar	✓	✓	×
Longitudinal bar	✓	✓	×
Pool	*scour holes*	✓	✓
Riffle	*shoals*	✓	✓
Run	✓	✓	✓

Braided channels are characterized by multiple channels and braid bars. Wandering channels, also defined as semi-braided or pseudo-meandering, comprise morphological units present in both braided and meandering rivers e.g. irregular pool-riffle sequences, bends, bifurcating channels around occasional medial or longitudinal bars. Channels are only classified as meandering where sinuosity (channel length / straight line valley length) exceeds 1.5 and the river is single threaded and dominated by point bars and well developed pool-riffle sequences. Meandering channels are characterised by a cycle of development from cutoff which straightens the channel to regained compound meanders. The dominant process is lateral accretion on the inside of bends and localised erosion on the outside of bends. Avulsion in the form of cutoff occurs when the meander neck is breached (neck cutoff) or point bar is cut (chute cutoff).

Wandering channels are also characterised by similar processes, although avulsions are more significant and may cut across large parts of floodplain as opposed to narrow channel necks or point bars. Avulsive behaviour produces rapid and sudden channel switching in such systems. Braided channels are characterised by multiple channel bifurcations around multiple medial and transverse bars in an unconstrained active channel. For a full review of braiding mechanisms, see Ashmore (1991), also Sambrook-Smith *et al* (2006).

However, this planform classification is inevitably generalised. The diversity of morphological units within alluvial channels must be recognised. There is no 'one size fits all'. Discussion emphasised the need to characterise a river, and more specifically a reach of channel, morphologically, and in a way which recognises that each system or reach is unique. To this end, identification of a river as braided, wandering or meandering in itself is inadequate. Effective management and matching to 'good' habitat requires a greater level of detail. There have been several attempts at channel pattern classification. Thorne (1997) recommends the use of Brice's (1975) scheme (Figure 3). This focuses on planform, notably the degree and character of sinuosity and braiding. Anabranching is also considered, but this type of channel is rare, if not absent, from the region (stable multiple channels separated by stable islands). A more comprehensive classification scheme is that devised by Rosgen (1994), which takes into account cross section and gradient. This framework is given in Figure 4 and Figure 5. Appendix 1 provides a summary for broad level classification in the Rosgen (1994) approach.

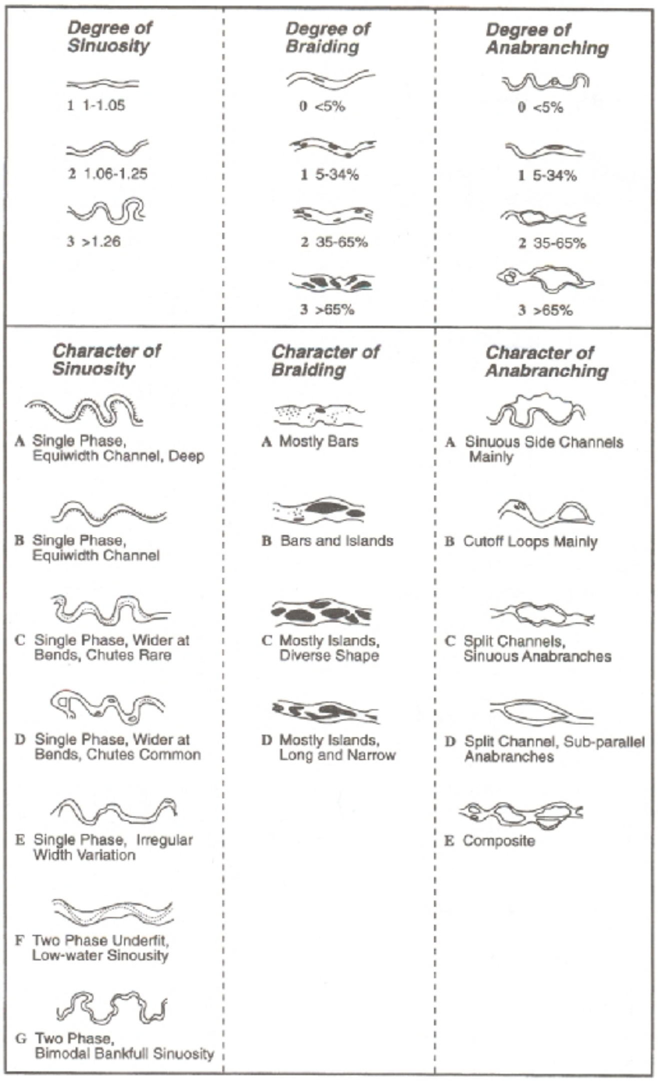


Figure 3: Channel planform classification (Brice 1975). *Source:* Fig. 7.25 Thorne *et al* (1997).

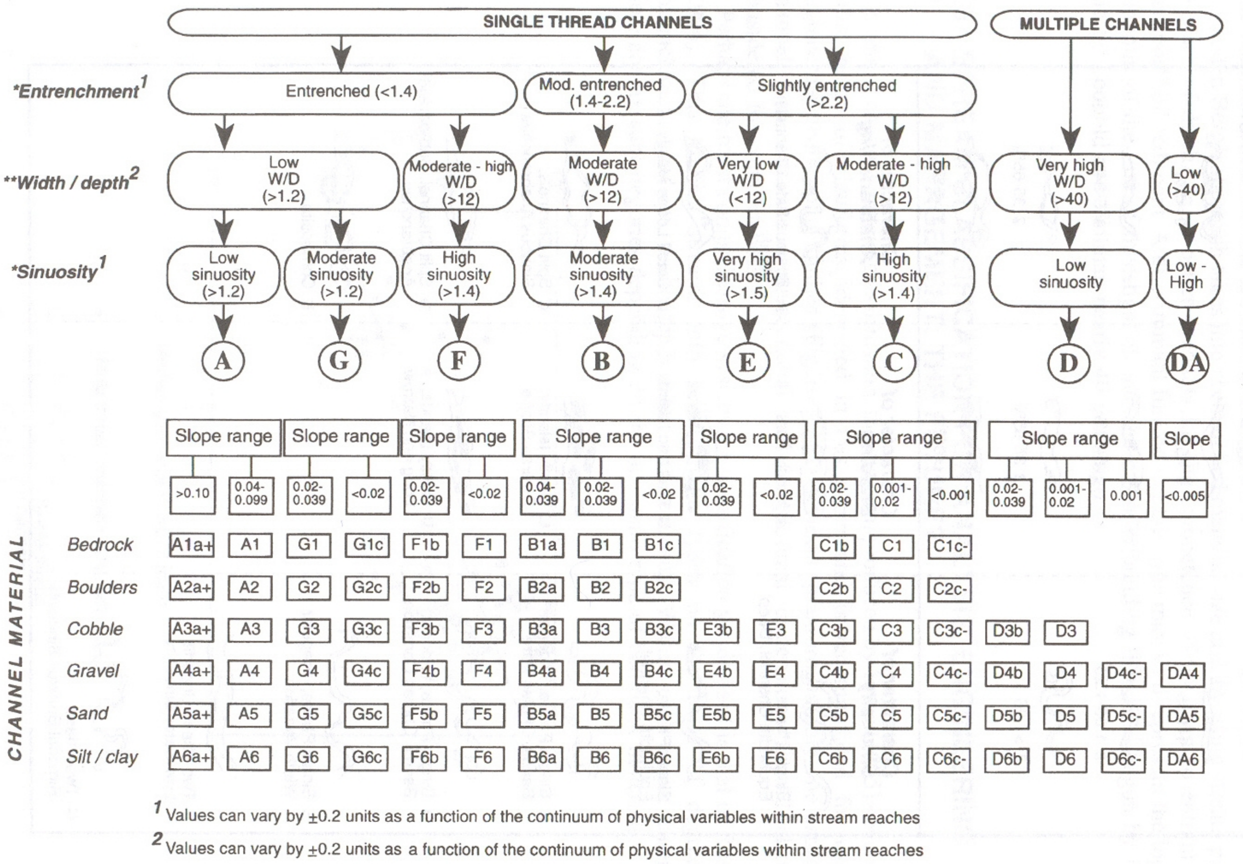


Figure 4: Classification key to Rosen's (1994) scheme. *Source*: Fig. 7.26 Thorne *et al* (1997).

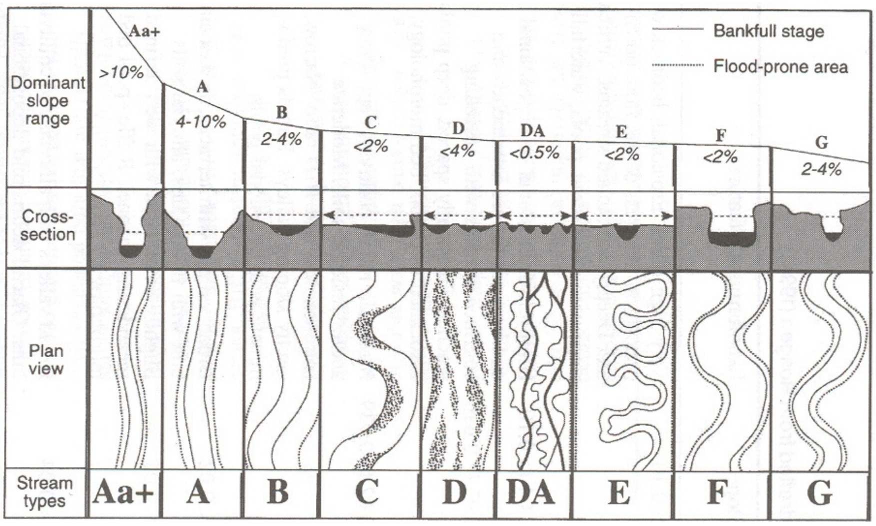


Figure 5: Longitudinal, cross-sectional and planform views of major channel types in Rosgen's (1994) classification scheme. Source: Fig. 7.27 Thorne et al (1997).

It should be emphasised that a shortcoming of such classification schemes is their failure to accommodate dynamic adjustment of the channel system. Reach morphology changes over time in response to flow and sediment regime. This occurs over long and short term, especially in relation to floods. Rivers are seldom in dynamic equilibrium (Thorne 1997) and are constantly adjusting towards an equilibrium form, but given the constant changes in flow and sediment regime, never quite attain that. Additional classification schemes have been developed based on adjustment processes and trends of channel change. The example of Downs' (1995) scheme is given in Figure 6.

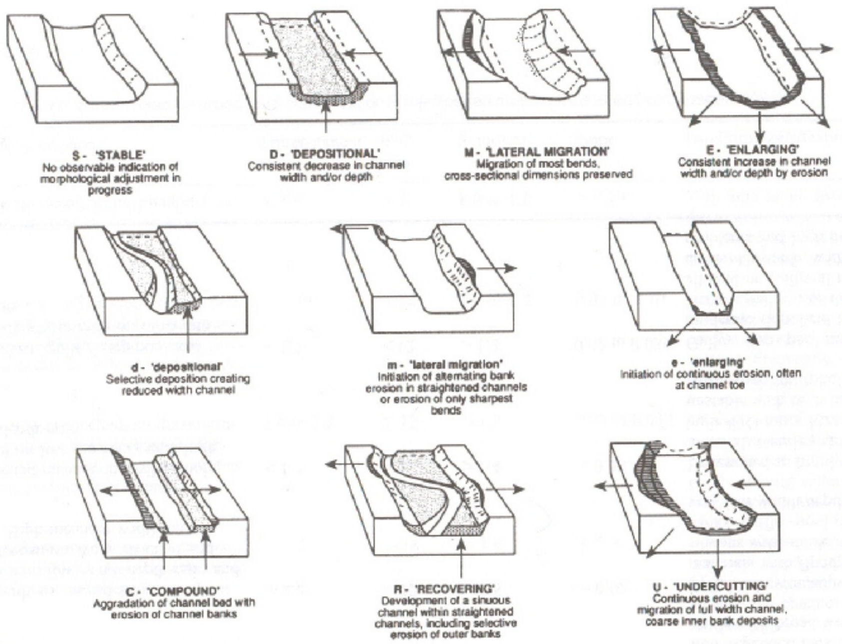


Figure 6: Downs' (1995) channel classification, based on trends and types of morphological change. *Source:* Fig. 7.28 Thorne *et al* (1997).

3.2 Measurement and monitoring approaches

Measurement and monitoring of channel morphology can be readily achieved at two levels outlined in sections 3.2.1 and 3.2.2. Recommendations are given in 3.2.3.

3.2.1 3-Dimensional survey

High resolution 3D characterisation of channel topography, based on intensive ground survey, or, if available, LiDAR, provides the possibility of detailed analysis of structure and change within specified channels. Repeat survey permits an assessment of sediment transfers between survey dates using morphological budgeting. This provides a lower-bound estimate of sediment volumes moved, due to intervening scour and fill and movement of sediment without morphological expression.

Morphological budgeting is based in this scenario on the difference between digital elevation models (DEMs). High resolution topographic data are used to generate DEMs using GIS software such as Surfer® or ArcGIS®. Within the GIS, DEMs are interpolated based on the field data collected. Some care needs to be exercised in selection of the most appropriate method of interpolation and geostatistical analysis may be required. Where the second DEM is higher than the first, sediment has been deposited, where it is lower, sediment has been scoured. An example of such analysis is given in Figure 7. It should be noted that this is not a precise method of measuring bedload transport. Deposition of thin bedload sheets may not be detected if the minimum level of change detection exceeds the median grain size of the reach, as such sheets may be a clast or two thick (Brasington *et al*., 2003). Hence, estimates of sediment transfer derived using this approach should always be viewed as lower bound (Fuller *et al*., 2003).

Normally, when using ground survey (RTK-GPS and theodolite-EDM), this approach is most appropriate in discrete reaches up to 2 km in length. Care should be taken in selecting reaches which well exceed the step-length of bedload transport in the reach (normally ~7 times the active channel width).

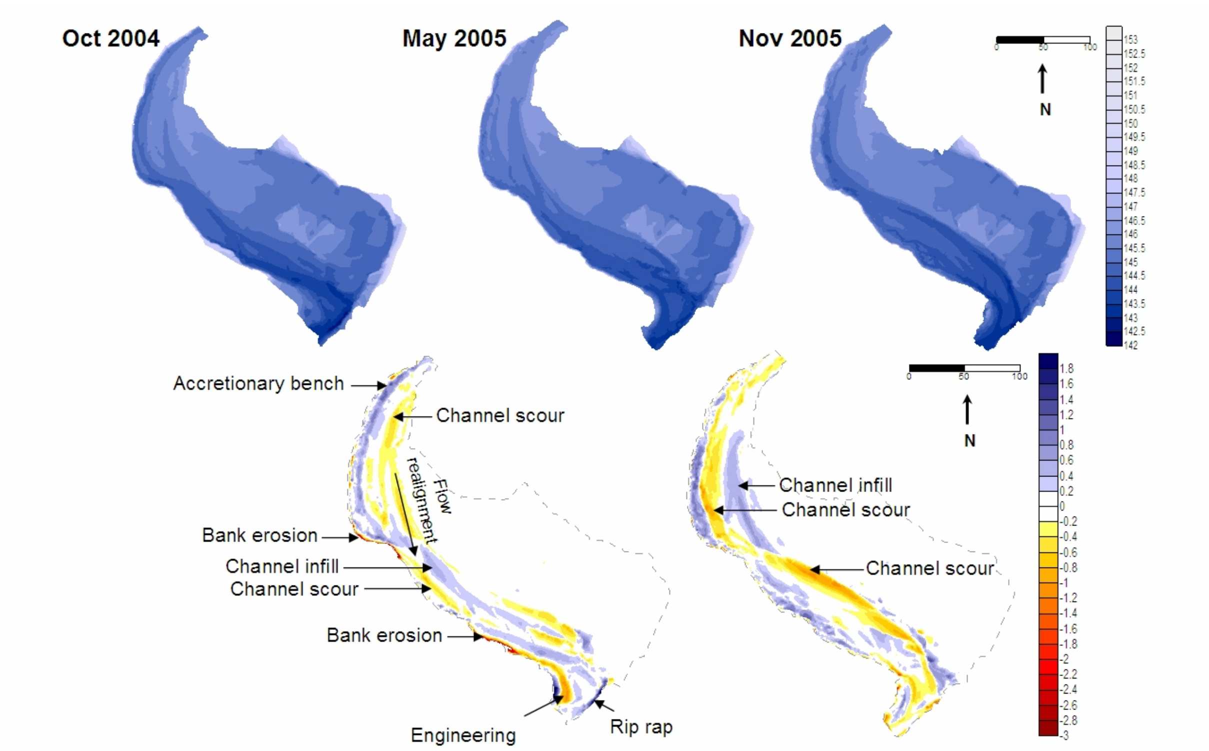


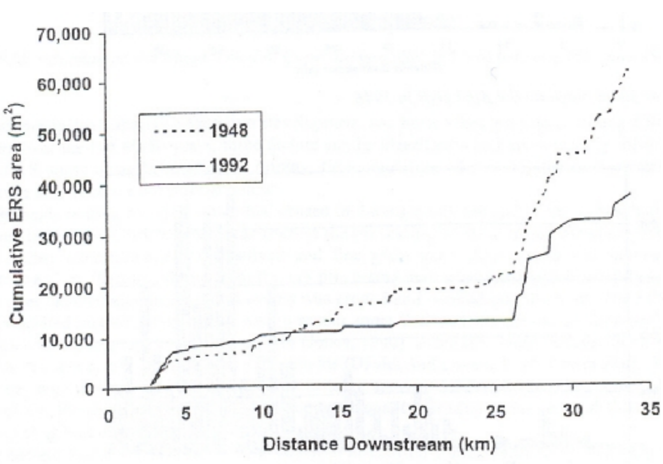
Figure 7: DEM differencing to identify morphological change in the Kiwitea at ~km 11 (after Fuller and Hutchinson 2006).

3.2.2 Exposed Riverine Sediment (ERS) Assessment

ERS refers to sediment deposited in the active channel, exposed at low flow, i.e. barforms. Exposed areas of river sediment are particularly sensitive to changes in hydrological regime and sediment supply (Brewer *et al*., 2000) and are important habitats in themselves (Petts *et al*., 2000). In addition, assessment of ERS would provide a useful tool in appraisal of reach or river characterisation and morphological diversity. At its simplest, ERS assessment provides a measure of bar surface area in a reach / system, which is a key physical habitat. Combined with geomorphic classification, ERS assessment can provide information on the types of barforms or channel, where each ERS area can be classified using schemes such as those shown in Figure 1 and Figure 3. This should permit linkages between ERS and morphological diversity to be made. More detailed analysis may also be feasible, as has been demonstrated by Petts *et al*. (2000) for the Fiume Tagliamento (Italy), where sediment sampling was also employed to characterise the composition and heterogeneity of contemporary ERS areas.

Assessment of ERS is based on whole-river or extended reach analysis using georectified aerial photography, which enables quantification of areas and features once edge effects and distortions have been removed. The most rapid means of assessment is analysis of digital orthophotos within a GIS, such as ArcMap. The approach involves a simple digitising of each ERS area in the reach of interest. Care should be exercised if river flow varies substantially between photography used in this analysis, as stage height will affect area of sediment exposed. Some compensation or adjustment may be required.

A study of ERS was conducted in Wales by Brewer *et al*. (2000) using aerial photography flown in 1946 and 1992. Their results, which provide an example of the type of analysis / output achievable in ERS assessment, are given in Figure 8. They observed a reduction in ERS, attributable to increased lateral stability, reduced bank erosion, reduced flood frequency and magnitude, and vegetation recolonisation. During discussion it was noted that rapid vegetation recolonisation or clearance for management purposes may affect results of ERS analysis. However, the former gives a statement on the degree of activity in a channel: frequent freshening of bar surfaces or bar destruction and re-formation, will remove / minimise vegetation on bar surfaces. The presence of vegetation indicates a degree of stability. Frequency of ERS analysis should be dependent on flow regime. A minimum of 5 years is recommended, but after each large flood (magnitude to be determined) in addition.



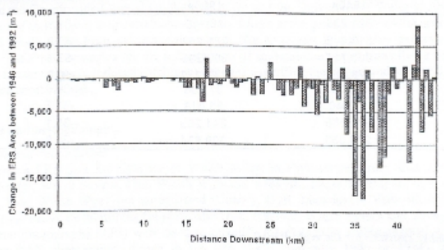


Figure 2 Change in ERS area per 500m reach on the Afon Dyfi between 1946 and 1992

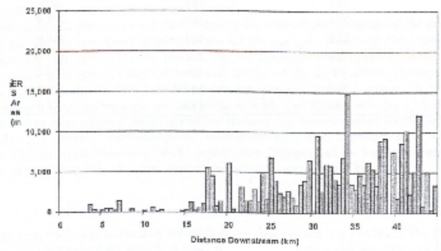


Figure 3 ERS area per 500m reach on the Afon Dyfi in 1992

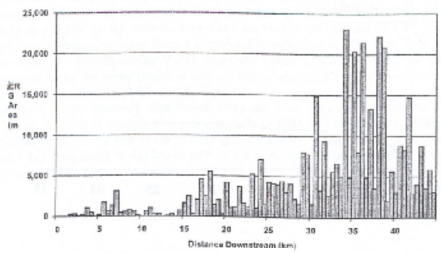


Figure 4 ERS area per 500m reach on the Afon Dyfi in 1946

Figure 8: ERS (Exposed Riverine Sediment) in Welsh rivers (Brewer et al., 2000)

3.2.3 Recommended approach to monitoring

To understand the impacts of channel engineering on reach morphology, key reaches should be selected with and without engineering. It may also be desirable to compare morphology between reaches in which contrasting engineering approaches (e.g. rock-work vs. willows) have been used. This can be achieved over time using archive aerial photography – before and after engineering. It can also be achieved in the present comparing engineered and non-engineered reaches, although care will be needed in reach selection to minimise the only variable to engineering. This could be difficult given the plethora of variables contributing to reach morphology, but could be valuable. ERS assessment would be especially suitable for large-scale appraisal, or historic change. 3D assessment would be suited to smaller-scale assessment of engineering impacts (e.g. Figure 7).

Historic changes in ERS would provide valuable information on changes taking place in the region's rivers over the last ~50 years. This provides context for the present channel configurations and any future changes (engineered or natural). Current ERS and river planform should be mapped from the most recent aerial photography. Linking geomorphic appraisal to ERS assessment would provide information on the relationships between ERS and morphological diversity. Re-mapping should take place at regular intervals, requiring a commitment to re-fly aerial photography of key reaches over the coming years. There should also be flexibility to acquire imagery in the aftermath of extreme events. Imagery should ideally be supplied rectified in digital format for use in GIS. Some investment will be needed to convert archive aerial photography to this format for analysis.

3.3 Maximising morphological diversity

Most rivers in the Manawatu region under the current flow and sediment regimes are wandering (semi-braided) to braided (braided reaches are evident in historic aerial photographs). This planform does provide a high diversity of habitats and may be conducive to fisheries in the region, by enhancing connectivity between key reaches within a river. In discussion, a high velocity, single thread channel was not deemed helpful in this context. Constraining channels reduces this diversity and may generate a high-velocity single thread run, with poorly developed pool-riffle units.

Maintaining sinuosity *per se* may not be desirable or effective in wandering rivers, which are naturally avulsive (Fuller *et al*. 2003). Habitat diversity may be better maximised by taking a holistic approach to assessing channel morphology, characterising reaches (cf. 3.1) by taking into account variables such as sinuosity, channel bifurcation, nature of barforms, degree of entrenchment, gradient, sediment type. Ecological expertise should be sought to match these morphological characteristics with desirable habitats. Channel characterisation should form the starting point for such an assessment. Thresholds for 'good' and 'bad' morphology are difficult to identify in isolation from a habitat appraisal. It should also be recognised that every reach is only in a state of quasi-equilibrium. Trends and types of morphological change should therefore be taken into account (cf. Fig. 6).

Protection and management of broader river corridors within which the river migrates and / or avulses provides for the maintenance of more natural river morphologies in the region. Broadening of some fairways was recognised in discussion as being valuable.

However, the feasibility is ultimately dependent on cost-benefit analysis. Nevertheless, it was acknowledged that new schemes should take this into account.

4. Key questions addressed

Are there any reasonably pragmatic and simple methods of measuring and defining quality of channel morphology, and thereby habitat heterogeneity, that Horizons could use?

Yes. Historic and ongoing mapping of channel planform and exposed riverine sediment (ERS) using aerial photography. Refer 3.2.2.

What are some monitoring recommendations for maintaining good channel morphology and enhancing poor channel sinuosity (both on a habitat and river length scale)?

Refer 3.2.3. Enhancement of morphology may require reverse engineering to broaden fairways. However, a focus on channel sinuosity may be misleading. It is preferable to take a holisitic approach to assessment of channel morphology. ERS as a means of reach characterisation provides a clearer focus.

How can these recommendations be utilized for policy development (down to a level of detail to develop plan rules) and for resource consent conditions to address any adverse impacts from river engineering works such as major channel diversions or bed lowering/ instream gravel excavation

Morphological diversity should be recognised as valuable in plans. There needs to be a shift away from the maintenance of regular curving channels, which effectively generate a continuous run. Even in some straightened channels (e.g. Hutt River) morphological diversity is achievable, with alternate / diagonal bars and well developed pool-riffle units developed (cf. Figure 2). Natural bedform development should be permitted within the river corridor / fairway to enhance morphological diversity.

How can Horizons address cumulative impacts on river sinuosity and instream morphology over time? (We would like to introduce some degree of cumulative assessment into our policy framework around the beds of rivers).

Sinuosity and morphology need to first be contextualised by identifying historic changes. Selected sensitive reaches should then be monitored. Refer 3.2.3

What different engineering methods can be applied to minimize environmental footprints or to actively participate in habitat enhancement (please provide examples that may be applied to the Horizons Region)?

Widths of channel fairways should be expanded to increase accommodation space for barforms and secondary or avulsive channels. This will maximise morphological diversity in the region's rivers.

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Appendix 1:

Table 1: Summary of criteria used for broad level classification in the Rosgen method (1994). *Source:* Table 7.3, Thorne *et al* (1997).

Stream type	General Description	Entrenchment ratio	*W/D* ratio	Sinuosity	Slope	Landform/soils/features
Aa+	Very steep, deeply entrenched, debris transport streams.	<1.4	<12	1.0 to 1.1	>0.10	Very high relief. Erosional bedrock or deposition features; debris flow potential. Deeply entrenched streams. Vertical steps with deep scour pools; waterfalls.
A	Steep, entrenched, cascading, step/pool streams. High energy/debris transport associated with depositional soils. Very stable if bedrock- or boulder-dominated channel.	<1.4	<12	1.0 to 1.2	0.04 to 0.10	High relief. Erosional or depositional and bedrock forms. Entrenched and confined streams with cascading reaches. Frequently spaced, deep pools, associated step-pool bed morphology.
B	Moderately entrenched, moderate gradient, riffle-dominated channel, with infrequently spaced pools. Very stable plan and profile. Stable banks.	1.4 to 2.2	>12	>1.2	0.02 to 0.039	Moderate relief, colluvial deposition and/or residual soils. Moderate entrenchment and *W/D* ratio. Narrow, gently sloping valleys. Rapids predominate with occasional pools.
C	Low gradient, meandering, point-bar, riffle/pool, alluvial channels with broad, well defined floodplains.	>2.2	>12	>1.4	<0.02	Broad valleys with terraces, in association with floodplains, alluvial soils. Slightly entrenched with well defined meandering channel. Riffle-pool bed morphology.
D	Braided channel with longitudinal and transverse bars. Very wide channel with eroding banks.	n/a	>40	n/a	<0.04	Broad valleys with alluvial and colluvial fans. Glacial debris and depositional features. Active lateral adjustment, with abundance of sediment supply.
DA	Anastomosing (multiple channels) narrow and deep with expansive well vegetated floodplain and associated wetlands. Very gentle relief with highly variable sinuosities. Stable stream banks.	>4.0	<40	Variable	<0.005	Broad, low-gradient valleys with fine alluvium and/or lucustrine soils. Anastomosed (multiple channel) geologic control creating fine deposition with well vegetated bars that are laterally stable with broad wetland floodplains.
E	Low gradient, meandering riffle/pool stream with low width/depth ratio and little deposition. Very efficient and stable. High meander/width ratio.	>2.2	<12	>1.5	<0.02	Broad valley/meadows. Alluvial materials with floodplain. Highly sinuous with stable, well vegetated banks. Riffle-pool morphology with very low width/depth ratio.

F	Entrenched meandering riffle/pool channel on low gradients with high width/depth ratio.	<1.4	>12	>1.4	<0.02	Entrenched in highly weathered material. Gentle gradients, with a high *W/D* ratio. Meandering, laterally unstable with high bank-erosion rates. Riffle-pool morphology.
G	Entrenched 'gulley' step/pool and low width/depth ratio on moderate gradients.	<1.4	<12	>1.2	0.02 to 0.039	Gulley, step-pool morphology with moderate slope and low *W/D* ratio. Narrow valleys, or deeply incised in alluvial or colluvial materials, i.e. fans, deltas. Unstable, with grade control problems and high bank erosion rates.

APPENDIX 2: REVIEW BY GRAEME SMART NIWA