Fluvial Geomorphology Investigation of the North Central CMA Region: Introduction to the Fluvial Information System (FIS)

ippel, Brett Anderson,

ephen Wealands, and

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Central CMA

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Fluvial Geomorphic Investigation of the North Central Region: Introduction to the Fluvial Information System (FIS)

For North Central CMA

Fluvial Systems Pty Ltd

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Author:	Chris Gippel, Brett Anderson, Tim Doeg, Steve Wealands, Glenn MacLaren
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Fluvial Systems Pty Ltd
PO Box 49
Stockton NSW 2295
fluvialsystems@fastmail.net
Ph/Fax: 02 49284128; Mobile: 0404 472 114

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Executive Summary

Summary to be prepared after receiving reviewer's comments.

1 Introduction

1.1 *Project objectives*

The objective of this project is to inform the North Central CMA of geomorphic processes within the region that threaten assets within the 56 priority waterway reaches identified by the North Central River Health Strategy (2005). More specifically, this project aims to:

- compile existing geomorphic information to provide a consistent approach across the region to allow comparative assessment between basins
- close sediment-related information gaps
- determine the level of threat to assets as a result of current and expected future geomorphic processes
- identify priorities for management based on the relative level of risks from geomorphic processes to prioritised assets
- relate management priorities to the targets set out by the North Central River Health Strategy (2005).

Gippel (2006) previously identified a range of sources of relevant geomorphic information in the North Central CMA region. This report utilises the information from those sources, plus additional sources. To facilitate both geomorphological understanding and management of the stream system, these information assets were translated into an accessible form and rated for relevance. In particular, information related to sediment dynamics, which exists at different scales and resolutions, was transformed into a uniform framework and information gaps identified and filled where possible. This unified sediment status data facilitated prioritisation of action to protect the highest value assets most at risk from degradation associated with geomorphic processes, and where management action is available with the potential to mitigate the risk. The transformed and integrated data were supplemented with data from targeted field inspection that also acted as ground-truthing. A key product was development of a Fluvial Information System (FIS) into which the North Central CMA's information resources can be organised and accessed via an intuitive computer interface. The FIS is a system that is provided with data relevant to geomorphological assessment, but is equally capable of storing and assembling data required by other river management activities into the future (e.g. hydrology, ecology, rehabilitation projects), as desired.

1.2 *Project structure*

The project was conducted according to a number of defined methodological steps:

Establish a defensible and unifying geomorphic theory that is tied to practical management concerns – the framework	From the global literature, establish a theoretical basis for undertaking geomorphic observations that are both feasible and useful. Feasibility was judged principally by practical matters to do with cost and time and whether the CMA can realistically undertake the work given current and likely future resources. Usefulness was judged by the ability of the variables to contribute to an explanation of a catchment's geomorphology that can lead to management recommendations.
Assembling the data	Collect together existing source materials identified by Gippel (2006), plus other data, according to the established framework. Interview relevant persons both within and external to the NCCMA to document the body of geomorphic knowledge.
Geomorphic classification	Develop a geomorphic model specific to the North Central region that allowed the similarity of different regions to be quantified and to provide the basis for information transfer from data-rich to

	data-sparse areas.
Consolidate data in ‘Fluvial Information System’	Extract data from the collected sources based on a list of sediment-related data types and spatially tag to a location and scale. This was a staged process.
Infill knowledge gaps as necessary	A range of approaches was examined for infilling sparse or missing sediment-related data. Information transfer was guided by the geomorphic classification. Field inspections were used to verify the interpolation, as well as to confirm the definition of assets and threats, and the designation of priorities.
Define assets and geomorphic threats	The assets within the North Central region have already been identified according to the triple bottom line assessments completed in compiling the River Health Strategy. This project focused on establishing a method for: a) providing a detailed assessment of geomorphic threats; b) identifying those assets that are sensitive to devaluation by geomorphic processes; and c) estimating the degree to which interventions of different types and costs could ameliorate the level of threat.
Develop method for recommending priorities for action	Based on the level of threat to assets, and the degree to which management action can influence such threats, an approach to establishing priorities for management was recommended.

2 Geomorphic Basis of the Approach

2.1 Objectives for undertaking a geomorphological assessment in the North Central CMA region

The objective of undertaking a fluvial geomorphic investigation of the North Central region is to develop strategies for future management based on risks to assets defined by the North Central River Health Strategy (2005).

The North Central CMA is concerned about the existence of information gaps in geomorphological knowledge about the region, which comprises the Loddon, Avon Richardson, Avoca and Campaspe catchments. Various geomorphological studies have been undertaken within the North Central CMA region over previous years. The approach to these studies has varied across the different basins. Within the context of regional priorities and targets identified by the North Central River Health Strategy (2005), there is a need to:

- compile all the existing information across the region,
- identify and address critical knowledge gaps,
- ensure consistency in information across all basins within the North Central region, and
- apply a consistent approach to allow comparative assessment of management priorities and actions across basins.

The North Central River Health Strategy (2005) identified waterway related assets based on their environmental, social and economic values (referred to as assets). There is an emphasis on ‘protecting the best first’. The statewide RiVERS database provides a consistent approach across the state to identifying priority reaches within the region, based on a scoring system applied to various environmental, social and economic assets within a reach. The database generates a risk rating for assets within a reach based on the likelihood of a particular asset being affected by a threat such as erosion. It is noted here that the geomorphic component of RiVERS system is rudimentary and has not been tested for its ability to distinguish geomorphic processes and form as they relate to management concerns.

The outputs of the RiVERS database were used to identify the priority reaches within the North

Central region. Further prioritisation then occurred using a number of principles, documented within the North Central River Health Strategy (2005), which provides regional direction for priority setting. As a result of the above assessments and prioritisation processes, 56 reaches were identified as priority within the region.

A fluvial geomorphology assessment would be expected to further inform the North Central CMA of priority management areas for ensuring that the threats of sediment related processes to assets are minimised.

The main critical geomorphological information gaps are perceived to be:

- active sediment sources,
- sediment loads or rates of change, and
- the state of sediment dynamics relative to reference, i.e. what would be expected for the sites in question?

2.2 Utility of geomorphological assessment

Most on ground stream management is concerned with 'controlling' the physical form, on the (widely held) assumption that a stream in dynamic equilibrium is an important requirement for ecological health. Note that dynamic equilibrium does not equate with absolute stability. Thus, monitoring relevant aspects of a streams geomorphology will inform management in terms of relative success of the works, and how to plan the works to optimize the desired effect. Examples of typical CMA work that is directly or indirectly related to control of geomorphologic processes are:

- Preventing avulsions
- Ameliorating bank erosion through:
    - Revegetation
    - Rock beaching
    - Groynes
- Ameliorating bed change through:
    - LWD installation
    - Rock chutes
    - Pile fields
    - Sand extraction from slugs
    - Installation of sediment traps
- Increasing physical diversity through:
    - LWD installation
    - Various habitat devices

There are well-established links between certain geomorphological aspects of streams and certain ecological aspects. Managing geomorphological condition is a component of managing for biodiversity.

Channel bed disturbance is widely recognized as a key process regulating riverine ecosystem structure and function (Lisle, 2005). Because characteristics of the hydrologic regime are easier to measure and more readily available than hydraulic and substrate stability data, streamflow metrics are frequently used as surrogates for disturbance. However, frequency, magnitude, and duration of bed movement and overbank flow depend fundamentally on local geomorphic context (i.e., channel and floodplain geometry, slope, bed particle size distribution, roughness) that dictates thresholds of hydrologic disturbance (Poff et al., 2006):

> "*Only by placing hydrology in a geomorphic context can we adequately characterize the*

> *hydraulic and habitat characteristics needed to effectively manage and restore river reaches" "…at the local scale of a river reach, geomorphic context is a key to understanding the actual or effective disturbance regime associated with a particular hydrologic regime. Our simple simulations make this point and indicate that fluvial ecologists need to forge new research in this area so that we may more accurately model the habitat template so critical to effective riverine management and restoration*" (Poff et al., 2006, p. 163).

2.3 Identified potential approaches to geomorphological assessment

While the Index of Stream Condition contains a sub-index that is concerned with geomorphology, it is too crude to provide managers with information about sediment transport processes. There are numerous other approaches to rapidly assessing geomorphic form and process in the field and from maps and other data, and this form of data collection could well have a role to play in a methodology aimed at identifying sediment sources and transport dynamics. However, to gain a meaningful understanding of sediment dynamics, other information will also be required. The scientific investigation of regional sediment dynamics can be distilled down to three main approaches, empirical studies, local-scale sediment transport modelling, and catchment-scale sediment budget modelling (Gippel, 2006):

1. **Empirical approaches**

   The empirical approaches involve examining each region on a case-by-case basis, perhaps formulating a conceptual model based on the global literature and theoretical understandings, seeking out all local recorded information that might be relevant (current and historical), developing a methodology based on selective sampling of areas, stream types, variables, or a stratification based on some other dimension of the problem, and then making inferences about the entire catchment on the basis of the results of the analysis. Stream classification (e.g. RiverStyles), if taken the step beyond merely mapping the distribution of types (i.e. explaining what the types mean in terms of stream dynamics), is an example of this approach.

2. **Local-scale sediment transport modelling**

   Local-scale sediment transport modelling involves application of hydraulic formulas that describe the process of sediment entrainment, transport and deposition to particular stream systems. Such studies require reasonably detailed data on channel morphology (cross-sections and long profiles) and hydrological data. These models are founded on well-known physical principles that describe the behaviour of sediment in water. While application of these models is widespread, it is far from a trivial exercise, and requires a good deal of experience to undertake the modelling and to interpret the results.

3. **Catchment-scale sediment budget modelling**

   Catchment-scale sediment budget models (of which SedNet is one example) link models of sediment availability (from slopes, gullies and channel banks) and hydraulic models of sediment transport and deposition to predict actual sediment delivered from a catchment rather than potential sediment transport. The models are applied over entire catchments by utilizing available digital elevation models, and other GIS-based data sets. Such models are structured to enable the determination of the contribution from each erosion source, at each point in the river network. These models are primarily intended for identifying the spatial distribution of sediment processes at the catchment scale, and model developers do not claim that they will make reliable predictions at the reach scale.

2.4 Adopted approach to geomorphological assessment

While not discounting the utility of the conventional approaches to regional-scale and catchment-scale geomorphological assessment, we propose a hypothesis that leads to a new approach. This hypothesis was driven by the practical reality that North Central CMA is not in a position to undertake detailed sediment modelling over their entire region, and was seeking a more cost effective way of delivering similar or even better outcomes (better in terms of how the outcomes link to management recommendations).

> *It is hypothesized here that the North Central CMA already possesses sufficient information on sediment dynamics to inform management in a reliable way.*

Our basis for this hypothesis is the large investment that the CMA has made in geomorphological and related investigations over the past decade or so. Testing this hypothesis requires review of the existing information, but not in the usual narrative form. The geomorphological data in the possession of the CMA exists in a multitude of forms, and to be able to utilise these data to obtain a regional-scale understanding of sediment dynamics, it was first necessary to transform the data into common metrics. Of course, had the geomorphological studies all been undertaken with a common methodology, or as a minimum requirement, been required to report on a common set of metrics, then this current task would be much simpler. Thus, if the hypothesis is supported, it is proposed that the CMA adopt certain minimum standards, common methodologies, and reporting requirements that all future geomorphological investigations should follow, so that the understanding of sediment dynamics can be readily and continually improved and updated.

In order to decide on a common currency into which all existing geomorphic data are converted, it is first necessary to establish a theoretical basis for the link between sediment dynamics and stream management. The common currency is actually a set of metrics, variables or indicators that are expressed in quantitative terms. A numerical approach is required for various reasons. The first is that where spatial data gaps appear it may be possible to in-fill them using modelling techniques, and modelling requires numerical data input. Secondly, sediment dynamics are concerned with the movement or otherwise of quantities of material in the landscape, so it would be preferable to express these processes using relative, if not absolute, scales, as opposed to classification scales or purely descriptive narrative. Thirdly, the data will ultimately be used for prioritisation of management actions, and this will most likely require integration with other numerically expressed ecological and/or economic data. So, as well as having a system that is well grounded in geomorphic theory, the selected variables and metrics need to satisfy certain criteria in order that they will be useful for the CMA’s intended purposes.

2.5 Review of some existing approaches to geomorphological assessment in Australia and elsewhere

2.5.1 Overview

Gippel (2007) recently undertook a stocktake of river health protocols in Australia. This revealed that physical form is not widely measured in a systematic way. Victoria and Tasmania (in development) have considered physical form as part of their indices of stream health. There have been some problems in achieving consistent and reliable application of the physical form sub-index of the Victorian ISC, which a recent review of geomorphic methods did not resolve. Queensland has used the State of the Rivers methodology for some time, but there is not a lot of support to extend and maintain this program; some categorisation of reaches for assessment has occurred in later State of the Rivers assessments based on classification by Geomorphic Assessment of Rivers (GAR) methodology.

NSW has undertaken a considerable amount of physical form assessment using the River Styles® methodology (a method of geomorphic stream classification) with almost 60 percent of the state’s rivers assessed. River Styles® includes post-classification stages, the first being assessment of river condition to predict likely future river form, and the second being prioritizing catchment management issues, and identification of suitable river structures for Rivercare. River Styles® can be used to separate rivers and reaches in management classes and develop different management objectives for these on the basis of predicted trajectory. River Styles®, or a modified version of it, has been applied in some catchments in Victoria, mostly in the Melbourne Water region

2.5.2 ISC in Victoria

The Index of Stream Condition is the standard method to assess river health in Victoria. The ISC is an integrated measure of stream health that is regarded as straightforward and transparent, intuitive, and an appropriate balance of: cost/speed; accuracy; and scientific rigour. The ISC is a referential approach and it measures change over the 10 – 15 year timeframe.

The components (sub-indices) of the ISC are:

- Hydrology;
- Streamside Zone;
- Physical Form;
- Water Quality; and
- Aquatic Life

The ISC assesses a stream network that covers 26,000 km stream length. It includes major rivers and their tributaries (1:250,000 scale) but does not concentrate on minor streams. The 1,100 reaches assessed are typically 10 – 30 km in length, with each being effectively homogeneous in terms of hydrology, forest cover and broad geomorphology.

Data are reported every 5 years (1999, 2004) with the next assessment due in 2009. Water quality and hydrology data are collected monthly, and macroinvertebrates are sampled in spring and autumn.

The Physical Form sub-index indicators are bank stability, presence of artificial barriers, and density and origin of coarse in-stream large wood (LWD). Equal weighting is given to bank condition and in-stream habitat.

The ISC uses test and reference sites. The scoring system scores each sub-index out of 10 in increments of 1, giving an ISC score out of 50. The values are given inverse ranking with the final score allotted to one of 5 condition classes.

The physical form sub-indices are scored by reference to descriptive ratings and reference photographs. The assessment is entirely visually based - measurements of width, depth, particle size, etc are not undertaken (White and Ladson, 1999).

In the second benchmarking of stream condition, undertaken in 2004, the original (1999) bed stability metric was removed because this property of streams was found to be highly variable and it was difficult to establish the metric on the basis of one field inspection. Most of the differences in physical form scores were due to random site selection (Department of Sustainability and Environment, 2005).

2.5.3 River Styles®

The River Styles® (http://www.riverstyles.com/), which has been applied mostly but not exclusively in New South Wales, includes post-classification stages, the first being assessment of river condition to predict likely future river form, and the second being prioritization of catchment management issues and identification of suitable river structures for Rivercare. The scheme is strongly evolutionary and it provides a common geomorphic language with which to describe the fluvial characteristics of rivers and predict their recovery potential. The method has three stages. The first stage is to determine the river type based largely on desktop analysis, with some field checking. The second stage is to measure condition relative to reference, and third stage is to assess recovery potential. A reasonable percentage of NSW has been assessed at the level of these three stages. Not all of the valleys have been assessed with the same level of rigour. For example, a ‘broad-brush assessment of geomorphic condition’ was undertaken of the streamlines examined in the Namoi valley study (Lampert and Short, 2004). As this was largely an assumptive process the term ‘indicative condition’ was adopted, based on three broad categories of condition – good, moderate and poor (Lampert and Short, 2004).

Stream condition is measured at the scale of the reach feature. Relative condition is with respect to a reference which is usually ‘assembled’. However, a reasonable number of reference reaches have now been surveyed in NSW and these can be used for comparison where appropriate.

The Stage 2 assessment requires measurement of up to 22 variables, with 6 of these being derived from other variables or calculated in the office. The field exercise requires 3 people about 2 hours to complete. Assuming that 2-3 sites can be completed in one day, this works out at about $1,000

– $2,000 per site for fieldwork. The office work probably takes at least as long again, for one person.

2.5.4 Assessing physical form of Tasmanian rivers

River Styles® framework has been applied in Tasmania (Jerie et al., 2003). The rivers of Tasmania have been placed into categories of river domains and fluvial mosaics by Jerie et al. (2003). The approach currently under development to the assess the physical form of Tasmanian Rivers (Slijkerman et al., 2007) aims to use the attribute tables associated with the fluvial mosaics defined by Jerie et al. (2003) to suggest relevant parameters that can be used to provide a measure of condition. The attribute tables associated with the fluvial mosaics may also be used to predict the degree of variation likely within each parameter, which will vary regionally. The number, and types, of measurements to be taken would be guided by the time constraints associated with the number of sites that need to be assessed. In addition to assessing reaches against expected conditions, a set of indicators/metrics will also be chosen from existing methods to characterise river features and allow detection of change. Most indicators of physical form are qualitative in nature and will require adjustment to provide a quantitative assessment without having to undertake some form of predictive modelling.

The Tasmanian ISC plans to measure the following variables:

- Planform:
    - Sinuosity
    - Number of Channels
    - Floodplain Features
- Cross-Sectional Form:
    - Bankfull Width:Depth Ratio
    - Bank Shape
    - Bank Condition (erosion)
- Bedform:
    - Roughness (barriers, flow types, wood, macrophytes)
    - Sediment Size

2.5.5 Geomorphic Assessment of Rivers (GAR) in Queensland

The Geomorphic Assessment of Rivers (GAR) (e.g. Brennan and Gardiner, 2004) is similar in to Stage 1 of the River Styles approach, includes new geomorphic categories, and involves mainly desk-top assessment. Where other data are available (e.g. State of Rivers, Technical Assessment Panel reports and other previous geomorphic reviews) they may also be incorporated into the assessment (Land & Water Australia, 2004).

The Geomorphic Assessment of Rivers (GAR) breaks down a length of river into reaches of similar character and behaviour (EPA Queensland, 2007). The first step of the GAR is a desk-top assessment to plot longitudinal profiles. Slope is then plotted. Stream power is calculated based on bank-full discharge and hydraulic slope. Tentative reach divisions are then determined. Aerial photos are analysed for visual indicators of river character and behaviour and divisions proposed. These divisions are compared with those previously calculated and adjustments made. Field surveys which include assessment of bed and bank material calibre are then used to confirm the assessment (EPA Queensland, 2007).

2.5.6 QHER(Quantifying the Health of Ephemeral Rivers) Assessment in South Australia

Most river health assessment programs have been designed to determine the health of permanently flowing streams in the eastern and southern regions of Australia. Many of South Australia's rivers are ephemeral, carrying significant flow only during the wet season (winter). DWLBC and SA

NRM boards identified this as a major information gap for managing dry land Rivers across Australia. The QHER (Quantifying the Health of Ephemeral Rivers) project (http://www.gu.edu.au/centre/riverlandscapes/content04f2.html) was funded by Land and Water Australia, and undertaken as a combined CRC for Freshwater Ecology and CRC for Catchment Hydrology project (both CRCs no longer operate).

The QHER project aimed to develop the most appropriate methods for quantifying the health of ephemeral rivers and streams. The project evaluated and compared a range of river health assessment methods, including those developed and in use within Australia as well as some used overseas. Field trials of indicators and assessment techniques were undertaken on ephemeral streams within South Australia. Themes included hydrology, physical form, fringing vegetation and biota.

This program identified, developed and modified river health assessment tools/methods that were the most appropriate for use in ephemeral rivers. The program developed written protocols for the use of the identified river health assessment tools and interpretation of data collected in a form that can be readily used by managers, NRM board officers and others with responsibilities and interests in assessing river health.

The Murray NRM Board has initiated a monitoring program using this method at 260 ephemeral stream sites across their region.

Costelloe and Ladson (2006) used the QHER data collected in the Eastern Mt Lofty Ranges to compare different ways of assessing physical form. They suggested five ways to assess the current stream state. These include the use of a: (i) reference condition, (ii) synthetic reference condition, (iii) disturbance gradient, (iv) trajectories of change, and (v) risk assessment. Of these, they used three groups of variables (Table 2-1).

Table 2-1.
Major categories of each of the geomorphic indicators. Costelloe and Ladson (2006).

Geomorphic indicator	Category
Bank erosion	Trajectory
Channel incision	Trajectory
In channel sediment storage	Trajectory
In channel sediment stability	Trajectory
Channel stability	Risk assessment
Bank stability	Risk assessment
Anthropogenic structures	Synthetic reference condition
Habitat complexity	Synthetic reference condition

Reference condition (i) uses real reference reaches (i.e. currently in relatively undisturbed condition) for comparison, while synthetic reference (ii) is derived from information from other studies and expert opinion. The disturbance gradient (iii) is a measure of the dominant cause of disturbance that results in fundamental and widespread changes in the health of that catchment and surrounding catchments. The disturbance gradient has to be a common cause of the deterioration of catchment health over a large region. The 'Trajectory of Change' (TOC) approach (iv) may be useful for identifying the site geomorphic response to long-term trends in the flow regime. For instance, increases in streamflow in response to catchment clearance can lead to channel incision and widening. In contrast, decreases in streamflow in response to increases in farm dam storage may lead to channel infilling. An advantage of this approach is that it provides information on basic processes that respond to a number of potential stressors and are not limited to a single disturbance gradient. Indicators that provide some measure of risk assessment of the potential of the river health to change are the fifth category (v). An example of this approach is an indicator of the potential for further channel incision, such as the stability of the channel substrate. This moves away from a purely disturbance gradient approach as these measures do not need to be significantly correlated to a disturbance gradient to be deemed useful.

Costelloe and Ladson (2006) did not provide sufficient analysis or discussion to enable evaluation of their methods, but they indicated that the geomorphic indicators can be used to identify the position of a reach in a trajectory of geomorphic change in response to catchment change. While this does not provide a direct measure of health it can be used to provide a context for the evaluation of other measures of stream health.

2.5.7 VEFMAP Victoria – monitoring channel form and dynamics

The Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) (Cottingham et al., 2005) has been established to coordinate the monitoring of ecosystem responses to environmental flows. Water will be delivered as environmental flows to achieve specific ecosystem outcomes in a number of Victoria's large regulated rivers. It is important to demonstrate whether or not the Environmental Water Reserves are achieving the desired ecosystem outcomes.

In each of the reaches previously identified for environmental flow enhancement environmental flows and other major influences (e.g. land use) will drive the ecosystem responses. In the VEFMAP program, (e.g. Chee et al., 2006) conceptual models were synthesised that illustrated how certain ecosystem components were believed to respond to environmental flows. The models suggested measurement endpoints (e.g. bank erosion, fish abundance) that can be obtained from various field programs (e.g. channel surveys and electrofishing for the two endpoints above). It is expected that these endpoints will respond to environmental flows. The responses will be tested using Bayesian or other analytical approaches (Chee et al., 2006).

The conceptual model for geomorphological response suggests sediment starvation widening and incision immediately downstream of dams, and aggradation and narrowing in the low capacity-high supply zone further downstream where tributaries deliver sediment to the main stream (Figure 2-1). This is a process model, based on the knowledge that the main drivers of morphological change are flow and sediment (Petts and Gurnell, 2005).

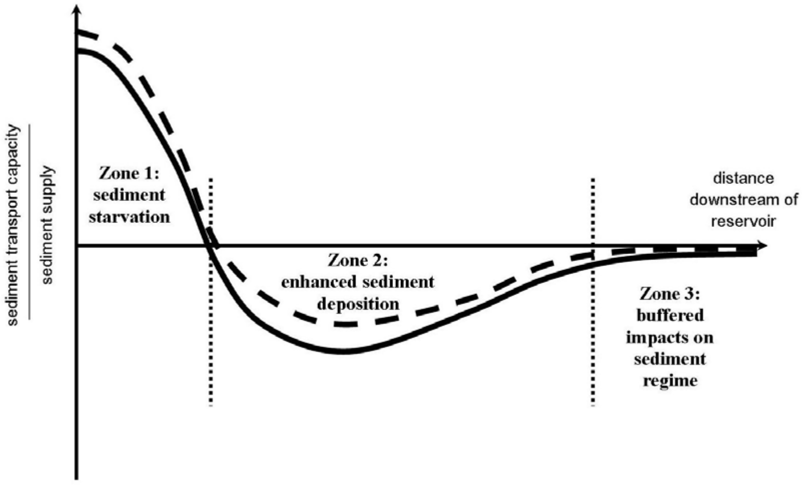


Figure 2-1. Conceptualisation of the change in sediment and flow regimes downstream of dams. The X-axis represents distance downstream from the reservoir, with Zone 1 being immediately downstream. Solid line: regulated flow conditions; dashed line: with environmental flow allocation. Source: Chee et al. (2006).

Based on this conceptual model, Chee et al. (2006) proposed that key endpoints to be monitored in the VEFMAP are: (i) changes in channel geometry (i.e. channel width, depth and complexity) (ii) changes in channel alignment (i.e. rates of bank erosion and deposition on benches) and (iii) changes in the frequency of geomorphologically significant events (i.e. frequency of events during which bed sediments are redistributed or there is development of meander bends and benches). It was recommended that sampling be concentrated in the aggradation zone, where the positive effects of environmental flows are expected to be greatest.

Chee et al. (2006) proposed a channel survey comprising cross-sectional and longitudinal bed profiles. The survey should use at least 15 permanently marked cross-sections surveyed to a fixed datum. The monitoring site should include at least one full meander wavelength. The cross-sections would be re-surveyed every 5 years. It was also proposed that a HEC-RAS hydraulic model be established for each surveyed site, so that relationships between water height and discharge could be established. The cost of undertaking the cross-section survey work and developing the HEC-RAS model is $7,000 per site (Angus Webb, pers. comm., November 2007).

Bed material movement is to be monitored by observing the movement of painted lines on exposed point bars (recorded in photographs). Geomorphologically significant events are defined as events where bed or bank sediments are mobilised. Geomorphic events will be identified by increased turbidity in the main channel associated with increased flows in the main channel (Chee et al., 2006). This will require setting up recording turbidity meters in the river.

It is important to recognise that VEFMAP is a targeted monitoring program specifically investigating the impacts of environmental flows rather than a general regional-scale geomorphological assessment protocol.

2.5.8 Diagnostic approach to geomorphological assessment

Montgomery and MacDonald (2002) developed a diagnostic approach to measuring geomorphic condition. Current practice in fluvial geomorphology stipulates that the diagnosis of physical channel condition include an evaluation of characteristics that are sensitive to changes in transport capacity (discharge frequency and magnitude), the amount and size of sediment, type and density of riparian vegetation, availability and abundance of flow obstructions (e.g. large woody debris and bedrock outcrops), geomorphic context (e.g. confinement and valley slope), and disturbance history (Figure 2-2). An understanding of channel condition and potential response depends on an evaluation of the current and future influence of each of the primary forcing factors (sediment load, transport capacity, flow obstructions, and riparian vegetation) within the existing bio-geomorphic context. Thus an assessment of stream condition requires an understanding of watershed as well as channel processes.

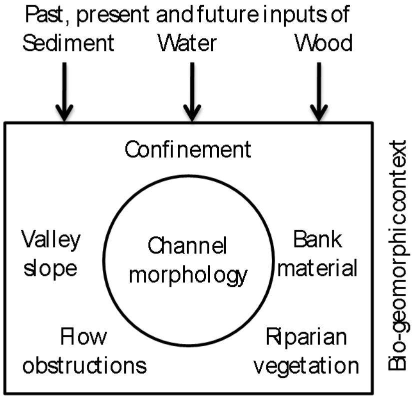


Figure 2-2. Controls on channel morphology. Source: Redrawn from Montgomery and MacDonald (2002).

The first step in the diagnostic procedure of Montgomery and MacDonald (2002) is to define the reach(es) of interest and place them in regional, watershed, and local context.

Changes in riparian vegetation, such as those that can accompany livestock introduction, may trigger channel change. Knowledge of the condition and changes in riparian vegetation often is needed to assess and interpret the condition of a river or stream relative to past and potential states.

Montgomery and MacDonald (2002) proposed that a number of valley bottom variables and active channel variables be measured (Table 2-2). Slope is a key parameter for interpreting channel condition, as it largely determines the expected channel types. Lateral confinement provides an initial guide to the potential range of channel response. Taken together, valley bottom slope and confinement imply probable channel form and general response potential, but do not usually indicate current stream condition.

Table 2-2
Role of Primary Field Indicators in Diagnosing Channel Condition. Montgomery and MacDonald (2002).

Field Indicators	Role
Valley Bottom Characteristics	
Slope	Primary control on channel type and style of energy dissipation.
Confinement	Primary control on possible planform channel patterns.
Entrenchment	Indicates longer-term balance between runoff and sediment loads, and likely range of responses to high flows.
Riparian Vegetation	Primary control on channel characteristics.
Overbank Deposits	Indicates type and magnitude of recent deposits.
Active Channel Characteristics	
Channel Pattern	Braided channels imply high sediment loads, non-cohesive banks, or steep slopes. Large amounts of LWD can also generate anastomosing channel form in lower-gradient channels.
Bank Conditions	Location and extent of eroding bank relative to stream type can indicate level of recent disturbance.
Gravel Bars	Number, location, extent, and condition related to sediment supply.
Pool Characteristics	Distribution and amount of fine sediment deposition can indicate role of flow obstructions and whether sediment loads are high for a given channel type.
Bed Material	Size and distribution of surface and subsurface bed material can indicate relative balance between recent discharge and sediment supply.

An entrenched channel is one where a small, active floodplain is isolated from the valley floor even during rare high-discharge events. A moderately-entrenched channel has an active floodplain that is inundated during moderately frequent discharge events, but the floodplain lies below a larger terrace that is only rarely subjected to flooding. A channel is not entrenched when the flood plain and valley floor are approximately coincident.

The presence and nature of overbank deposits can indicate the type and magnitude of past disturbances.

Pertinent channel attributes reflect current and past sediment supply, transport capacity, flow obstructions, riparian vegetation, and past disturbance.

A change in channel type or sinuosity in sequential aerial photographs can indicate a significant change in sediment supply, transport capacity, riparian vegetation, or the supply of wood debris. For example, dredging and historical removal of wood from the Willamette River, Oregon, was associated with a change in the channel pattern from a complex anastamosing system to a single thread channel (Sedell and Froggatt, 1984).

Bank erodibility and bank erosion are controlled by the channel type, location within the channel, history of high flows, bank material composition, and the amount of bank protection offered by vegetation and wood debris. Qualitative descriptions of bank erosion can be strengthened by estimating the percentage of the bank length undergoing active erosion, but the amount of bank erosion should be interpreted within the context of the dominant channel-forming processes and the bank material. Bare, eroding banks on the outside of meander bends may be expected in pool-riffle channels. Bank erodibility and bank erosion are controlled by the channel type, location within the channel, history of high flows, bank material composition, and the amount of bank protection offered by vegetation and wood debris. Qualitative descriptions of bank erosion can be strengthened by estimating the percentage of the bank length undergoing active erosion, but the amount of bank erosion should be interpreted within the context of the dominant channel-forming processes and the bank material. Bare, eroding banks on the outside of meander bends may be expected in pool-riffle channels.

Gravel bars are sediment accumulations within the channel that are one or more channel widths long. Bars typically form where the stream gradient is less than about 0.02, and the bankfull width-to-depth ratio is greater than about 12. The size, stability, and location of gravel bars can be a strong indicator of a change in sediment supply or transport capacity. For example, medial bars within a channel or bar deposits on the outside of a meander bend can indicate an increase in sediment supply, a decrease in transport capacity, or both. Conversely, channel narrowing and an increase in bar stability — usually caused by vegetation colonization — indicates a decrease in sediment supply, a decrease in the frequency and magnitude of high flows, or both. Gravel bar characteristics, therefore, need to be interpreted according to channel type, valley configuration, position in the channel network, and the nature of the bar-forcing mechanisms.

Channel width generally increases with the square root of the drainage area, and depth increases as a power function of the drainage area. However, there can be substantial local and regional variability in these relationships. Reference relationships should be developed from field measurements in relatively undisturbed basins. An understanding of the geomorphic context and disturbance history is therefore necessary to evaluate the causes of local variability in channel dimensions, width-to-depth ratios, or hydraulic geometry.

Pool depth and pool volume are ecologically important characteristics that can vary with sediment load and pool-forcing mechanism. Large increases in sediment load can reduce pool depth and pool volume.

The size of particles on and below the channel bed surface is sensitive to changes in the volume and size distribution of the sediment supply, transport capacity, and abundance and size of wood debris. Both an increase in basal shear stress and a reduction in sediment supply can cause winnowing, and thereby a coarsening of the bed surface. Conversely, an increase in the supply of fine sediment or a decrease in the size of high flows can lead to a reduction in the size of the particles on the bed surface. Higher wood loading provides greater hydraulic roughness, which also favors a fining of the bed surface, whereas lower wood loading can decrease hydraulic roughness and result in bed surface coarsening. The amount and location of fine sediment on the channel bed provides additional diagnostic information. In some channel types the volume of fine sediment overlying coarser material in pools can serve as an index of fine sediment supply. The spatial distribution of fine sediment can indicate the relative magnitude of the fine sediment load, but the calibration of this indicator will vary with channel type and other factors such as the local geology.

2.5.9 Modelling sediment dynamics

For stream channels, Rowntree and Wadeson (1999) identified the problem of determining departure from geomorphic reference condition as one of measuring the extent to which changes are observed in three key groups of factors:

1. System connectivity:

    the connectivity between channel network and hillslopes

    the connectivity within the channel network

    the connectivity between the channel and the riparian zone

2. Sediment balance:
    - the sediment supply from the hillslopes
    - the sediment supply from the channel
    - the capacity to transport sediment

3. Resistance of the channel to change:
    - the resistance of the channel perimeter

These factors are closely linked to the factors used to classify floodplains under the Nanson and Croke (1992) and related classification schemes, i.e. distribution of energy (stream power of flowing water) and resistance (related to particle size).

When the National Land and Water Resources Audit was charged in 2001 with assessing the physical condition of Australia's rivers, Prosser et al (2001) took a process approach (i.e. SedNet models). Stream form was not measured at all, with necessary form variables being estimated using regional relationships. This process approach is consistent with the proposition that form is the result of sediment supply, hydraulic capacity to move sediment and the resistance of the channel to erode or for sediment to be entrained. Also, it is known that most of the changes to channel form in Australia have come about because of a major change in one of those three controlling variables (i.e. hydrology, sediment supply or resistance of the bed and banks to erosion). Thus, the change in form should be predictable from variables that capture these processes. Gippel (2005) developed an Index of Floodplain Condition on the basis of the NLWRA data.

One of the weaknesses of SedNet models is the lack of empirical channel morphology data, so these models could be improved by availability of the right field data. These data would be bed particle size, bank cohesivity (particle size measure), channel width, Manning's n (roughness measure), and degree to which the steam bed and banks are stabilized by vegetation (using a measure of cover). By informing the SedNet models with empirical data, the models would be sensitive to changes in conditions that determine the output. In this way, the SedNet models would themselves be a monitoring tool.

Future SedNet modelling efforts would benefit from collection of certain field data. Even without running a SedNet model, bed stability and bank can still be assessed by estimating stream power, using slope (measured from DEMs) and discharge estimates. These process-based variables are linked to ecology, especially through the disturbance hypothesis.

Channel dimension and bed material size data combined with modelled stream power could be used to predict the past disturbance regime of sampled sites, and could also be used to plot a map of the disturbance for the entire basin for any particular year or period of years. This could help explain observed temporal variations in ecological data. Modelling stream power distribution at the catchment scale is a well-established procedure, and has been applied in some Australian catchments (Jain et al., 2006; Reinfields et al., 2004; Worthy, 2005).

2.6 Theoretical and practical basis of a geomorphological assessment approach

2.6.1 Overview

A mixed form- and process-based assessment is proposed for geomorphic assessment of the North Central CMA region. This will be based on a number of field variables, complemented by derived variables from desktop analysis and modelling.

Lane (1955) proposed that a channel will be maintained in dynamic equilibrium when changes in sediment load and bed-material size are balanced by changes in streamflow or channel gradient (Figure 2-3). A change in one of these four factors causes changes in one or more of the other variables such that a stable condition tends to become re-established. According to Lane (1955), the sediment particle size controlled its likelihood of movement, but in fact, the inherent stability of bed and bank material can be enhanced by live vegetation and wood debris. A change in the volume of sediment being supplied to a stream can also alter stream dynamics in cases where the stream lacks the capacity to transport all of the material.

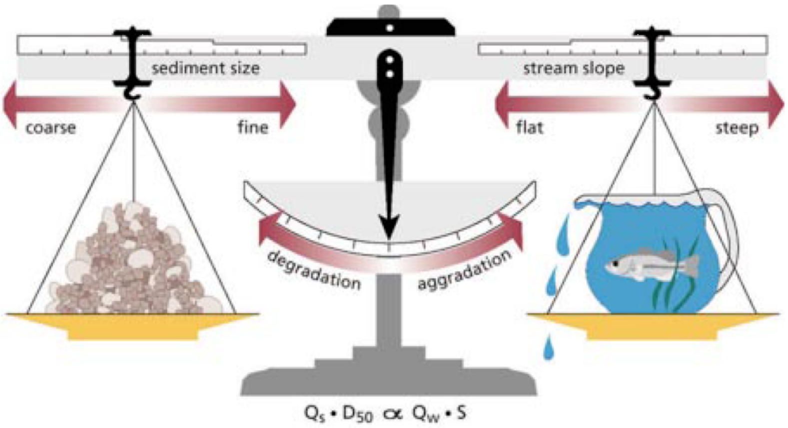


Figure 2-3. Lane's (1955) stream power proportionality equation that expresses the stream dynamic equilibrium. Channel Q_w is the stream flow discharge, S is the channel gradient (slope), Q_s is the sediment discharge, and D_{50} is the median grain size of the bed material. Source: Montana Department of Natural Resources and Conservation (2001), redrawn from a figure in Lane (1955).

The stream equilibrium concept of Lane (1955) can be elaborated as a principle that stream physical form adjusts to the interaction of three main process factors:

1. sediment supply (from hillslopes, banks and in-channel),
2. energy (capacity of the stream to mobilize and transport materials – hydrology and hydraulics), and
3. resistance of the channel and floodplain to change (inherent cohesivity of banks/floodplain surfaces and size of bed material, and enhanced cohesivity from large woody debris and riparian vegetation).

Physical form is in long-term dynamic equilibrium (i.e. erosion and deposition processes both occur within expected bounds) when the three key process factors are balanced. Physical form will be on a long-term trajectory of change in a certain direction when these process factors are unbalanced. Many streams in the North Central CMA region may not be in balance (which would be conducive to relative stability), but rather be either recovering from a previous major change in one of the three main process factors, or changing in response to current disturbances. Change through time is to be expected, even for reference physical form. A stream management-focused monitoring methodology needs to be sensitive to change in the controlling process factors and the resulting form variables over the 1 – 100 year timescale.

Geomorphic processes and condition can be measured and expressed relative to absolute scales, or even using a relative scale specific for the region. However, it may also be desirable to measure form and process against reference condition. This would make for a more universally applicable method. However, definition of reference is a difficult problem, and it is beyond the scope of the current project.

Good or desirable geomorphic condition is a state that does not limit the achievement of good or desirable ecological condition. Reach-scale condition metrics have an associated underlying principle that is related to condition (Table 2-3). The literature contains a wealth of information indicating that ecological condition (i.e. vegetation, fish and macroinvertebrates) is related to geomorphological condition (defined as the balance of sediment supply, transport capacity and resistance to erosion – which gives rise to a distribution of geomorphological forms at the stream type and reach scales).

Table 2-3.

Underlying geomorphic condition principles for reach-scale process and form conditionmetrics.

Reach-scale metrics	Underlying condition principles – condition is relative to reference
Channel form	Overly wide/narrow or shallow/deep channels (compared to reference) indicate a change in the balance of sediment supply, capacity to transport sediment, and/or resistance of the channel to erosion. This is often associated with altered physical habitat structure. Such changes also indicate altered floodplain hydraulic connectivity (e.g. an incised channel has reduced connectivity). A general principle is that high geomorphic diversity (within the limits of the geomorphic setting) is associated with high biotic diversity (vegetation, fish and macroinvertebrates).
Bed dynamics	Periodic disturbance of the bed (e.g. redistribution and downstream transport of bed material, and flushing of fines) is required to maintain ecological processes (esp. for macroinvertebrates). Excessive bed disturbance frequency or intensity, or reduced sediment supply, can be associated with poor ecological condition through degradation of physical habitat (incision); inadequate disturbance can give rise to fine sediment on top of and within the substrate; excessive sediment supply can lead to aggradation (e.g. sand slugs) and low diversity of channel form (processes that impact on vegetation, fish and macroinvertebrate condition).
Bank dynamics	Maintenance of rates of erosion and accretion of the banks within natural ranges (stream type-dependent) is desirable from a geomorphic perspective, but excessive erosion frequency or intensity can be associated with poor ecological condition through excessive sediment production, excessive disturbance, or degradation of physical habitat (processes that impact on vegetation, fish and macroinvertebrate condition). The condition of riparian vegetation is strongly associated with the condition of bank dynamics.
Floodplain	Floodplain geomorphic condition depends on the form of the floodplain features being intact (i.e. the various floodplain forms have not been overly modified by land use) and the floodplain being inundated at the desirable frequency, duration and velocity/shear stress (a function of the stream's hydrology, the hydraulic relationship between floodplain form and channel form, and floodplain roughness). Floodplain condition is also dependent on an intact sediment transport regime (i.e. intact connectivity, and sediment supply rate within desirable range). Maintenance of floodplain geomorphic form and process is important for maintenance of the condition of fish and floodplain vegetation in particular.

2.6.2 Spatial scales of sediment dynamics and channel form response

Schumm (1977) envisaged a broad-scale system of three functional zones based on sediment transport (Figure 2-4). Most of the sediment from the production zone passes through the transfer zone but because temporary and intermittent storage of material occurs, this may take a considerable time (Pickup, 1985). Alternating scour and fill is characteristic of the transfer zone as material is added to or removed from temporary storage (Pickup, 1985). The sink occurs downstream of the transfer zone and is an area of sediment accumulation. The rate of accumulation in a sink may be highly variable depending on the rate of delivery, shifts in the locus of deposition and the position within the sink (Pickup, 1985). While the variables of the fluvial system show general downstream patterns of change, there are not necessarily any discontinuities at the boundaries of the geomorphological zones (Figure 2-4).

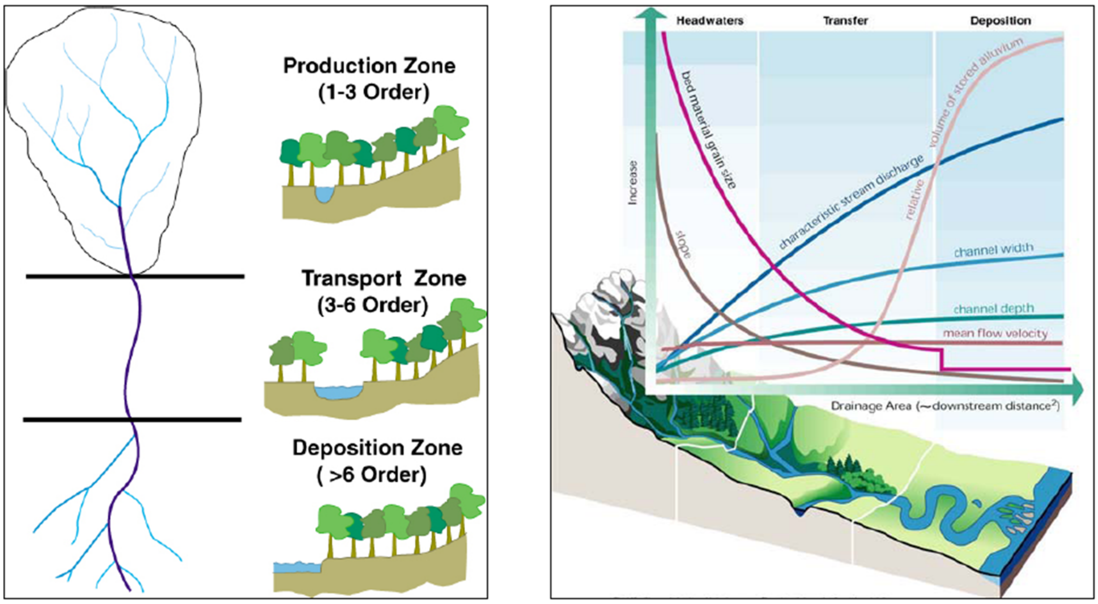


Figure 2-4. Schumm's (1977) three functional zones of the stream: zone of production, zone of transfer or transportation, and zone of deposition (left). The hydrologic and geomorphic changes among the three functional zones of the streams (right). Source: FISRWG (1998).

An objective method of drawing the boundaries of Shumm's (1977) three functional zones has never been proposed in the literature. Montgomery and Buffington (1997) proposed a general model that seemed to be primarily based on slope classes (Figure 2-5). Whittington et al. (2001) and Thoms et al. (2001) called Schumm's (1977) zones Valley Process Zones (VPZ). They also defined these zones at a smaller scale, called Functional Process Zones (FPZ), defined by gradient, stream power, valley dimensions and boundary material. The source zone contained FPZs Pool, Upland gorge and Armoured, the transport zone contained the FPZs Mobile and Meander, and the deposition zone contained the FPZs Anabranch, Distributary and Lowland Gorge. While Whittington et al. (2001) and Thoms et al. (2001) provided a list and description of the variables used to map FPZs and VPZs, they did not provide a methodology that would enable a practitioner to undertake such mapping.

In reality, within Schumm's (1977) broadly defined functional zones, at smaller scales, examples of all three sediment transport processes may be observed.

Over the catchment-wide spatial scale, different channel types can be found, and Schumm (1977) related the stability of channels to the kind of sediment load and the channel type (Figure 2-6). While these channel types would show a spatial distribution that roughly correlated with the three functional zones, from the management perspective, it would be important to characterize stream channel processes at a scale more detailed than the broad functional zone. Schumm's (1977) classification includes two 'relative stability' axes (Figure 2-6). This is an important concept from the perspective of assessing geomorphic stability, because depending on position in catchment and stream type, different inherent (reference) stability should be expected. Thus, channels with naturally low relative stability should be managed within broader boundaries than channels with naturally high relative stability.

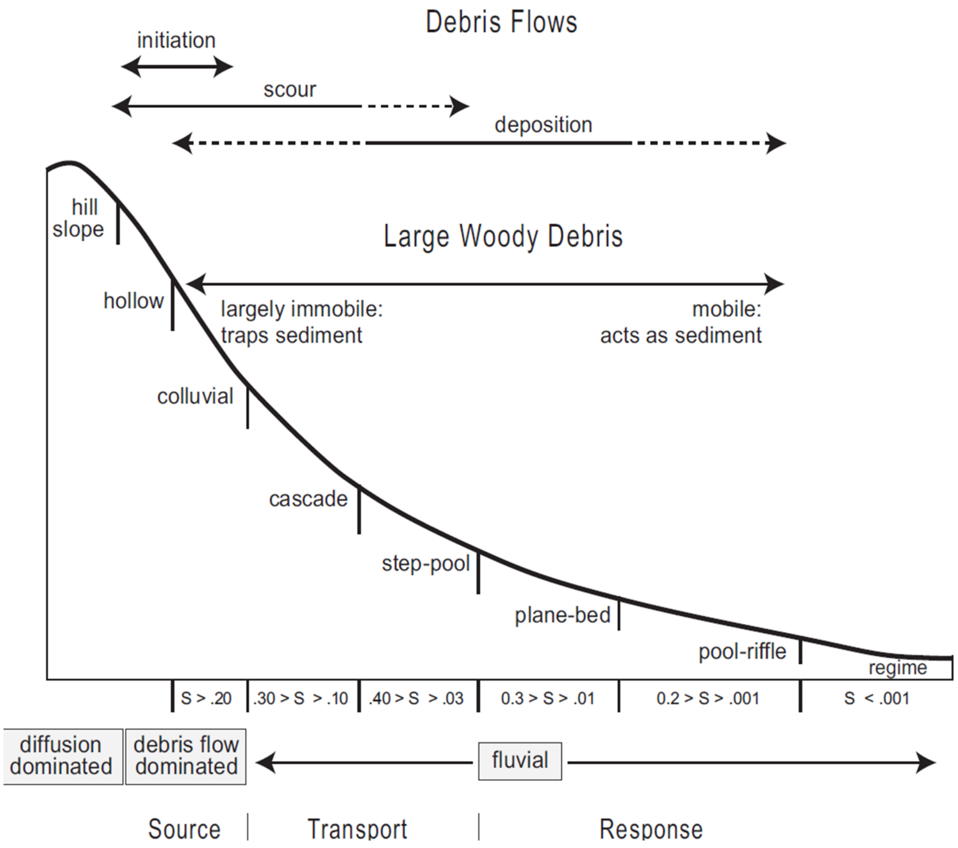


Figure 2-5. Idealised long profile showing distribution of alluvial channel types and controls on channel processes in mountain drainage basins. Source: Montgomery and Buffington (1997).

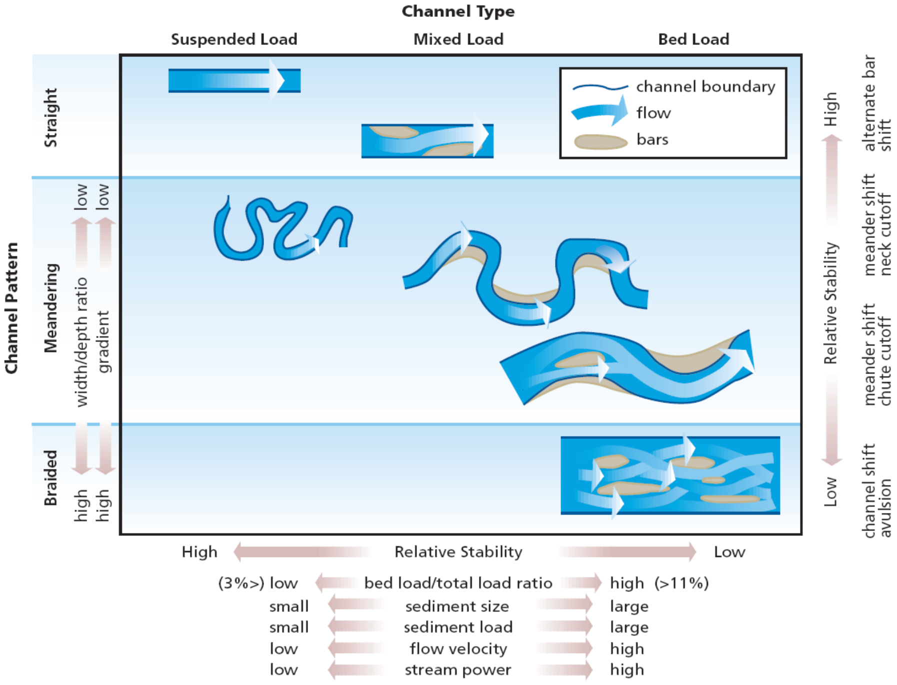


Figure 2-6. Schumm's classification of alluvial channels, which relates channel stability to the kind of sediment load and channel type. Source: As modified by FISRWG (1998) from original figure in Schumm (1977).

Along the length of a river, its relative stability could be variable depending on its stage of disequilibrium in response to a disturbance (such as flow regulation) (Figure 2-7). Channel evolution models predict that a river may present quite a variable state of stability along its length and through time, with relative stability of bed and banks also varying.

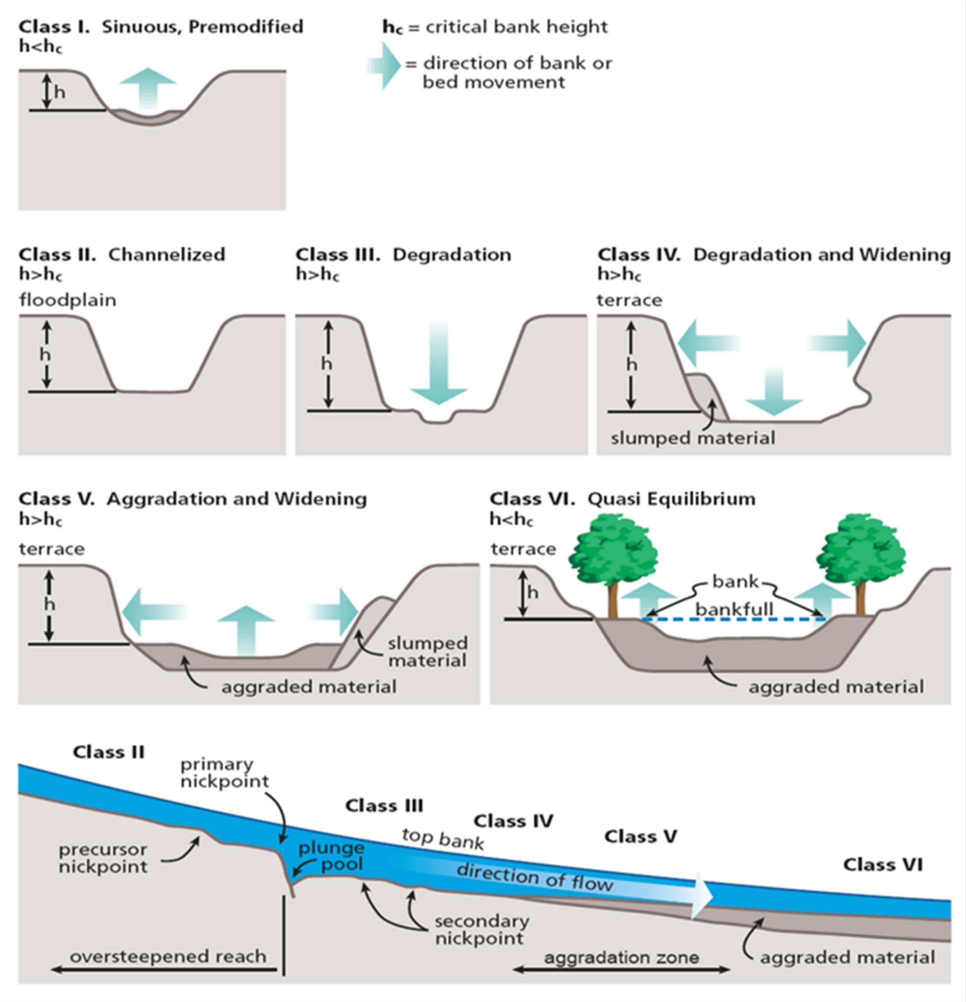


Figure 2-7. Channel evolution model. A disturbed or unstable stream can be in varying stages of disequilibrium along its length or profile. Source: FISRWG (1998), based on Simon (1989).

Stream channel stability processes also vary at the reach scale. In meandering lowland rivers, meanders grow both laterally and in the downstream direction. The helical flow pattern through a meander determines where erosion and deposition processes are dominant. Centrifugal force draws water toward the outside bank (cut bank) causing erosion, while sediment eroded from the outside bank is deposited on the inside bank and also transported downstream. Bagnold (1960) and later, Nanson and Hicken (1986), developed an empirical relationship between the ratio of meander bend radius (r) to channel width (B), and meander migration rate (M). The highest migration rates occurred on bends with r/B ratios of 2.5 - 3.5. Migration (erosion) rates rapidly declined for r/B values greater or less than 3.

At the local scale, the relative stability of channel banks depends on bank geometry, bank material, and coverage and type of vegetation. In general, rock is the most stable material. Fine cohesive bank material (i.e. containing a significant clay component) is more stable than coarse material. The higher and steeper the bank, the more prone it is to failure (Figure 2-8).

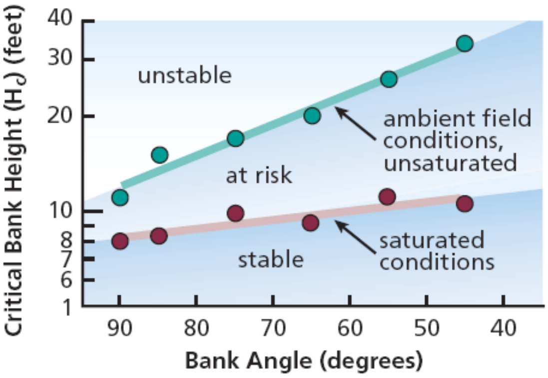


Figure 2-8. Example of a bank stability chart for estimating critical bank height. Source: FISRWG (1998).

Riparian vegetation and aquatic macrophytes act to increase flow resistance, and therefore reduce the rate of fluvial scour and bank failure (Prosser et al., 1999). The cohesive strength of riparian vegetation has been shown to stabilise banks (Abernethy and Rutherfurd, 2000). Beeson and Doyle (1995) assessed 748 stream bends for stream erosion after large floods and found that the vegetated banks showed much less erosion than those with semi- or un-vegetated banks. Vegetation on the banks also reduces the velocity of water flowing through it, encouraging sediment accumulation (Lewis and Williams, 1984). Abernethy and Rutherfurd (1996) and Abernethy and Rutherfurd (1998) proposed that the stabilising effect of bank vegetation varied throughout the stream network, generally decreasing downstream.

There is considerable debate in the literature regarding whether channels are more stable under tree or grass bank cover. Studies of gravel-bed rivers in Colorado by Andrews (1984), in Britain (Hey and Thorne, 1986), and in New South Wales, Australia (Huang and Nanson, 1997), revealed a consistent pattern of narrower channels in forested riparian zones. In contrast, Trimble (1997), in a study in Wisconsin, found that streams running through forest were significantly wider than those in pasture. This was confirmed by a New Zealand study by Davies-Colley (1997). However, this latter study found that width was independent of vegetation cover for catchments draining an area greater than 30 km^2. It was postulated that as stream power increased with basin area, the protective influence of grassy vegetation became less important. Riparian trees can shade banks, eliminating grass cover, and exposing bank surfaces to erosion. The process that explains channels being wider under forest is woody debris and in-channel trees (especially willows) deflecting flows onto the banks and eroding them (Gordon et al., 2004).

2.6.3 Time scales of sediment processes and channel adjustment

Stream management is generally concerned with changes that occur over the $10^0 – 10^2$ year timeframe. The geomorphic variables that change over this timeframe (cross-section form to plan form scales) are characteristic of the reach scale of $10^0 – 10^2$ m (Figure 2-9). In general, the larger the length scale of the attribute, the longer it takes to adjust. Adjustment rate can be equated with relative stability. Meander wavelength may adjust locally over the 10^1 - 10^2 year time scale through avulsions or capture of the main flow by an anabranch. However, for most Australian rivers, a significant region-wide shift in meander wavelength in response to a change in flow and/or sediment regime would probably occur over a longer time scale (10^3 years). Note that this process can be assisted by human intervention, such as the practice of artificial meander cutoff.

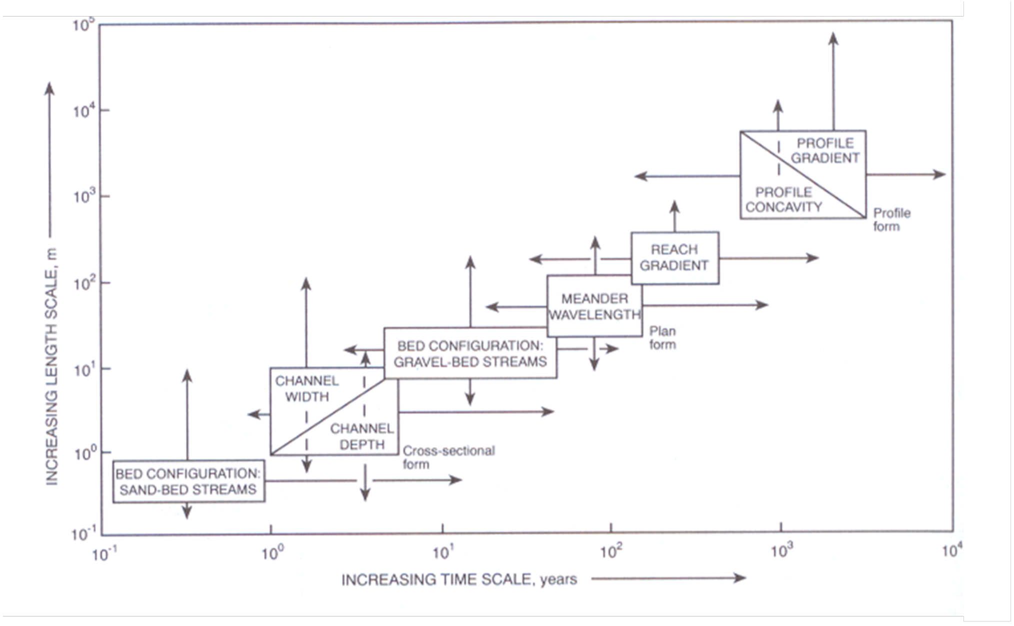


Figure 2-9. Timescales of adjustment of various channel form components. Source: Knighton (1998).

2.6.4 Forms of bank instability

Bank failures in riverine systems occur through one of three main modes:

1. Subaerial erosion,
2. Scour, and
3. Mass failure (including drawdown failure).

These modes of failure do not always occur in isolation, with it often being the case that one or more of these modes of failure occur in combination. Bank erosion can also be a by-product of bed scour, as the channel deepens, increasing shear stresses and undermining weaker soil layers that might get exposed.

Sub-aerial erosion

Streambanks that are exposed to air are subject to erosion from a variety of processes which are largely external to river flow. These processes are windthrow, frost heave, rilling, rainsplash, dessication, slaking and trampling. Such processes are collectively termed subaerial erosion (Rutherfurd, 2007). Some of these processes directly cause erosion, while others render bank material more susceptible to later erosion by wind or by water scour. Subaerial processes are usually much less important than the processes of scour and mass failure (Rutherfurd, 2007). Usually, they are only apparent when these other erosion processes are limited, or where the climate is extremely cold or wet. Couper (2003) found that river banks with high silt–clay contents, although more resistant to fluvial erosion, are the most susceptible to erosion by subaerial processes.

Scour

Scour occurs when the force applied to a bank by flowing water exceeds the resistance of the bank surface to withstand those forces (Rutherfurd, 2007). The potential for scour is traditionally described by boundary shear stress, which is a measure of the drag exerted on a unit area of the channel perimeter, which is a function of flow depth and slope. Scour is most pronounced at the outside of meander bends. Another form of bank scour is due to wave action. Wave action can be important in regulated rivers where the river level is held within a relatively narrow band for long periods of time.

Mass failure

Bank erosion can occur by whole blocks of material sliding or toppling into the water (Rutherfurd, 2007). Mass failure of river banks typically occurs in floodplain reaches, where banks usually consist of cohesive material resistant to scour. Cohesive banks are eroded primarily by mass failure under gravity. The shape and extent of mass failure is a function of the geometry of the bank section, the physical properties of the bank material, and the type and density of vegetation. Drawdown failure is a type of mass failure.

Combined scour and mass failure

It is often the case that fluvial scour is concentrated on a part of the bank profile, causing notching or undercuts. As a notch deepens the overlying material eventually topples through mass failure, and the material is washed away through fluvial scour.

Drawdown failure

During high flow conditions, high water levels will exist within the bank material and outside of the river bank face in the river channel itself. Saturation causes the weight of the soil to increase, and the resistance (cohesion and friction) of the soil to reduce. At high flow levels the water in the river exerts a stabilizing pressure on the bank slope. The stabilizing pressure is lost when the river level drops during flood recession. If the water level drops so rapidly that the pore pressures within the slope do not have time to change in equilibrium with the drop in external water level, the risk of bank failure will increase significantly. This type of failure is known as rapid drawdown failure (some authors reserve the term ‘slumping’ to describe this type of failure). High permeability materials (such as sands and gravels) can drain during rapid drawdown, but low permeability materials (clays and silts) cannot. Thus, drawdown failure is typically a problem associated with fine-grained bank materials.

Rivers with natural hydrology experience drawdown during flood recessions, and the bank slope and channel width will, over time, naturally adjust to the typical recession regime. In rivers with a regulated flow regime, the length of time that flows are high may be longer (such as channels where the flow is at capacity through the entire irrigation season), the drawdown rate may be artificially high (as controlled by operation of an upstream regulator or weir), or drawdown may be artificially frequent (as required to meet the downstream demands). For these reasons, there is a long-held conventional belief that rapid drawdown in regulated rivers adversely affects river bank stability (Arnott, 1994). Green’s (1999) review of literature found very few observations of drawdown failures, but found a lack of consensus on the importance and magnitude of drawdown induced bank failures.

2.6.5 Reach-scale bed stability processes

Stream beds are often composed of material different in character to that of the banks, because the bed material may have been transported from an upstream area, or perhaps the bed of the stream is cut into a different geological layer. Sediment motion consists of three stages: initiation of motion, downstream transport and deposition.

Bedload transport is usually conceptualised as a threshold process; that is, the rate of transport is considered to be very low up to a certain critical streamflow, and beyond this streamflow transport increases at a faster-than-linear rate (Ferguson, 2005).

Bed stability depends not only on the capacity of the flow to mobilize, transport and deposit sediment, but also on the availability of sediment (i.e. the sediment supply). Bed material is sourced from the banks and also from the catchment slopes and gullies via tributaries. It is generally acknowledged that in Australia, the main period of catchment sediment delivery, in the early part of the previous century, corresponded with rapid expansion of agriculture and associated vegetation clearing. Since that time, the volume of material sourced from catchments has slowed as gullies have stabilized, and erosion control has become standard practice (Gippel and Collier, 1998; Rutherfurd, 2000; Rutherfurd and Gippel., 2001). Bed aggradation followed by degradation can progress slowly downstream in association with migration of sediment slugs released during the period of excessive catchment erosion (Bartley and Rutherfurd, 2005).

Stream reaches with a high relative sediment supply, where the volume of sediment overwhelms the capacity of the stream to transport the material, generally exhibit bed aggradation with unsorted, fine surface textures (Figure 2-3). Reaches with a low relative sediment supply, on the other hand, have the ability to transport most of the sediment supplied to the stream with little storage of sediment, leaving behind only the least mobile particles.

The hydraulics of sediment transport are modified by large woody debris. Over long time scales, wood-rich rivers may retain more sediment and have lower sediment transport rates and steeper slopes than comparable wood-poor channels (Gippel, 1995; Montgomery et al., 2003; Montgomery and Pie´gay, 2003).

Bed stability can be affected by disturbances downstream. Channels generally incise through the process of nick-point migration, with the nick-point moving upstream from its point of initiation (Figure 2-7), stopping only when the river lacks the capacity to scour the bed.

2.6.6 Hydraulics of channel stability

Chow (1981, p. 164) noted that:

> "*The behavior of flow in an erodible channel is influenced by so many physical factors and by field conditions so complex and uncertain that precise design of such channels at the present stage of knowledge is beyond the realm of theory*."

Since that time there have been developments in the level of sophistication of river channel modeling capacity, but there have been no major advancements in relevant theory. The mobilisation and transport of unconsolidated material (such as sand, gravel, cobbles etc) can be predicted reasonably well on the basis of shear stress, and there are numerous methodologies in the literature based on this approach. Prediction of the mobilisation (i.e. scour) of consolidated sediments (i.e. clay-rich bed and banks) is not so amenable to a physical modelling approach, and most methods rely on empirical data from long-standing field and experimental studies.

The two hydraulic methods that have been most commonly applied to the problem of determining when the channel boundary is stable/unstable are the method of permissible velocity, and method of permissible tractive force (shear stress) (Chow, 1981). It is important to realize that while this approach has been applied extensively in the river engineering industry throughout the world for decades, like all empirically based approaches, it remains subject to uncertainty. The velocity and shear stress indices are complementary – the predicted threshold of stability of a given material, when converted from velocity or shear stress to discharge, is similar for both methods.

The maximum permissible shear stress/velocity approach only indicates whether a material subject to erosion falls into the category of stable or unstable, i.e. it does not predict degrees of instability. However, it can be assumed that the further away is the velocity or shear stress from the threshold of instability, the higher is the risk of erosion. In practice, the calculated thresholds of stability are not sharply defined boundaries of stability. Variability of the composition of the bed and bank materials, variability in the resistance of the channel offered by vegetation, and downstream, vertical and across-river variations in velocity and shear stress mean that the thresholds are simply a guide to when the overall state of the channel shifts from being more prone to stability to being more prone to instability for the given flow conditions. Sediment and soil properties naturally vary within a river reach. Thus, the maximum permissible velocity and shear stress will vary along a river reach (i.e. some areas will be more stable than others).

There are two main hydraulic approaches for defining the threshold of coarse bed material transport: either mean shear stress is used or, following Bagnold (1977; 1980), unit stream power. Recent work by Ferguson (2005) convincingly argues in favour of adopting stream power rather than shear stress for the estimation of bed load transport rates in coarse-bedded rivers.

Mean stream power per unit bed area can be calculated from gross channel properties (width and slope), together with the discharge provided by the catchment, without needing to know within-channel flow properties such as depth or velocity. The relationship can be used to estimate the critical power to move the average bed grain size, or grains coarser or finer than this, from knowledge only of channel gradient and average bed grain size. Ferguson (2005) improved the Bagnold relationship, but assumptions must, however, be made about the critical Shields stress to move the average grain size and the parameter that quantifies hiding and protrusion effects. Petit (2005) is an example of the application of specific stream power to predicting bed material mobility.

Stream power per unit length of channel (i.e. not taking channel width into account) has been demonstrated to show a distinctive downstream pattern, peaking in the mid-catchment zone, with explainable discontinuities also possible (Figure 2-10) (Knighton, 1999; Lawler, 1992; Lawler, 1995; Lecce, 1997; McEwan, 1994; Fonstad, 2003; Reinfelds et al., 2004; Jain et al., 2006; Lawler et al., 2007). The upper-mid catchment zone of higher stream power would logically correspond with Schumm's (1977) sediment transport zone (Figure 2-4).

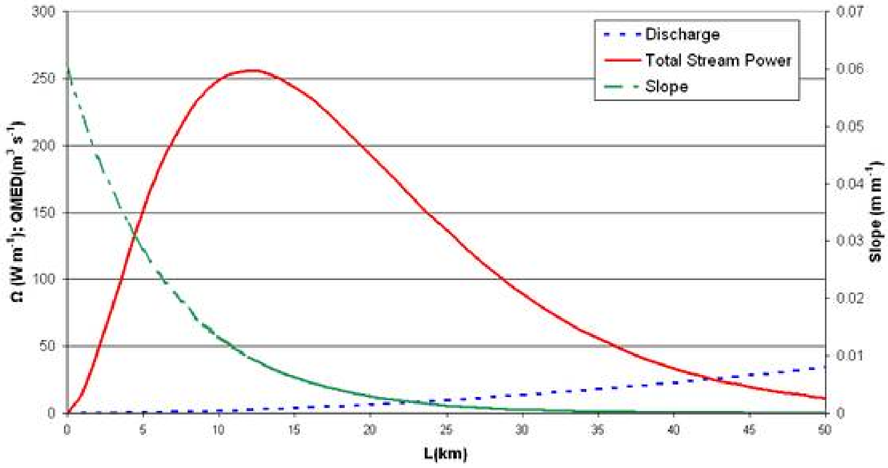


Figure 2-10. Longitudinal (downslope) distribution of total stream power. Source: Adapted from Lawler, (1992).

The normal variety of geomorphic settings in a catchment produces deviations from expectation, which has implications for the movement and storage of material in the fluvial system (Lecce, 1997; Knighton, 1999). The detailed study of Fonstad (2003) coupled with field channel surveys produced comparisons of predicted versus current (equivalent to observed over expected). Greater sediment storage occurs in the headwaters and lower valleys where stream power is low, whereas little sediment is stored in mid-basin reaches where stream power is high (Lecce, 1997). Worthy's (2005) use of high-resolution LiDAR data from the Cotter River demonstrated a real and underlying complexity of fluvial processes that theoretical models, and point observations, fail to predict. With this type of data, the stream power equation can now find application at a small sub-catchment scale. This enables calculation of stream power values at any point in a stream. The LiDAR data also allows a more meaningful stream power per unit bed area to be calculated, which allows prediction of bed material mobility in channels, and scour and deposition potential on floodplains.

Downstream plots of stream power distribution express the mean stream power for a particular discharge index (Figure 2-10). Stream power also varies considerably though time, as a non-linear function of discharge, so geomorphological processes and forms at any point on a stream are a product of the stream power or shear stress regime (i.e. the distribution of stream power or shear stress through time). Julian and Torres (2006) conducted a detailed study of fluvial scour-type bank erosion by separating estimated bank excess shear stress into four properties: magnitude, duration, event peak, and variability. Excess shear stress is the shear stress in exceedance of that required to cause mobilization of the bank material. Stepwise regression showed that the event peak (maximum peak) of excess shear stress best predicted cohesive bank erosion at the two transects with moderate critical shear stresses, while the variability (all peaks) of excess shear stress best predicted erosion at the transect with low critical shear stress. However, the stream banks examined by Julian and Torres (2006) were not particularly high in silt-clay content. For streams with high silt-clay content (as would apply in lowland reaches) Julian and Torres (2006) were of the opinion that the duration of excess shear stress was the most important variable (Figure 2-11). The time series of excess shear stress could be estimated from discharge time series, cross-section, and bank particle size data.

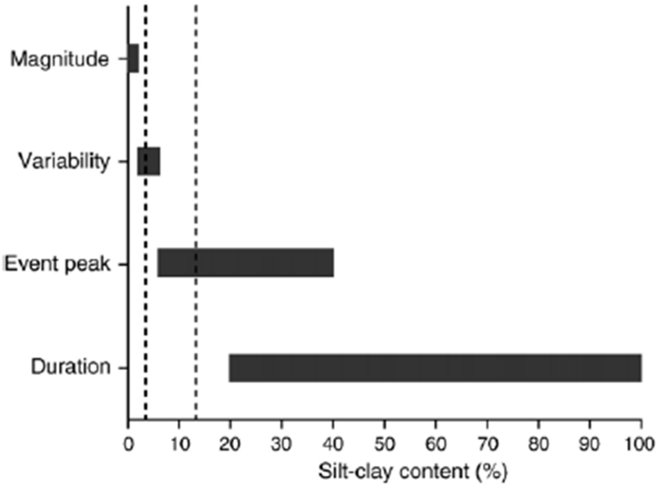


Figure 2-11. Conceptual model by Julian and Torres (2006) of best excess shear stress (also discharge) predictors for erosion rates of cohesive riverbanks. The vertical dashed lines represent the range of bank silt–clay content used in the study of Julian and Torres (2006).

2.6.7 Role of hydrology in channel stability

Hydrology plays a critical role in stream channel dynamics, because the flow of water supplies the energy to mobilize and transport materials. Although stream flow and geomorphological process and form are strongly linked, even in regulated rivers it cannot be assumed that apparently impaired channel geomorphic condition is solely a function of flow modification. In many regulated rivers, the channel condition is a product of myriad impacts (Gippel, 2002a; Gippel, 2002b).

The relationships between hydrology and geomorphology were summarized by Gippel (2002a) and Gippel (2002b). These papers noted that while geomorphic models generally have a high level of uncertainty associated with their predictions, there is plenty of empirical evidence to support the basic contention that regulated rivers undergo morphological adjustment.

Channel form is a complex function of flood frequency, flood duration, sediment transport and boundary conditions (resistance of bed and banks). The main concepts in this respect are bankfull flow, channel maintenance flow, dominant discharge and effective discharge. It has long been thought that the process of channel formation was fundamentally associated with such flows, which can be expressed in terms of a consistent frequency and magnitude, but this idea has been seriously challenged, especially with respect to the Australian context (Gippel, 2002a; Gippel, 2002b).

Some studies have found that the dominant/effective discharge of Australian rivers crosses a broad range, suggesting that channels are naturally adjusted to a wide range of channel forming flows. This wide band of effective discharge possibly explains the common existence of complex channel morphologies in Australian rivers. Regulated regimes tend to have a narrower effective discharge band, and simpler channel morphologies would be expected under these conditions (Gippel, 2002a; Gippel, 2002b).

Flows with long durations often have a more significant effect on erosion of the channel boundary than short-lived flows of higher magnitude (Fischenich and Allen, 2000, p. 2-23). Fischenich (2001, p. 6) recommended application of a factor of safety to the maximum permissible velocity "when flow duration exceeds a couple of hours". Graphs are provided in Fischenich (2001) for factoring according to event duration. The marked effect of flow duration on erosion risk raises the possibility that there is no such thing as a maximum permissible velocity below which erosion does not occur (Chow, 1981, p. 166). Cyclic stresses, even very small, can destroy any material bonds; it is only a matter of the number of cycles to break the crystalline bonds in a rock, and the electromagnetic bonds in a clay (Seed et al., 2006). This is why natural rivers that are used for conveying irrigation flows for long periods through summer tend to increase in width, regardless of the cohesivity of the banks. The findings of Julian and Torres (2006) (Figure 2-11) supported this proposition.

While streamflow metrics are frequently used as surrogates for channel disturbance, the frequency, magnitude, and duration of bed movement and overbank flow depend fundamentally on local geomorphic context (Poff et al., 2006). Simulations of bed mobility (i.e. a shear stress dependent process) in two distinct geomorphic contexts by Poff et al. (2006) revealed that flow regime alone does not necessarily adequately describe disturbance regime; knowledge of local geomorphology and associated bed mobility adds additional, critical information needed to assess effective disturbance regime in stream and river channels.

2.6.8 General model of adjustment in alluvial rivers

Although the river geomorphic system is in some respects indeterminate, which prevents close prediction of form from process, various process and form variables can be conceptually linked. The model of Richards (1982) (Figure 2-12), applies to alluvial systems, but also works for bedrock controlled systems simply by removing some variables and links. Two variables missing from the model of Richards (1982) are large woody debris, which influences bed stability, and bank vegetation, which influences bank stability. These variables, which had not received much research effort at the time that Richards (1982) developed his conceptual model, have a modifying influence on the inherent sediment variables 'bank material' and 'bed material'.

The general conceptual model of Richards (1982) (Figure 2-12) indicates which variables influence width and depth and meander wavelength (the variables that adjust over management timescales and therefore indicate relative 'stability' of the channel). Thus, if it is not practical to measure the form variables width, depth and meander wavelength, then the process variables can be considered as potential monitoring variables.

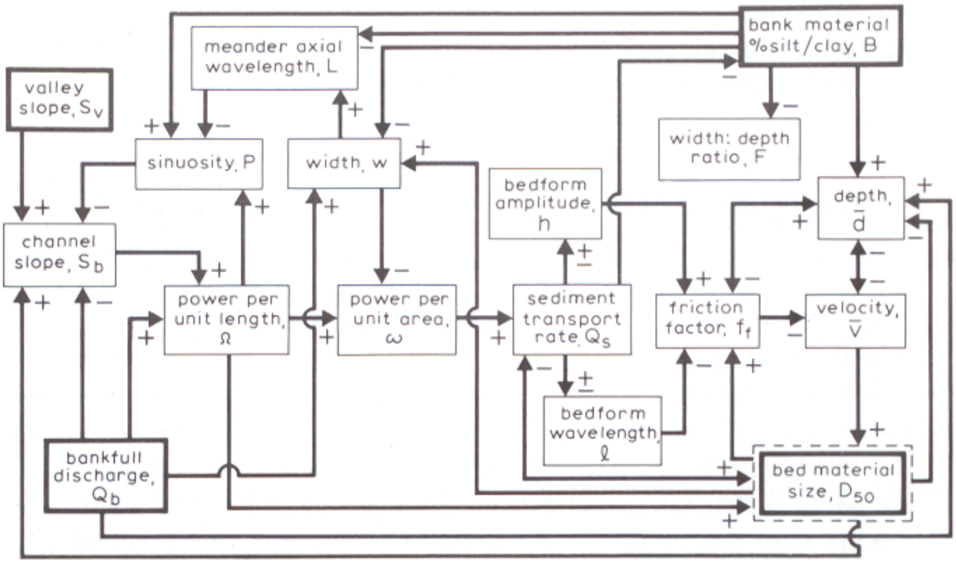


Figure 2-12. The alluvial channel system. Independent variables have heavy outlines. Bed material size is semi-independent. Direct relationships are shown by +, inverse by -, placed

by arrow showing direction of influence. Some links are reversible. Source: Richards (1982, page 26).

It has to be remembered that the fluvial system is always dynamic, so positive and negative responses indicated in the model of Richards (1982) are always active to some degree. What is important from a management perspective is not the ‘noise’ associated with the dynamic equilibrium state, but a persistent change in a variable over time.

The model of Richards (1982) does not include the time dimension, so it has to be remembered that the interactions indicated in the model do not necessarily occur instantaneously. There could be significant lags in response of form variables from the time when a process variable changes.

The alluvial channel model of Richards (1982) does not depict the concept of channel migration. Channel migration is the movement of a channel in space, while at the same time retaining its mean width, depth, slope and sinuosity. On the ground, it might appear that a channel shows signs of being ‘unstable’, because even the casual observer might see banks eroding, riparian trees falling into the river, sediment being reworked, and physical habitat being modified. This form of ‘instability’ reflects the process rate, and does not necessarily indicate that there is anything ‘wrong’ with the river (in a natural river, the ecology adjusts to the natural hydrological and geomorphological process rates). The process rate is inherent, so some rivers are naturally more geomorphologically active than others (Figure 2-6). In general, Australian rivers tend to adjust slowly due to cohesive banks, low sediment supply and low gradients. Regulation of a river might alter the process rate (either slow it or speed it), but this would nearly always be associated with a persistent change in the one or more process or form variables. Similarly, disturbance of riparian vegetation for example would increase the bank erosion process rate, but the channel would also likely widen.

There is no doubt that, traditionally, much of the work undertaken to control river geomorphology has been aimed at slowing or halting the process rate, rather than addressing a system imbalance. This is because in many situations people do not tolerate any degree of channel migration, regardless of how costly it is to achieve absolute stability. In urban areas this is understandable, but the same philosophy may not be appropriate for rural areas. Aerial images of lowland rivers often show signs of extensive channel migration. The natural rate of migration would likely change through time as the process drivers (hydrology and sediment supply) naturally change over this time scale. What this means for monitoring of channel stability is that channel migration has to be considered separately from changes in width, depth and sinuosity. Thus, casual observations of ‘instability’, such as might be inferred from seeing local bank collapse, on their own reveal nothing about whether the river is changing in width and/or depth. Topographic surveys that target the most active parts of channels (meander bends) give a false impression of the overall channel migration rate. The implication of this is that proper monitoring of the rate of change in channel form requires carefully planned, extensive and frequently repeated topographic surveys. In practice, success is difficult to achieve because of practical/technical difficulties, the high cost, and the need to maintain the program for a long time (i.e. through periods when management and funding priorities might shift).

2.7 Links between geomorphological process/form and ecological health

2.7.1 Positive relationships

In the Bega River catchment, NSW, Chessman et al. (2006) found that good (relative to reference) geomorphic condition was significantly associated with differences in biological assemblages other than fish. Twice as many taxa appeared to favour sites in good geomorphic condition as favoured sites in poor condition. Many of the taxa associated with sites in poor condition were alien taxa introduced to Australia since European settlement. Thus, protection of reaches that are in good geomorphic condition is likely to be critical for the maintenance of indigenous biodiversity, and rehabilitation of geomorphic condition can assist in the rehabilitation of native riverine biota.

Measurements of channel width and depth can provide not just absolute data, but the variability in these data indicates the heterogeneity of the channel form. There is a general belief among river ecologists that high physical heterogeneity delivers greater diversity of habitats, which is beneficial to the biota (Kemp et al., 1999) (Figure 2-13). This was summarized by Bartley and Rutherfurd (2005) as follows: "…physical diversity and heterogeneity in streams is known to correlate well with biological diversity (e.g. Chisholm et al., 1976; Downes et al., 1998; Gorman and Karr, 1978) and reduced surface roughness and heterogeneity can in turn reduce species diversity, population abundance and recruitment (McCoy and Bell, 1991; Kolasa and Rollo, 1991). Thus, physical diversity is acknowledged as one indicator of stream health (Norris and Thoms, 1999) and diversity of habitat." Jungwirth et al. (1995) found a positive relationship between mid-channel depth variation and fish species diversity. Brunke et al. (2001) found that particular physical habitats, in terms of biodiversity, were colonized by distinct faunal assemblages. Also, there are known strong links between the distribution and loading of large woody debris in streams and aspects of stream health (Gippel, 1995).

Disturbance is widely recognized as a key process regulating riverine ecosystem structure and function (Resh et al., 1988; Townsend, 1989; Poff, 1997; Lake, 2000). Disturbance can be caused by hydrological events, but also by associated geomorphological events, such as bed and bank instability. A recent review by Florsheim et al. (2008) found that bank erosion is an important component of the natural disturbance regime of river systems and is integral to long-term geomorphic evolution of fluvial systems and to ecological sustainability. Bank erosion is therefore a desirable attribute of rivers (Florsheim et al., 2008).

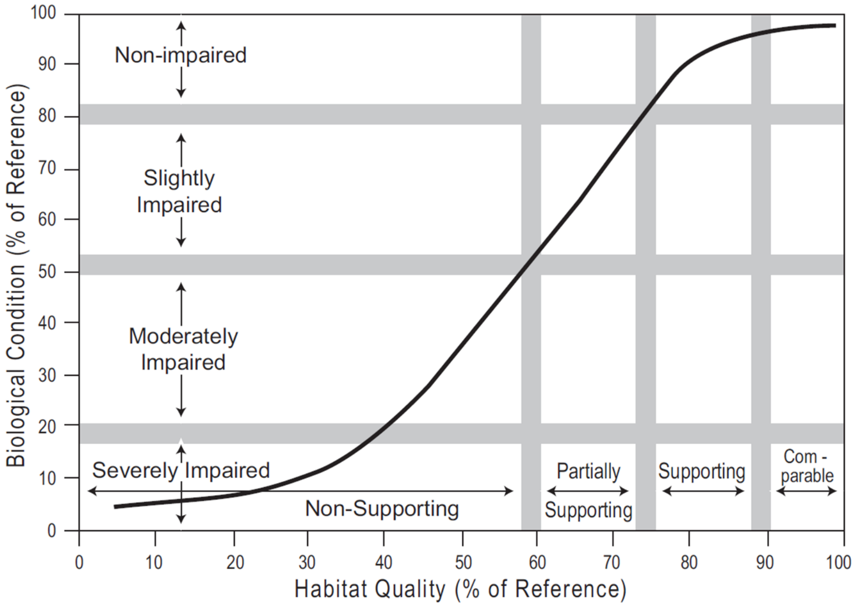


Figure 2-13. Theoretical relationship between physical habitat quality and biological condition. Source: Plafkin et al. (1989).

Yarnell et al. (2006) found that reaches with a moderate relative sediment supply exhibit the greatest geomorphic diversity by creating channel conditions with both variety in geomorphic features, such as scour pools and depositional bars, and a variety of surface textures from differential sorting of sediments at variable flows. Multiple field studies have also shown, however, that internal channel structures, such as large woody debris and boulders, create local scour and deposition resulting in increased pool and bar frequency. Reaches with a greater spatial extent of structures therefore may exhibit greater habitat heterogeneity. The presence of in-stream structural features may act in conjunction with the relative sediment supply to increase habitat heterogeneity in all cases, but particularly when there is a moderate relative sediment supply (Yarnell et al., 2006) (Figure 2-14).

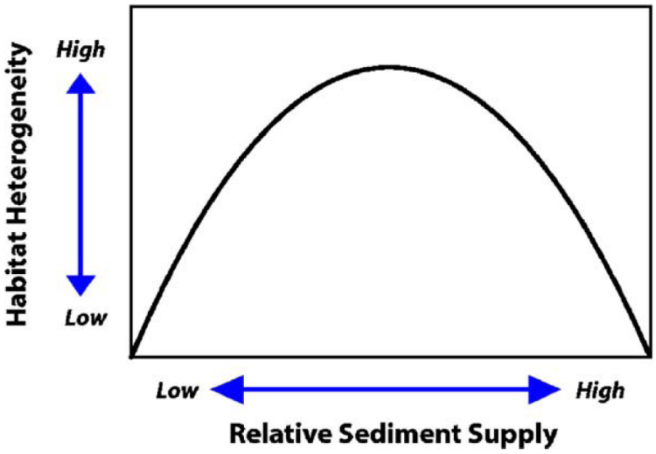


Figure 2-14. Hypothesized theoretical relationship between physical habitat heterogeneity and relative sediment supply. Source: Yarnell et al. (2006).

2.7.2 Negative relationships

Given that a number of positive relationships have been found between some geomorphological attributes of streams and ecological health, it is not surprising that a number of negative ecological impacts have been associated with degraded geomorphological characteristics of streams. This is true of large woody debris removal (Gippel, 1995), channel complexity, and coarse and fine sediment deposition. Semeniuk (1997) noted that human impact on stream systems often leads to a simplification of their physical or geomorphological structure, or reduced ‘geodiversity’.

Sheldon and Thoms (2006) found that flow regulation has greatly reduced channel complexity in parts of the Barwon-Darling River and this has resulted in a potential decrease in the retention of organic matter. This organic matter is critical to the aquatic food web of the system (Sheldon and Thoms, 2006).

Casatti et al. (2006) compared the fish assemblage structure from streams with different intensities of physical habitat degradation and chemical water pollution by domestic sewage in southeastern Brazil. The quantitative structure of the fish fauna showed significant correspondence with physical habitat condition but not with chemical water quality. The results indicated that in the focused agricultural region, streams with high physical habitat integrity possess a differently structured fish fauna than streams with relatively low physical habitat integrity, reinforcing the importance of the physical habitat quality.

Sediment slugs, which are large anthropogenically derived pulses of (usually sand-sized) bed sediment, appear to reduce the morphological variability of stream systems through space and time. In a study of Creightons Creek, Victoria, Bartley and Rutherfurd (2005) found that all eight physical measures showed that the area impacted by a sediment slug was less diverse in terms of its geomorphic variability than the unimpacted reaches. This suggested that massive increases in sediment load to streams had reduced the geomorphic complexity of the stream, and in turn, the diversity of habitat for biological communities.

Sediment deposition in streams can affect primary producers in streams such as periphyton and aquatic macrophytes. Given that periphyton form the base of the food chain, any impact on this component would likely be manifested in invertebrate and fish communities (Waters, 1995; Wood and Armitage, 1997). Hogg and Norris (1991) investigated the impact of sediment loads from land clearing and urban development on the macroinvertebrate pool fauna of the Murrumbidgee River. They found that sediment deposition on the bed was the major cause of impairment to macroinvertebrate abundance.

Covering the surface of coarse substrate by fine sediment deposition can lead to increased mortality of fish eggs, larvae and juveniles in gravel spawning species (Cordone and Kelley, 1961). Loss of pool habitat through sedimentation is also likely to have a detrimental effect on fish fauna because pools provide rearing habitat for many fish species (Waters, 1995) Doeg and Koehn (1994) found that a dam desilting event in an upland stream had a detrimental impact on the macroinvertebrate fauna, but one year after the event the fauna had recovered to higher diversity and density levels than before the event. This particular stream had an undisturbed catchment and major tributaries which may have aided recovery. Regardless, it does indicate recovery potential in streams impacted by fine surface sediment deposition, so management action to ameliorate this problem would be worthwhile.

Erosion of catchment slopes and river channel boundaries, as well as releasing coarse material that might deposit on and within the native bed material, releases fine silts and clays that travel in suspension during runoff events. Some highly disturbed streams that flow through clay rich sediments are chronically impacted by elevated suspended solids concentration. Turbidity is the optical effect caused by fine suspended solids in the water column, but the term turbidity is colloquially understood to mean ‘suspended solids concentration’. High turbidity affects fish and aquatic life by interfering with the penetration of sunlight (Davies-Colley and Smith, 2001). Submerged aquatic vegetation requires light for photosynthesis. This vegetation provides essential food, nursery areas, shelter and habitat for diverse communities of biota. If light levels become too low, primary production may effectively cease. High concentrations of suspended matter may clog the gills of fish and shellfish cause direct mortality. Most fish use their vision for predation and the location of prey can be highly influenced by clarity of the water environment. Turbidity can significantly affect the predator- prey interactions in aquatic systems, but these effects can be both positive and negative (Van de Meutter et al., 2005; de Robertis et al., 2003; Utne-palm, 2002), and in some cases turbidity may be unimportant (Stuart-Smith et al., 2007). The reduction in macroinvertebrate faunal abundance in the lower River Murray during the period 1980-1985 was considered to be the result of long periods of high turbidity experienced in South Australia due to the operation of Lake Victoria and the high proportion of the turbid Darling River released from that lake (Bennison et al., 1989).

2.7.3 Defining acceptable or natural limits of geomorphologic variability

While it is clear that river systems are geomorphologically dynamic, and it is also quite clear that a degree of variability is an important aspect of maintaining stream health, an overly dynamic system can lead to ecological impairment. Thus, from the perspective of managing stream geomorphology, it would be important to define the natural or acceptable limits of variability within which the system would be allowed to adjust without any need for intervention. However, definition of natural variability requires certain assumptions to be made. The first assumption concerns the time period over which the variability is to be considered. The longer the period, the greater will be the range of variability. For this project, the management timescale of up to 100 years was assumed, although it is recognized that over a period of 1,000 or 10,000 years a river will probably show a much greater range in stability. The second assumption concerns the definition of ‘natural’.

Karr (1995) and Karr and Chu (1999) defined ecosystem health as the preferred state of ecosystems that are modified by human activity, while ecological integrity is an unimpaired condition, reflective of natural, pristine, reference or benchmark ecosystem. The natural condition does not typically exist as an idealized balanced or equilibrium state. Rather it is dynamic, often changing in an indeterminate way (Belovsky, 2002). Thus, the idea of defining a fixed state of ideal stream condition as a reference point from which to grade stream health may have intuitive appeal, but it is far from straightforward in practice. River channels can undergo considerable change through time, but remain in the same mean condition (Figure 2-15). Under some circumstances geomorphic thresholds can be crossed, after which return to the original physical state should not be expected. The channel then finds a new dynamic equilibrium. Over the long term of 1,000+ years, rivers should be expected to undergo significant changes in form, in response to changes in the controlling factors, and also in response to crossing of internal thresholds (e.g. natural cut and fill cycles).

Pristine condition is usually interpreted to mean the so-called ‘primitive’ or ‘original’ state that existed prior to intensive and widespread disturbance by humans. A complicating factor here is that if significant climatic change occurs, a disturbed river would not be expected to return to its original or pristine (pre-human disturbance) condition, even if it was fully restored and the whole catchment designated a wilderness area. Also, some disturbances may have ceased and some may still be operating. Even when a disturbing activity (such as river regulation) has ceased or been ameliorated its legacy may still exist as a major stream disturbance.

The pre-disturbance condition may refer to conditions that prevailed prior to a specific disturbance, such as a certain degree of flow regulation. The term ‘natural’ can mean ‘not affected by humans or civilization’ but probably is too ambiguous to be of any real value in describing the condition of a river or stream (Gordon et al., 2004). When referring to ecological potential as it relates to some pre-disturbance condition, it is important to explicitly state the historical time period to which ‘pre-disturbance’ refers.

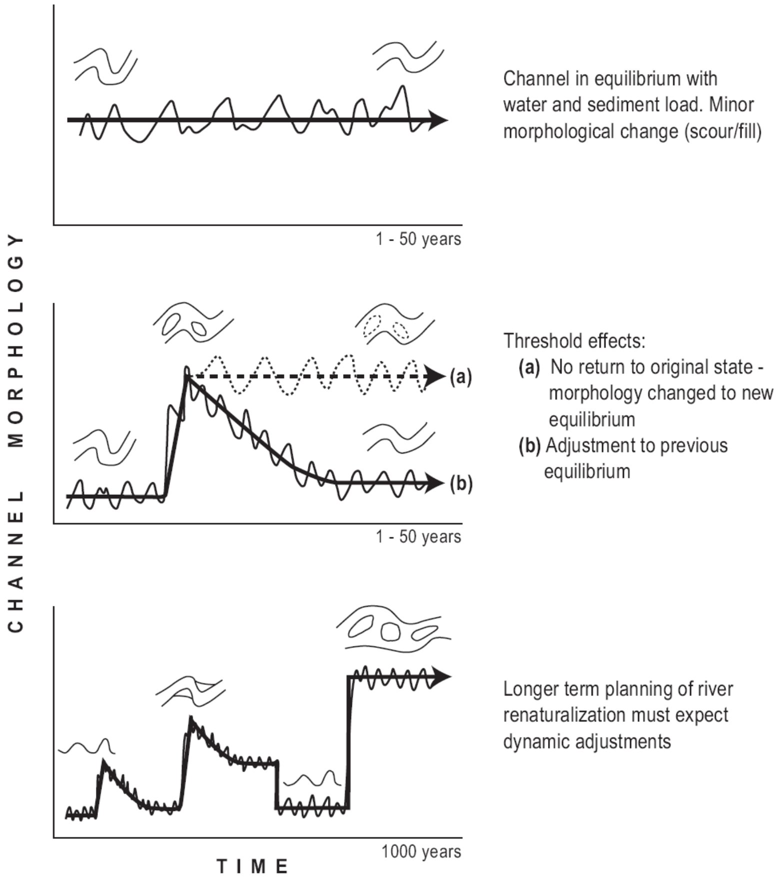


Figure 2-15. Geomorphic dynamic equilibrium concept. Source: Sear (1996).

Defining acceptable limits of geomorphologic change requires an assumption to be made regarding to whom or for what the limits are acceptable. This is a potentially contentious issue, as some people interpret ecologically desirable channel ‘disturbance’ processes (within the range expected for a channel in dynamic equilibrium) as undesirable ‘instability’. Some landholders might regard natural rates of channel mobility as an inconvenience at best, and a significant cost at worst. River management has a tradition rooted in civil and hydraulic engineering. Most of the work was grounded in well-established theory of stable channel design. The inherently dynamic nature of rivers was seen as an annoyance that should be controlled, or if structures failed, as a catastrophic and unusual event.

Acceptable limits of change could also be interpreted to mean acceptable to the ecological components of the river if the river is to achieve and maintain a healthy state. It may be possible to link the requirements of the ecological components of the river to certain limits of channel stability, but this would first require a research effort to establish the links for the rivers in question. Such information is not available for the rivers of the North Central CMA region.

2.7.4 Summary of geomorphologic-ecologic process links

The literature suggests a number of key geomorphological processes and forms that are closely related to ecological health (Table 2-4). These variables are strong candidates for inclusion in a methodology for monitoring stream geomorphological form and process.

Table 2-4.
List of the geomorphic variables most relevant to ecological health.

Geomorphic variable	Desirable condition for ecological health
Diversity (variability) of channel form (bed and banks)	High diversity
Mobility of bed material	Regular mobilization within reference range
Bank erosion (channel migration, not expansion)	Regular erosion within reference range
Sediment supply (native sediment)	Moderate level (within transport capacity)
Coarse sediment (sand) slug	Not present as thick migrating surface layer
Fine (silt) sediment deposition	Not present over coarser native bed material)
Turbidity (also reflects suspended solids concentration)	Not chronic and low peaks

2.8 List of potential variables

Many reach-scale geomorphic characterization schemes attempt to visually assess the relative stability of bed and banks (i.e. incising/aggrading and eroding/stable) or record the presence/absence or relative dimensions of a range of geomorphic features or units (such as pools, riffles, undercuts, bars, benches, hydraulic features, etc.) that might be associated with associated with certain stream types, processes or levels of disturbance. These approaches suffer from subjectivity of measurement. It would be preferable to directly measure rates of change and undertake objective measurements that reflect the geomorphological diversity of channel form.

It was considered important for the proposed geomorphic assessment methodology to share some compatibility with the Sustainable Rivers Audit (SRA) (Davies et al., 2008). The SRA will assess Physical Form at the Valley and Valley Zone scales, using a new methodology currently being trialed. The SRA methodology will be based on metrics and indicators relating to channel form, bank dynamics, bed dynamics, and floodplain features. The SRA will sample randomly stratified sites, rather than attempt to assess the condition of an entire river network, as is proposed here. However, it may be possible to share some data, or at least compare results, if some of the variables are measured in the same way. One difference between the SRA and the present project is that the SRA is a systematic assessment of health across the entire Murray-Darling Basin, while this project is concerned with developing a geomorphology-focused approach that delivers information especially targeted at management. The list of potential variables for the SRA methodology was consulted for this project, and then slightly expanded (

Table 2-5).

The recommended approach is to limit field observations to a core group of universal form and process variables that are relatively easy and quick to measure in the field (

Table 2-5). These variables relate directly to the three main process factors (sediment supply, transport capacity, and resistance to erosion). Critically, data on these variables is likely to be available for at least some stream reaches in the existing literature and data held by the CMA, and it should be possible to extract it in a consistent way. However, collection of this form of data will be an on-going task that both fills the knowledge in terms of spatial coverage, and detects major changes through time within specific reaches.

The other recommended primary variables and derived variables can be measured using desktop techniques (

Table 2-5). Some variables are known to be insensitive to change over time for certain stream types, so would not necessarily require the same measurement effort at sites where change was expected. For example, width, depth, bank angle and plan form variables are relatively insensitive to change in bedrock controlled streams, while these variables can change in alluvial streams.

Sediment transport measurement can rely on existing empirical suspended sediment (and or turbidity) data from the Victorian Water Quality Monitoring Network, while an alternative would be to undertake catchment scale stream power analysis (

Table 2-5). Assessment of the regime of excess shear stress and hydrology would be limited to gauging stations, unless hydrological modeling was undertaken. The SedNet modelling undertaken in 2001 for the National Land and Water Resources Audit (NLWRA) is another potential source of CMA-wide sediment data.

Stream class is included in the list of potential variables (

Table 2-5) for the reason that if something is known about the main geomorphic processes and forms associated with each stream class (including trajectory of change, sensitivity to disturbance, and likely response to management intervention) then catchment-wide mapping of stream class would essentially solve the problem. The difficulty lies in (i) collecting the data required to make the classification, (ii) matching the scale of classification (usually broad) to the scale of interest for stream management (ultimately at the reach scale) and (iii) assuming regionally-uniform geomorphologic stream behavior for given stream classes. Stream classification can be undertaken using an established methodology (e.g. River Styles®), or by statistical analysis of data that becomes available through other non-specific efforts.

Each geomorphic variable potentially has a reference condition (

Table 2-5). Expressing the quantity of a variable relative to reference state is a way of expressing the departure of the condition from a benchmark. It would be possible then to express departure from reference as relative risk to stream health, with this leading to priority for management action. Reference is not necessary, as the quantity of a variable can be expressed as an absolute value.

From the collected data, four core geomorphic indicators could be generated that express relative condition of

- channel form,
- bank dynamics,
- bed dynamics, and
- floodplain.

All suggested potential variables (Table 2-5) first require evaluation for their practicality of measurement, and value in terms of returning information relevant to management of stream health.

Table 2-5.
Potential variables for geomorphic assessment of the North Central CMA region. 'NCCMA(2006) W&CD' refers to North Central CMA Waterway and Catchment Descriptions.

Variable	Possible way to measure	Potential reference measure
Channel dimensions		
Width (and variability of)	15-20 spot readings (range finder or tape measure) [or LiDAR, or NCCMA (2006) W&CD]	Reference sites
Depth (and variability of)	15-20 spot readings (range finder or tape measure) [or LiDAR or NCCMA (2006) W&CD]	Reference sites
Width/Depth ratio	Derive from primary measurements [or LiDAR]	Reference sites
Stream features (undercuts, bars, levees, etc)	Presence/absence in field	Reference sites
Bank stability		
Bank angle	15-20 spot readings (range finder) [or LiDAR]	Theoretical based on bank material properties
Bank cohesivity	Hand texture estimate percent clay	Assume unchanged
Bed stability		
Bed material size (relative stability from stream power)	Wolman pebble count on riffle or hydraulic control for >sand, otherwise, sand, silt, clay classes [or NCCMA (2006) W&CD]	Reference sites for given stream type, or model
LWD density	Rapid estimates using counting (standard from literature), or riparian vegetation density as a surrogate	Theoretical based on natural riparian vegetation density
Hydraulic roughness		
Manning's n roughness coefficient (channel and floodplain)	For channel: Chow's (1959) table, or empirical equation of Dingman and Sharma (1997). For floodplain: Based on vegetation cover/landuse	For channel: based on reconstructed LWD and particle size. For floodplain: based on reference vegetation
Resistance to sediment mobility		
Vegetative cover of banks and floodplains	Percent of sampled length bare	Modelled
Vegetative cover of bed	Percent of sampled length bare	Modelled
Energy to mobilize sediments		
Stream power	Derive from discharge, slope, and channel width - regional relationship (desktop)	Derive on basis of reference channel morphology and discharge
Excess shear stress (regime)	Requires discharge and channel dimensions and bank and bed particle size	Requires reference hydrology and physical form
Hydrological regime	Requires discharge time series	Requires reference hydrology
Floodplains		
Active width	Field or Victorian hydrology layer for 1:100 year flood extent	Based on reference hydrology
Structures	Record all structures (agencies to maintain a database – desktop)	Assume none existed
Floodplain land use	Existing mapping, satellite	Existing mapping of reference land cover
Sediment dynamics		
Bed sediment load	LWRA/SedNet data	Model prediction
Suspended sediment load	LWRA/SedNet data	Model prediction
Channel coarse sediment deposition	LWRA/SedNet data	Model prediction
Floodplain deposition	LWRA/SedNet data	Model prediction
TSS and turbidity data from the VWQMN	Statistical analysis of available data	Not available
Stream classification		
Geomorphic class	Apply existing method, or analyse relevant data as it is becomes available over time	Assume unchanged

2.9 *Criteria for accepting geomorphic form and process indicators*

2.9.1 Adopting a set of criteria

In establishing a new method for evaluating the geomorphic condition of a catchment or region, it is necessary to not only ground the method in defensible geomorphic theory, but to make critical choices when it comes to the practicality of selecting variables or indicators on which to base the metrics. There are an infinite number of ways to measure the geomorphology of a river and catchment. Whenever a geomorphologist, or a non-geomorphologist following a geomorphic method, makes observations they are making an extremely limited set of observations. Whether the operator realises it or not, these variables were at some stage chosen by someone, or a group of people, over a host of other potential variables. Often, the choice of variables made by a method's designers is strongly influenced by what others before them have done, or conditioned by their own experiences of what seems to work. A more rigorous methodology is to assess the merit of proposed indicators on the basis of a set of established criteria. The US Environmental Protection Agency has established a list of suitable criteria for ecological monitoring programs (Jackson et al., 2000), and we adapted this to the proposed fluvial geomorphic assessment method.

The US EPA guidelines are organized within four evaluation phases: conceptual relevance, feasibility of implementation, response variability, and interpretation and utility. We have modified the guidelines of Jackson et al. (2000) to make them applicable to a geomorphic assessment (the original guidelines applied specifically to ecological monitoring programs).

Phases of evaluation of geomorphological variables and metrics (indicators) for their suitability to inform regional-scale assessment of sediment dynamics

Phase 1:	*Conceptual Relevance*: Is the indicator relevant to stream health in general and to sediment dynamics specifically?
Phase 2:	*Feasibility of Implementation*: Are the methods for sampling and measuring the geomorphic variables technically feasible, appropriate, and efficient for use in an on-going assessment program?
Phase 3:	*Response Variability*: Are human errors of measurement and natural variability over time and space sufficiently understood and documented that they can be managed and/or taken into account?
Phase 4:	*Interpretation and Utility*: Will the indicator convey information on geomorphological condition (trajectory of process and form) that is meaningful to stream management decision-making?

In order to evaluate a proposed methodology, it is necessary to consider the guidelines in some detail:

Phase 1: Conceptual Relevance

The indicator must provide information that is relevant to societal concerns about geomorphic condition. The indicator should clearly pertain to one or more identified assessment questions. These, in turn, should be germane to a management decision and clearly relate to geomorphic components or processes deemed important in geomorphological condition (which is a component of ecological condition).

Guideline 1. Relevance to the Assessment

It must be demonstrated in concept that the proposed indicator is responsive to an identified assessment question and will provide information useful to a management decision. For indicators requiring multiple measurements (indices or aggregates), the relevance of each measurement to the management objective should be identified. In addition, the indicator should be evaluated for its potential to contribute information as part of a suite of indicators designed to address multiple assessment questions. The ability of the proposed indicator to complement indicators at other scales and levels of geomorphic organization should also be considered. Redundancy with existing indicators may be permissible, particularly if improved performance or some unique and critical information is anticipated from the proposed indicator.

Guideline 2: Relevance to Ecological Function

It must be demonstrated that the proposed indicator is conceptually linked to the geomorphic function of concern. A straightforward link may require only a brief explanation. If the link is indirect or if the indicator itself is particularly complex, geomorphic relevance should be clarified with a description, or conceptual model. A conceptual model is recommended, for example, if an indicator is comprised of multiple measurements or if it will contribute to a weighted index. In such cases, the relevance of each component to ecological function and to the index should be described. At a minimum, explanations and models should include the principal stressors that are presumed to impact the indicator, as well as the resulting geomorphic response. This information should be supported by available literature.

Phase 2: Feasibility of Implementation

Adapting an indicator for use in a program that is proposed for wide-scale application must be feasible and practical. Methods, logistics, cost, and other issues of implementation should be evaluated before routine data collection begins. Sampling, processing and analytical methods should be documented for all measurements that comprise the indicator. The logistics and costs associated with training, travel, equipment and field and laboratory work should be evaluated and plans for information management and quality assurance developed.

Guideline 3: Data Collection Methods

Methods for collecting all indicator measurements should be described. Standard, well-documented methods are preferred. Novel methods should be defended with evidence of effective performance and, if applicable, with comparisons to standard methods. If multiple methods are necessary to accommodate diverse circumstances at different sites, the effects on data comparability across sites must be addressed. Expected sources of error should be evaluated. Methods should be compatible with the design of the program for which the indicator is intended. Plot design and measurements should be appropriate for the spatial scale of analysis. Needs for specialized equipment and expertise should be identified.

Sampling activities for indicator measurements should not significantly disturb a site. Evidence should be provided to ensure that measurements made during a single visit do not affect the same measurement at subsequent visits or, in the case of integrated sampling regimes, simultaneous measurements at the site. Also, sampling should not create an adverse impact on protected species, species of special concern, or protected habitats.

Guideline 4: Logistics

The logistical requirements of an indicator can be costly and time-consuming. These requirements must be evaluated to ensure the practicality of indicator implementation, and to plan for personnel, equipment, training, and other needs. A logistics plan should be prepared that identifies requirements, as appropriate, for field or desktop measurements.

Guideline 5: Information Management

Management of information generated by an indicator, particularly in a long-term monitoring program, can become a substantial issue. Requirements should be identified for data processing, analysis, storage, and retrieval, and data documentation standards should be developed. Compatibility with other systems should be considered, such as the internet, established federal standards, geographic information systems, and systems maintained by intended secondary data users.

Guideline 6: Quality Assurance

For accurate interpretation of indicator results, it is necessary to understand their degree of validity. A quality assurance plan should outline the steps in collection and computation of data, and should identify the data quality objectives for each step. It is important that means and methods to audit the quality of each step are incorporated into the measurement program design. Standards of quality assurance for an indicator must meet those of the targeted program.

Guideline 7: Monetary Costs

Cost is often the limiting factor in considering to implement an indicator. Estimates of all implementation costs should be evaluated. Cost evaluation should incorporate economy of scale, since cost per indicator or cost per measurement may be considerably reduced when data are collected for multiple indicators at a given site (for field collected data). Costs of a pilot study or any other indicator development needs should be included if appropriate.

Phase 3: Response Variability

It is essential to understand the components of variability in indicator results to distinguish extraneous factors from a true environmental signal. Total variability includes both measurement error introduced during field and desktop activities and natural variation. Natural variability can include temporal (within the field season and across years) and spatial (across sites) components. Depending on the context of the assessment question, some of these sources must be isolated and quantified in order to interpret indicator responses correctly. It may not be necessary or appropriate to address all components of natural variability. Ultimately, an indicator must exhibit significantly different responses at distinct points along a geomorphic condition or process gradient. If an indicator is composed of multiple measurements, variability should be evaluated for each measurement as well as for the resulting indicator.

Guideline 8: Estimation of Measurement Error

The process of collecting, transporting, and analyzing geomorphic data generates errors that can obscure the discriminatory ability of an indicator. Variability introduced by human and instrument performance must be estimated and reported for all indicator measurements. Variability among field crews and office personnel should also be estimated, if appropriate. If standard methods and equipment are employed, information on measurement error may be available in the literature. Regardless, this information should be derived or validated in dedicated testing or a pilot study.

Guideline 9: Temporal Variability - Within the Field Season

It is unlikely in a field measurement program that data can be collected simultaneously from a large number of sites. Instead, sampling may require several days, weeks, or months to complete, even though the data are ultimately to be consolidated into a single reporting period. Thus, within-field season variability should be estimated and evaluated. It may be necessary that indicators are applied only within a particular season or flow condition. This optimal time frame, or index period, reduces temporal variability. The use of an index period should be defended and the variability within the index period should be estimated and evaluated.

Guideline 10: Temporal Variability - Across Years

Indicator responses would be expected to change over time. Estimates of variability across years should be examined to ensure that the indicator reflects true trends in geomorphic condition for characteristics that are relevant to the assessment question. To determine inter-annual stability of an indicator, monitoring must proceed for several years at sites known to have remained in the same geomorphic condition.

Guideline 11: Spatial Variability

Indicator responses to various environmental conditions must be consistent across the monitoring region if that region is treated as a single reporting unit. Locations within the reporting unit that are known to be in similar geomorphic condition should exhibit similar indicator results. If spatial variability occurs it may be necessary to normalize the indicator across the region, or to divide the reporting area into more homogeneous units.

Guideline 12: Discriminatory Ability

The ability of the indicator to discriminate differences among sites along a known geomorphic condition gradient should be critically examined. This analysis should incorporate all error components relevant to the program objectives, and separate extraneous variability to reveal the true environmental signal in the indicator data.

Phase 4: Interpretation and Utility

A useful geomorphic indicator must produce results that are clearly understood and accepted by scientists, engineers, river managers, policy makers, and the public. The statistical limitations of the indicator's performance should be documented. A range of values should be established that defines geomorphic condition in relation to indicator results (i.e. the values are on a scale of high to low or more to less). Finally, the presentation of indicator results should highlight their relevance for specific management decisions and public acceptability.

Guideline 13: Data Quality Objectives

The discriminatory ability of the indicator should be evaluated against program data quality objectives and constraints. It should be demonstrated how sample size, monitoring duration, and other variables affect the precision and confidence levels of reported results, and how these variables may be optimized to attain stated program goals. For example, a program may require that an indicator be able to detect a twenty percent change in some aspect of geomorpholoical condition over a ten-year period, with ninety-five percent confidence. With magnitude, duration, and confidence level constrained, sample size and extraneous variability must be optimised in order to meet the program's data quality objectives. Statistical power curves are recommended to explore the effects of different optimization strategies on indicator performance.

Guideline 14: Assessment Thresholds

To facilitate interpretation of indicator results by the user community, threshold values or ranges of values should be proposed that delineate acceptable from unacceptable geomorphological condition (i.e. to distinguish when action is required). Justification can be based on documented thresholds, regulatory criteria, historical records, experimental studies, or observed responses at reference sites along a condition gradient. Thresholds may also include safety margins or risk considerations. Regardless, the basis for threshold selection must be documented.

Guideline 15: Linkage to Management Action

Ultimately, an indicator is useful only if it can provide information to support a management decision or to quantify the success of past decisions. Policy makers and resource managers must be able to recognize the implications of indicator results for stewardship, regulation, or research. An indicator with practical application should display one or more of the following characteristics: responsiveness to a specific controlling agent, linkage to policy indicators, utility in cost-benefit assessments, limitations and boundaries of application, and public understanding and acceptance. Detailed consideration of an indicator's management utility may lead to a re-examination of its conceptual relevance and to a refinement of the original assessment question.

2.9.2 Applying the criteria

Although ideally the adopted criteria would be applied in a rigorous way, for this project it was not possible to apply every one of the recommended criteria in this way. This project is ambitious because it attempts to development a new approach to geomorphic assessment. Before the method (or more specifically, the selected indicators) can be assessed against all of the recommended criteria, a period of data gathering, field testing, data analysis, end user experience, and reporting are required. While we stand by the criteria, we were unable to fully implement this evaluation at this stage. Our partial application of the criteria was aimed at identifying a group of core indicators that were suitable for characterising stream geomorphic trajectory.

The evaluation (Table 2-6) suggested that most of the variables have reasonably high relevance, which is not surprising considering that the list was based on a thorough theoretical framework. Feasibility of measurement presented more of a problem, as some variables are either technically difficult to measure, or are expensive to measure. No variables scored highly on response variability. This is because of the inherent (natural) variability of geomorphic variables and the lack of information regarding acceptable levels of variability before management action is warranted. Interpretation and utility was judged on whether or not the variable was likely to resonate with stream managers and the public.

The overall evaluation score suggested that some of the more obscure variables such as Manning's n and stream power are low priority for inclusion, as are floodplain variables (mainly because of the very low rates of change expected). Sediment dynamics variables are potentially useful, but there may be problems with the cost of modeling and the utility of some variables is questionable (i.e. how to translate bed material sediment loads to management action). In general, the channel form variables offer the highest potential, along with the bed and bank stability variables.

Table 2-6.
Evaluation of potential variables for geomorphic assessment of the North Central CMAregion. Three point scale is used: high, moderate and low.

Variable	Conceptual relevance	Feasibility	Response variability	Interpretation and utility	Overall
Channel dimensions					
Width (and variability of)	high	moderate	moderate	high	mod-high
Depth (and variability of)	high	moderate	moderate	high	mod-high
Width/Depth ratio	moderate	moderate	moderate	high	mod-high
Stream features	high	low	moderate	moderate	moderate
Bank stability					
Bank angle	moderate	moderate	moderate	high	mod-high
Bank cohesivity	high	moderate	low	moderate	moderate
Bed stability					
Bed material size	high	moderate	high	high	high
LWD density	high	moderate	high	high	high
Hydraulic roughness					
Manning’s n roughness coefficient	moderate	low	moderate	low	low-mod
Resistance to sediment mobility					
Vegetative cover of banks and floodplains	high	moderate	moderate	high	mod-high
Vegetative cover of bed	moderate	moderate	low	high	moderate
Energy to mobilize sediments					
Stream power	high	low	low	low	low
Excess shear stress regime	high	low	moderate	moderate	moderate
Hydrological regime	moderate	low	moderate	high	mod-high
Floodplains					
Active width	low	high	low	low	low
Structures	moderate	low	moderate	high	moderate
Floodplain land use	moderate	moderate	moderate	high	moderate
Sediment dynamics					
Bed sediment load	high	low	low	moderate	low-mod
Suspended sediment load	moderate	low	low	high	moderate
Channel coarse sediment deposition	high	low	moderate	high	moderate
Floodplain deposition	low	low	low	low	low
TSS and turbidity data from the VWQMN	moderate	moderate	low	moderate	moderate
Stream classification					
Geomorphic class	moderate	low	low	moderate	low-mod

3 Assessment of the Fluvial Geomorphology of the NorthCentral CMA Region

3.1 *Introduction*

This section summarises the data collected during the course of this project. There were a limitednumber of consistent sets of data that were widely available and at the appropriate scale:

- Topographic and streamline data,
- Gully density,
- Victorian Water Quality Monitoring Network summarized turbidity data (Hunter and Zampatti, 1994), and
- The North Central CMA (August 2006) Waterway and Catchment Descriptions information sheets.

Although discharge data were available for a reasonably large number of gauging stations, these data were not analysed due to the impracticality of such an exercise.

Although the Waterway and Catchment Descriptions information Sheets had extensive coverage, these data were far from ideal, mainly because they were not collected with geomorphological assessment in mind.

3.2 *Terrain analysis*

Terrain analysis refers to numerical processing of terrain (topographical) data to transform it, combine it, or classify it into new data layers, either for further processing or for visualization. Terrain analysis was undertaken using SAGA (System for Automated Geoscientific Analyses) (URL: http://www.saga-gis.org) . SAGA is an open source grid-based Geographic Information System (GIS). It was developed at Goettingen University in Germany. Version 2.0 is the second major release of the SAGA program. One of the groups of modules in SAGA is Terrain Analysis. Algorithms are available for mapping slope, aspect, curvatures, curvature classification, analytical hillshading, sink eliminition, flow path analysis, catchment delineation, solar radiation, channel lines, relative altitudes, wetness index, index of valley bottom flatness etc.

The purpose of terrain analysis was to seek a way of classifying the North Central CMA region into geomorphic functional zones, as a form of classification. Schumms' (1977) three function zones of source, transport and deposition may be adequate as a conceptual model, but it proved difficult to classify the region into such simple zones. Numerous terrain variables and combinations of terrain variables were computed and mapped, but none of these produced an entirely satisfactory result. The main problem is that each sub-catchment also potentially possesses the three functional zones, which makes the zone boundaries incompatible when the analysis is run at different scales.

The slope classes of the model of Montgomery and Buffington (1997) (Figure 2-5) are broad and over-lapping, but selection of three slope classes that fell within the source, transport and deposition zoned produced a map with a potentially useful classification, although there were very few areas falling into the high slope class (mostly in the upper Avoca catchment) (Figure 3-1). Another problem with this map is that the streams themselves are of lower slope than the immediate valley slopes that they drain, so the perimeters of the zones are complex (Figure 3-1).

The Sustainable Rivers Audit (Davies et al., 2008) reported on stream health at two scales: the Valley scale and the Valley Zone scale. Valleys are similar to the major hydrologically defined catchments (i.e Avoca, Loddon, Campaspe, with the Avon-Richarson falling into the Wimmera Valley). Valley Zones were defined by altitude as lowland (0 – 200m), slopes (200 – 400 m), upland (400 – 700 m) and montane (> 700m). A division of the North Central CMA region according to this classification produced a potential source, transport and deposition zonation, but there was little montane area, and the Avoca and the Avon-Richardson lacked upland areas (Figure 3-1). Overall, terrain analysis was not particularly useful when applied at the region-wide scale. Terrain analysis is more suited to analyzing processes at the grid-cell scale. In fact, catchment-scale sediment models (such as SedNet) perform similar sorts of calculations at this scale.

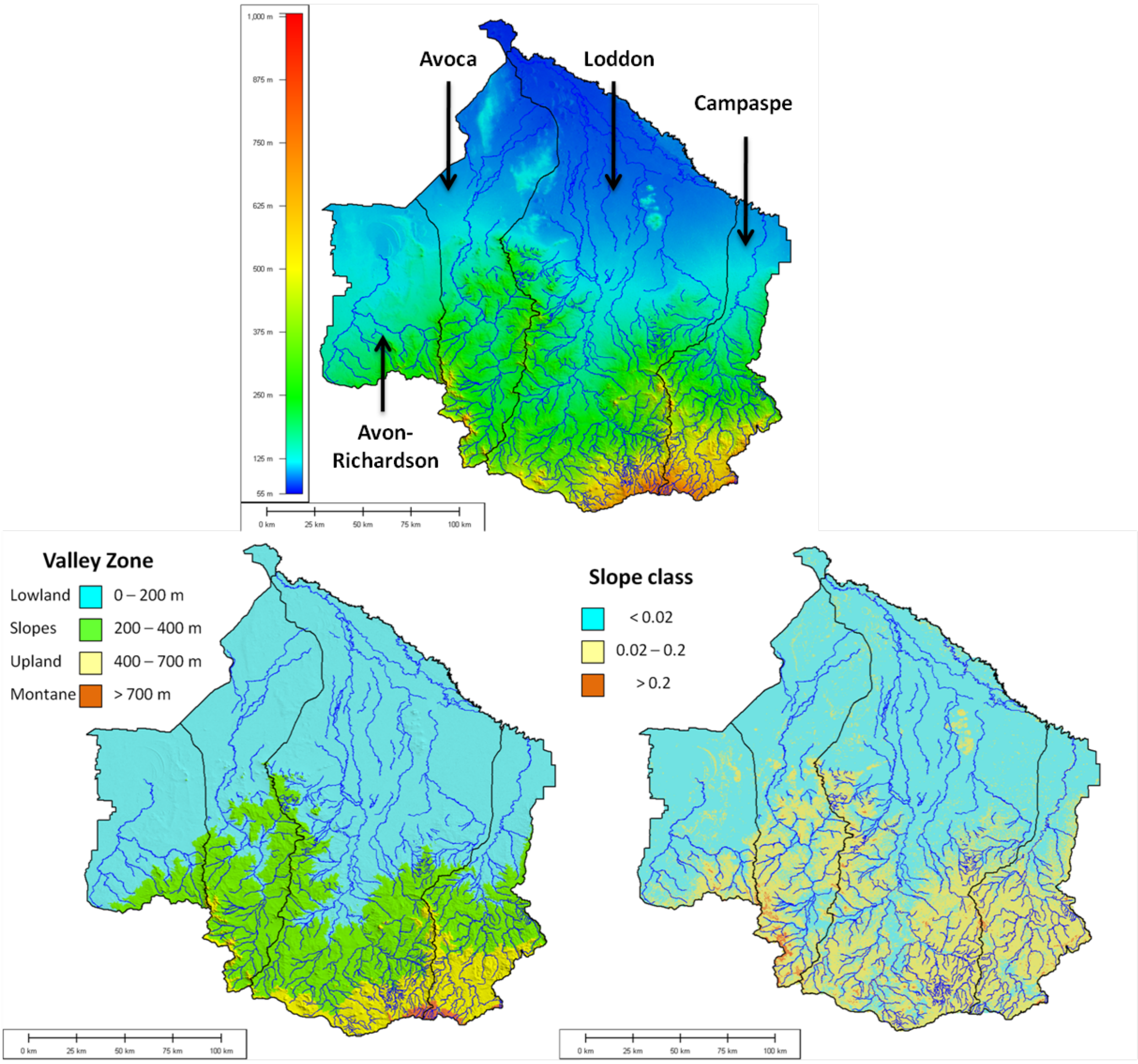


Figure 3-1. North Central CMA region topography, and geomorphic zones defined by altitude and slope classes.

3.3 Gully distribution

A map of gully distribution was produced in 2001 for the North Central CMA region as an input to the SedNet modeling for the National Land and Water Resources Audit. Although a copy of the finished map was obtained for this project (Figure 3-2), the original data were not available. The data appear to originate well before 2001, as the distribution of gullies on this map is the same as that on a map of gullies in Victoria dated 1982 (Figure 3-2). The distribution of gully density is related to the terrain. The highest gully densities (Figure 3-2) correspond quite well to the areas of highest slope (Figure 3-1). The only exception is the steep land on the south-eastern part of the region (far upper Loddon and upper Campaspe), which is free of gullies. While some of this steep, gully-free land is forested, the distribution of gullies is also partly controlled by geology and soil type.

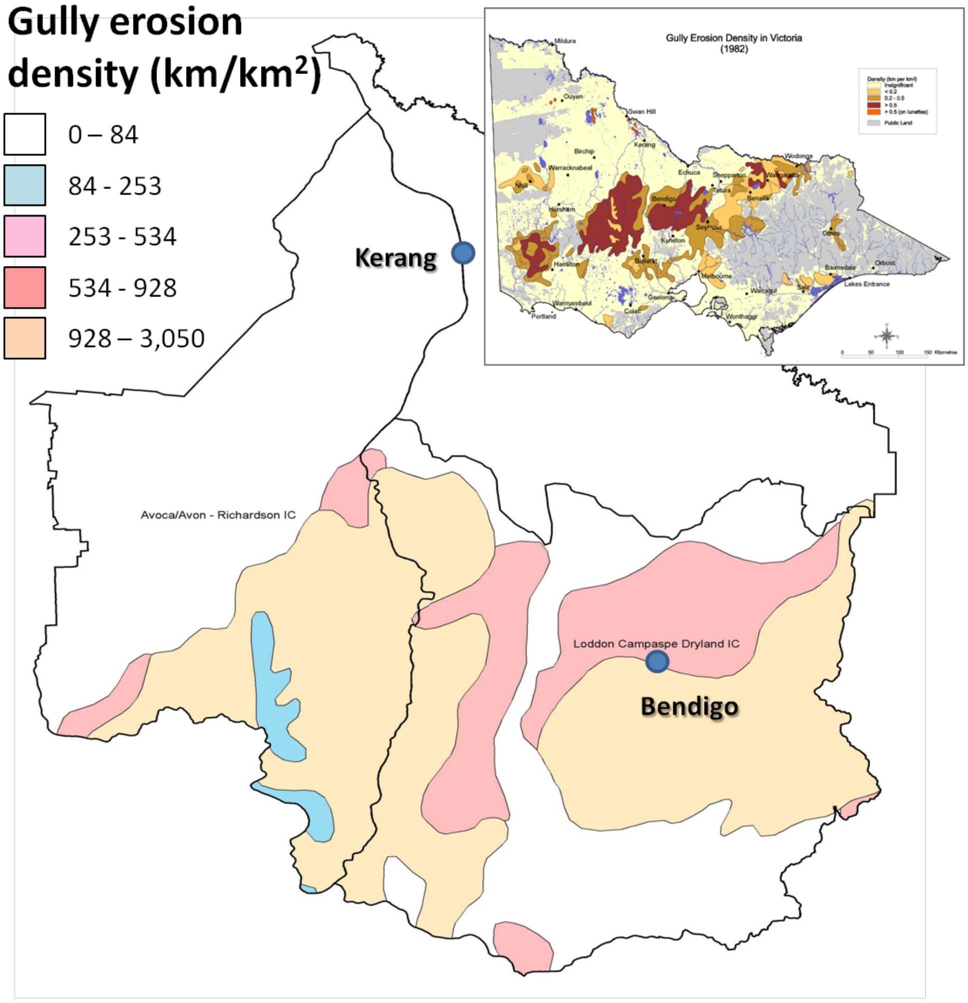


Figure 3-2. Gully erosion density map for the North Central CMA region prepared for the NLWRA (2001).

3.4 *Turbidity*

Hunter and Zampatti (1994) analysed all of the data collected by the Victorian Water Quality Monitoring Network from 1975 to 1992 and presented summaries as percentiles, means and standard deviations. While some total suspended solids (TSS) data were available for 13 stations in the North Central CMA region, 34 stations had turbidity data, and because turbidity is measured more frequently than TSS, there was more data per site. The median number of turbidity samples per site was 144. The sampling locations were not evenly distributed, with few in the Avon-Richardson and Avoca catchments (Figure 3-3).

The water quality data indicated that water was more turbid in the Avon-Richardson and the north-eastern Loddon catchments (Figure 3-3). The headwater areas had low turbidity (Figure 3-3). The ratio of 90th percentile turbidity to 10th percentile turbidity produced a different pattern. This index expresses the difference between the high values of turbidity experienced (usually in storm events) to the low values experienced (usually during baseflow times). Thus, a high ratio suggests that storm events carry relatively highly turbid water. Such streams were found in the mid-Campaspe, far upper-western Loddon and the central-Avoca (Figure 3-3). There is a suggestion in the data that these areas correspond with the areas of high gully density (Figure 3-2). These areas are likely to have readily available sources of fine sediment available in bare gully surfaces that is washed into the stream during storm events, but during baseflow the water is relatively clear because the gullies are high on the slopes where water is not flowing. This pattern of turbidity may produce a distinctive ecological response, but adequate data are not available to test this.

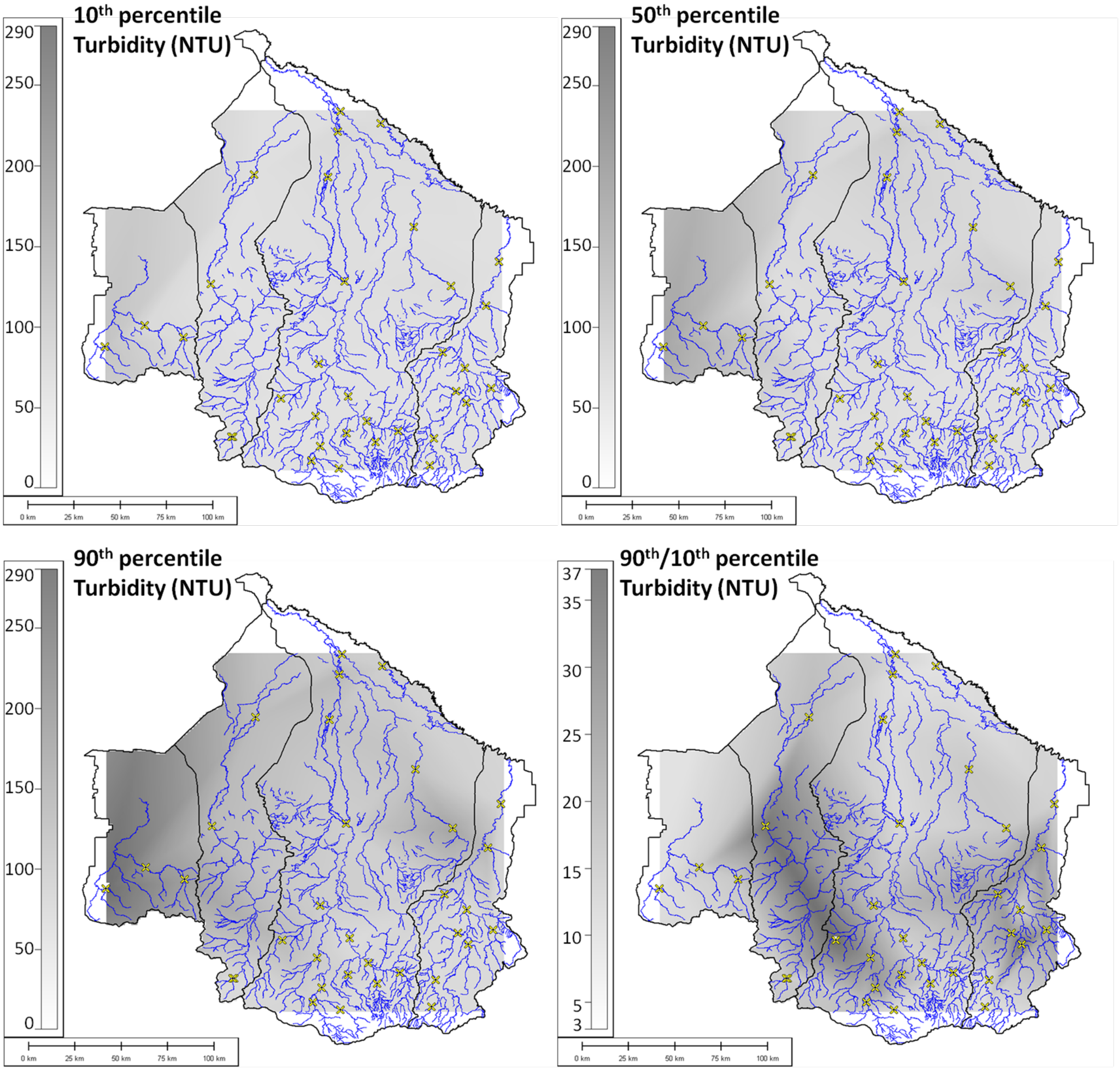


Figure 3-3. North Central CMA region turbidity data. Yellow crosses indicate water quality monitoring station.

3.5 North Central CMA (August 2006) Waterway and Catchment Descriptions information sheets

In 2006 The Waterways of the North Central region – catchment and waterway descriptions project was completed. The project was undertaken by the North Central Catchment Management Authority (CMA) over several years. Major preparation contributions were made by Angela Gladman, Greg Peters, Greg Chant and Nathan Day. The catchment and waterway descriptions aimed to:

- provide a general picture of the major waterways in the catchments using all currently available information

- inform the general public, stakeholder groups and organisations about waterways in the catchments
- provide a education resource for students
- contribute to the background information used in funding applications by individuals, community and Landcare groups and other organisations
- link closely to the North Central River Health Strategy (North Central CMA, 2005).

The methodology involved extensive field surveys, aerial photo and map interpretation, literature reviews and community input. The key steps were:

- identification of major waterways
- compilation and review of relevant literature
- survey of rapid assessment points along major waterways
- aerial photo interpretation of the riparian vegetation
- completion of background investigations into aquatic life and water quality
- community, agency and Indigenous River Health Forums
- public release of draft waterway summaries and incorporation of comments
- completion of the draft River Health Plans
- review of the draft River Health Plans to reflect the North Central River Health Strategy
- renaming of the document to align with its final content
- completion, production and public release of ‘Waterways of the North Central region – catchment and waterway descriptions’.

Although metadata and methodological details were not made available, and nor were the original data, it was possible to extract data in a numerical form from the published information sheets for each stream or stream reach. This necessarily involved subjective interpretation, because the documents themselves contained virtually no numerical information. A methodology was devised to extract information on a number of key variables that appeared to be consistently described in the information sheets.

The bed material particle size was described in every information sheet. The description often included more than one material size, which is not surprising as river bed material is rarely homogeneous. In this project it was of interest to know the dominant native bed material (i.e. the natural material) and the nature of any layer deposited on the bed surface (probably due to anthropogenic disturbance). In many cases this was clearly stated in the information sheet. In other cases there were problems in interpretation, either because there were contradictory descriptions in the one sheet, or because it was not clear which was the dominant material. Assuming that the authors were systematic in their approach to documentation, we assumed that the first mention material was the dominant material, unless it was stated otherwise in the sheet. There was one other more serious problem with the particle size description. This related to the liberal, and possibly often incorrect, use of the term ‘silt’. Technically, silt is sediment of a size 3.9 μm to 62.5 μm in diameter (Gordon et al., 2004, page 116). It is possible to distinguish silt from clay and sand in the field using hand-texturing techniques, but there is no indication in the catchment and waterway descriptions literature that this was followed. Unfortunately, the terms ‘silt’ and ‘siltation’ are used colloquially to mean any form of sedimentation on a stream bed, regardless of particle size. It appears that in at least some of the information sheets where silt is described it actually means sand. In dubious cases we checked other descriptions of the river in the ‘Guide to the Inland Angling Waters of Victoria’ (Tunbridge and Rogan, 2005) or relied on field inspection.

To simplify the classification of bed particle size, the dominant particle size was noted [bedrock (R), cobble (Co), gravel (Gr), sand (Sa), silt (Si), clay (C), vegetation (Vg) and organic matter (Or)], and a second class was created for each dominant class if it had a covering of silt.

The trajectory of the channel was often noted in the information sheets. The trajectory refers to whether the stream physical condition is moving away from or towards an equilibrium or former state. In cases where this was not mentioned, either it was assumed that the stream was in dynamic equilibrium or an assessment was made on the basis of other indirect information provided in the sheet.

Bank erosion severity was classified in each information sheet. This information was transferred directly from each sheet.

Degree of bed incision was, like trajectory, sometimes explicitly described, while in other cases it was either not mentioned or it was inferred.

It was assumed that the presence of sand slugs was easily identified. This was mentioned in a number information sheets. As a general rule, unless this was specifically stated in the sheet, the presence of a sand slug was not inferred.

Channel complexity was inferred from descriptions of sinuosity and depth and variability of pools, large woody debris, riffles and other features like undercuts. In general, the descriptions in the sheets were consistently worded, so it was possible to rate complexity from the descriptions with a fair degree of precision.

The analysis was undertaken for the Avoca, Avon-Richardson and Campaspe catchments (comprising seven FIS units). Although this approach involved extraction of existing data, it proved to be a time consuming process. The Loddon catchment was not initially included in this analysis; it was considered lower priority for data collection because it has been the subject of a detailed SedNet study (SKM, 2002a; SKM, 2002b).

Overall, the geomorphic condition of 315 FIS reaches (2,527 km) was assessed from the catchment and waterway descriptions. This involved 53 reaches (473 km) from Avon-Richardson (FS Unit 1), 41 reaches (349 km) from Lower Avoca (FS Unit 2), 83 reaches (669 km) from Upper Avoca (FS Unit 3), 30 reaches (214 km) from Coliban (FS Unit 6), 53 reaches (397 km) from Upper Campaspe (FS Unit 7), 47 reaches (357 km) from Middle Campaspe (FS Unit 8), and 8 reaches (68 km) from Lower Campaspe (FS Unit 9).

3.5.1 Bed material

Dominant bed material followed the expected pattern, with coarser material being present in the upland reaches, while lowland reaches were dominated by clay, silt and sand (Figure 3-4). The upper and mid-catchment zones were more variable in their bed material composition compared to the lowland reaches. There were many instances of a silt layer being present over the native bed material, but there remains some doubt about whether this is actually silt or some other particle size (possibly sand).

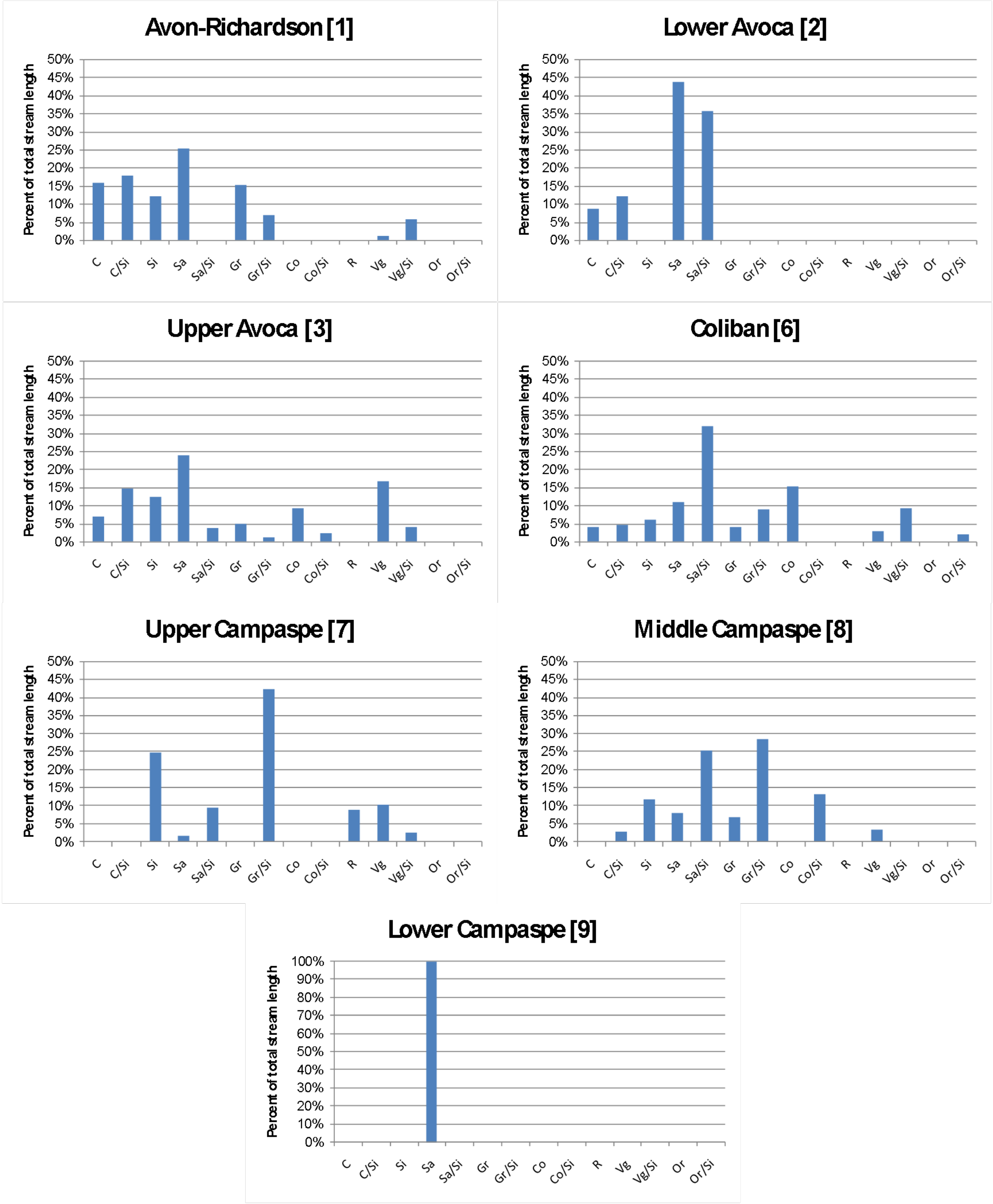


Figure 3-4. Distribution of bed material particle size data extracted from catchment and waterway descriptions. Codes are for dominant material being bedrock (R), cobble (Co), gravel (Gr), sand (Sa), silt (Si), clay (C), vegetation (Vg) and organic matter (Or). Secondary classes were formed for the dominant class covered by a layer of silt.

3.5.2 Trajectory

Trajectory was one of the less certain variables to be extracted from the catchment and waterway descriptions. For this reason, although a five-point scale was devised, the upper and lower scores were rarely used (Figure 3-5). Most reaches fell into the equilibrium class, although there were many reaches that significant bank erosion or a surface sediment layer that caused it to fall into the slowly degrading class.

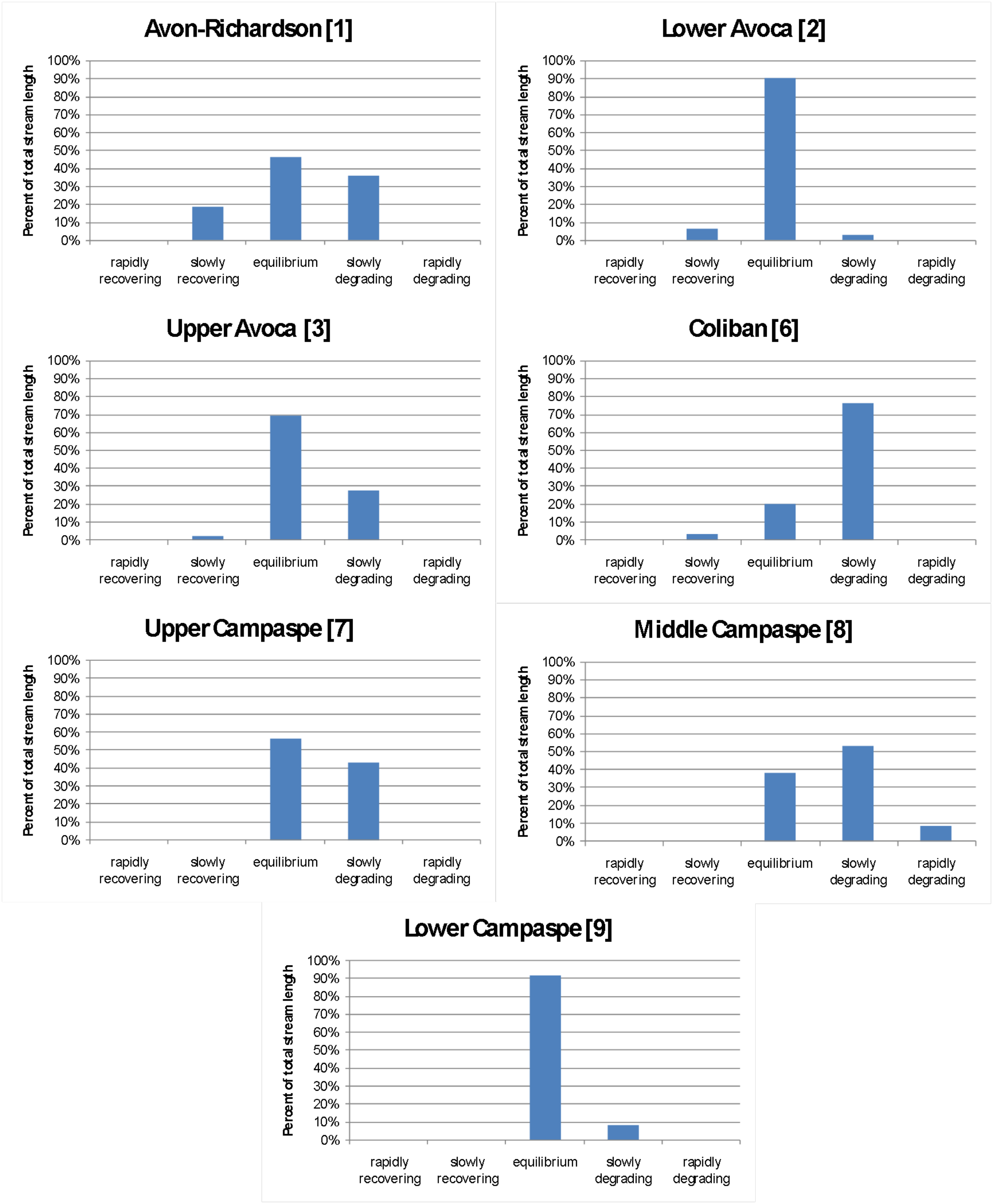


Figure 3-5. Distribution of stream channel geomorphic trajectory, extracted from catchment and waterway descriptions.

3.5.3 Bank stability

Bank stability was well described in the catchment and waterway descriptions. There was a reasonable spread of bank stability across the units, although the majority of reaches were in reference stability or slight deviation from reference (Figure 3-6). With this variable, reference was interpreted to correspond to a description of no erosion or insignificant erosion. The highest incidence of significant bank erosion was found in the Coliban and Middle Campaspe Units.

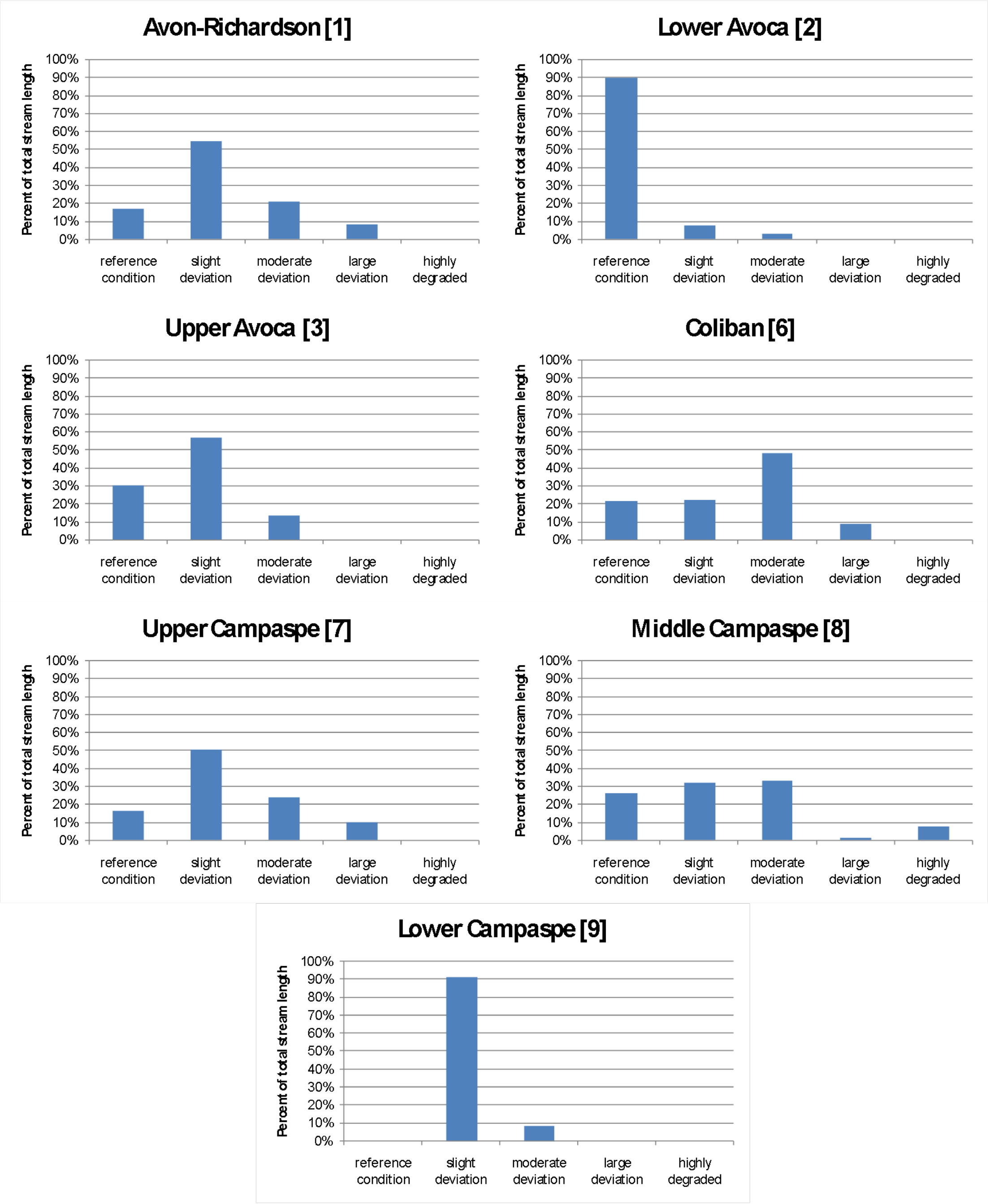


Figure 3-6. Distribution of bank stability, extracted from catchment and waterway descriptions.

3.5.4 Incision

Incision refers to a relatively deep and narrow channel that has obviously cut downwards into alluvial material. Normally an abandoned upper terrace would be the indicator. Incised channels were not common in the region (Figure 3-7). This could be a true reflection of the state of the channel network, or it could be that the observers were not skilled at recognizing incision (which is difficult to do visually, even for an expert).

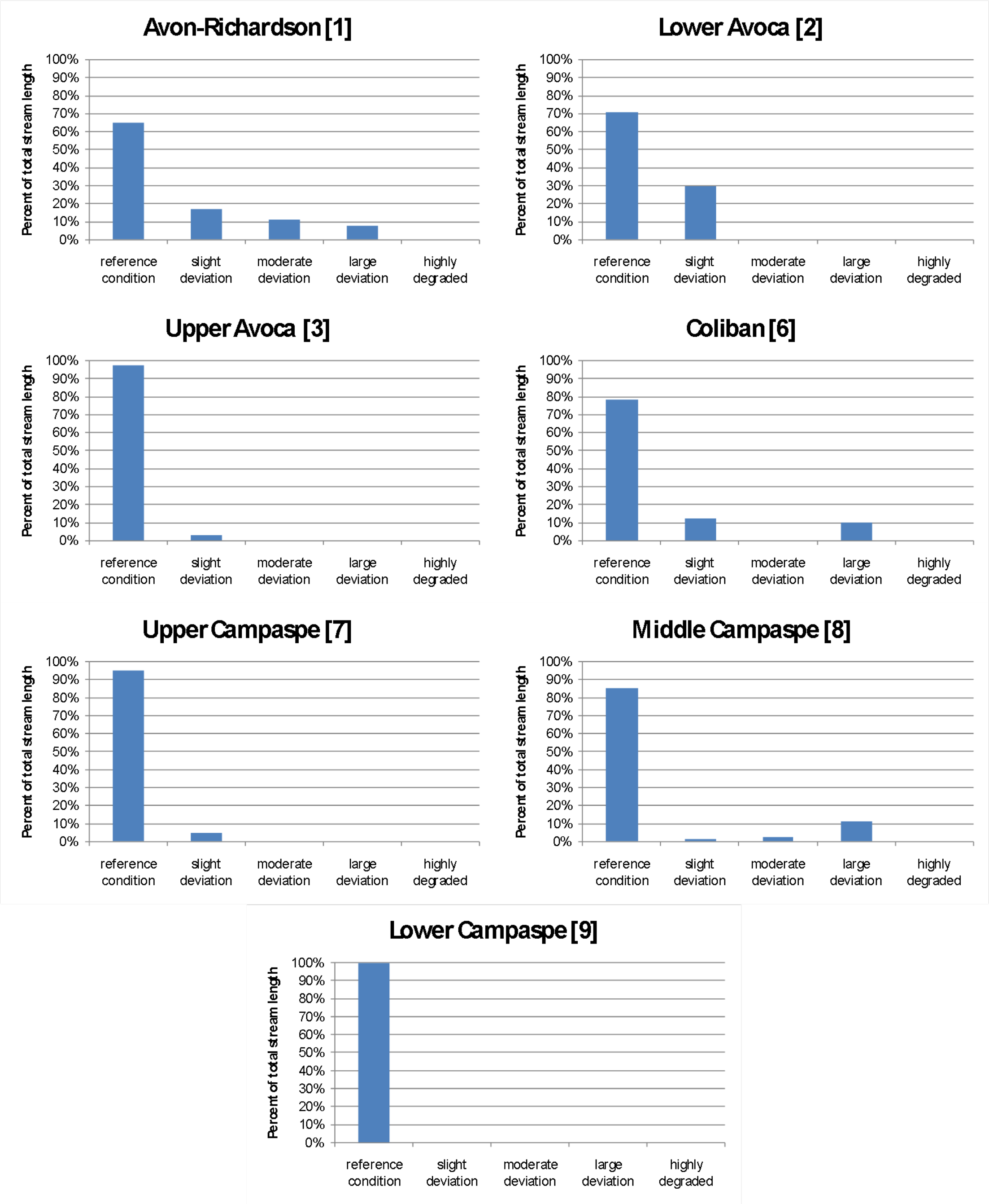


Figure 3-7. Distribution of bed incision, extracted from catchment and waterway descriptions.

3.5.5 Sand slugs

It was expected that the observers had the ability to recognize the presence of sand slugs, as their general location within the region is known. In some cases it may be difficult to discriminate between a naturally sandy bed and a migrating sand slug, because sand slugs are likely to be found in rivers where there is a natural supply of sand-sized bed material. Sand slugs were limited to a minority of reaches in the Coliban, and to a lesser extent the Upper Campaspe and Middle Campaspe (Figure 3-8). This generally accords with the expected distribution.

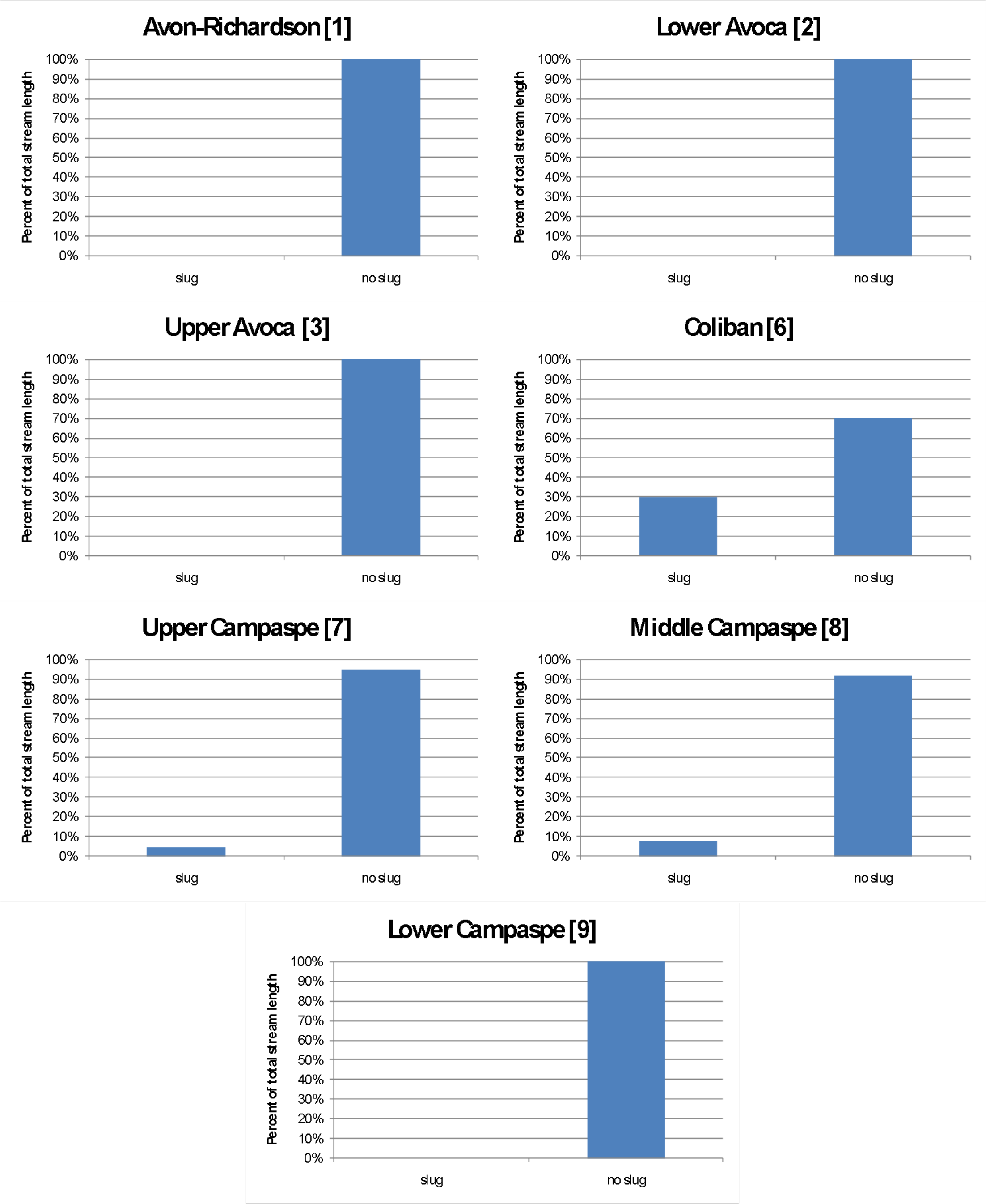


Figure 3-8. Distribution of sand slugs, extracted from catchment and waterway descriptions.

3.5.6 Channel complexity

Channel complexity indicators were consistently described in the catchment and waterway descriptions. However, although a five-point scale was used to describe complexity, the highest variability class was not used. This came about because it was not known if the descriptions covered many reaches that actually fitted this class (Figure 3-9). In general, rivers with sedimentation problems scored low channel complexity, although very few of these were described as lacking any variability.

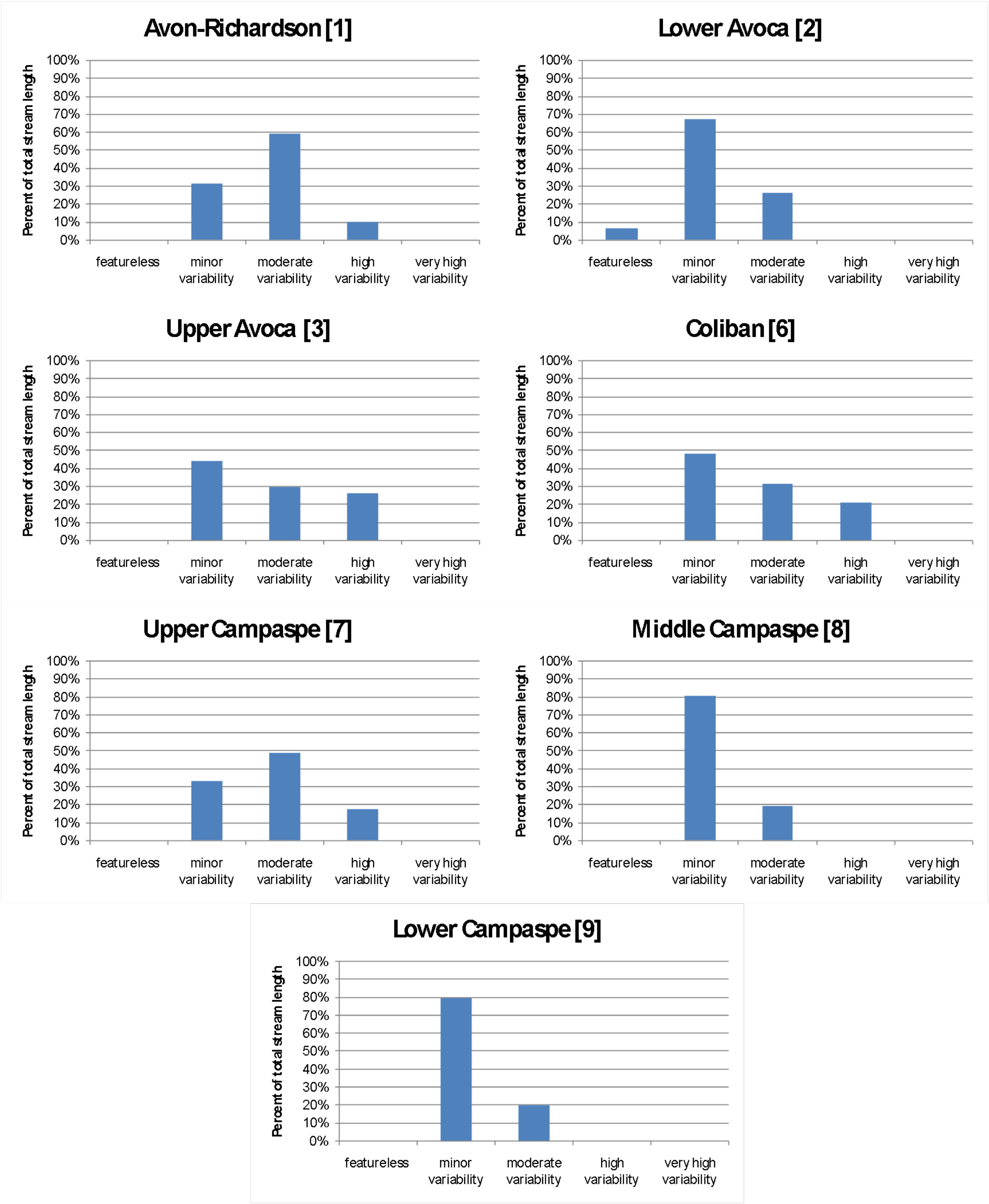


Figure 3-9. Distribution of channel physical complexity, extracted from catchment and waterway descriptions.

3.6 *Quantifying geomorphic data from literature*

As well as sourcing data from the North Central CMA catchment and waterway descriptions other textual forms of information were interrogated for useful data. A comprehensive review of literature relevant to the geomorphology of the North Central CMA region was undertaken by Gippel (2006). That review is not reproduced here. However, for this project, that body of literature was re-visited. Rather than produce a narrative form of literature review, the various reports were interrogated with respect to producing numerical data concerning a set of key geomorphic characteristics. Those characteristics were the same as those considered when extracting numerical information from the catchment and waterway descriptions sheets, except that the channel complexity variable was not included (due to the general lack of consistent commentary on this variable). Overall, this resulted in observations for 235 stream reaches. These data were included in the FIS.

The problem encountered with extracting numerical data from the general literature was the high degree of variability in methodologies, reporting and terminology, even though most of the studies were ostensibly concerned with understanding some aspect of the fluvial geomorphology of stream reaches or wider areas. Also, it was rarely possible to find information on all key geomorphic variables for any particular site, making it difficult to make direct comparisons with data from the catchment and waterway descriptions.

3.7 Field assessment of geomorphic state

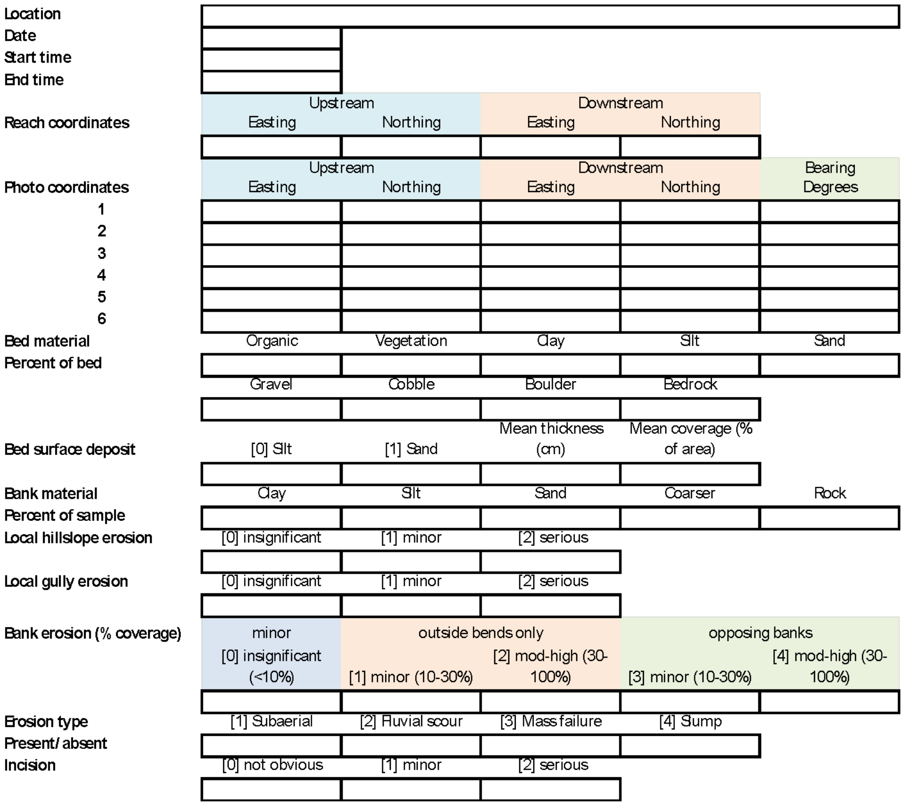
While information was available on the geomorphic forms and processes in the North Central CMA region, there was a need to undertake some ground truthing. There was also a need to develop for the CMA a standard methodology for undertaking rapid geomorphological assessment at the reach scale, so that into the future the FIS can be populated with consistent and informative data.

A standard field methodology was developed and trialed. A total of 36 sites were assessed using the methodology, although as the field work was used to develop the method, not all of the final variables were measured at all of the sites. The variables were selected according to the evaluation for feasibility, relevance, response variability and utility (Table 2-6). The field methodology was also designed to be as objective as possible, repeatable, easily learned, flexible (to handle different stream types and sizes), and rapid (maximum 1 hour for team of2 operators).

The field data are recorded on three field sheets (Figure 3-10, Figure 3-11 and Figure 3-12). It would be preferable to set up a standard data entry form on a field laptop computer or PDA. The device could be loaded with digital maps and aerial photographs of the area being visited to assist with site selection and location.

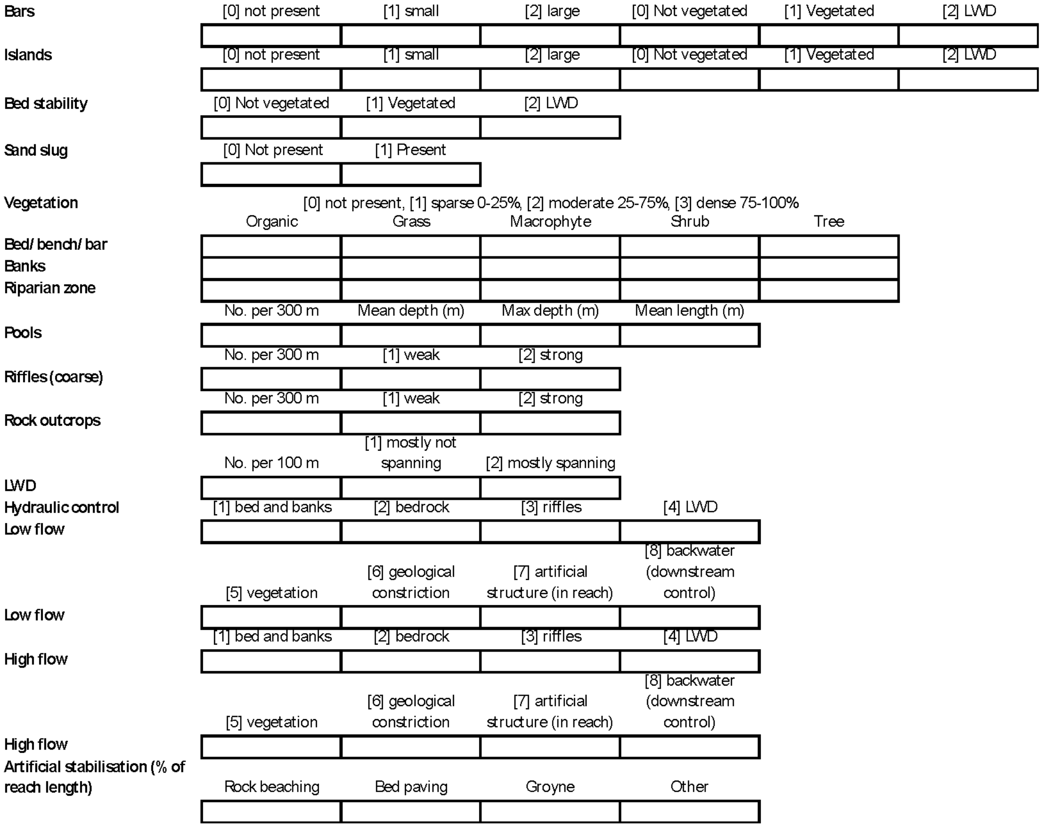
It was considered important that the fieldwork could be completed without requiring the services of a professional surveyor, or a professional geomorphologist. Thus, the channel geometry surveys are undertaken using laser rangefinder (or tape measure as appropriate) with inclinometer. Other measurements include estimates of percentage coverage, or counts per stream length. Bed material size is measured using a pebble count, and bank material composition is estimated using hand texturing. The work is done at the selected stream site, although information on local hillslope and gully sediment sources needs to be collected from the general area. The methodology concentrates on the channel, as this is where most of the geomorphological temporal change and spatial variability is likely to be encountered in most rivers.

It is intended that this methodology can be employed at any site at any time. All CMA field staff can be trained to undertake the work, so that any time they are required to be in the field they can value-add by undertaking a number of geomorphological assessments. The field assessment will return the same geomorphologic information as was collected for the catchment and waterway description project (plus additional information), except that the information is consistently and objectively derived.



Location					
Date					
Start time					
End time					
	Upstream		Downstream		
Reach coordinates	Easting	Northing	Easting	Northing	
	Upstream		Downstream		Bearing
Photo coordinates	Easting	Northing	Easting	Northing	Degrees
1					
2					
3					
4					
5					
6					
Bed material	Organic	Vegetation	Clay	Silt	Sand
Percent of bed					
	Gravel	Cobble	Boulder	Bedrock	
Bed surface deposit	[0] Silt	[1] Sand	Mean thickness (cm)	Mean coverage (% of area)	
Bank material	Clay	Silt	Sand	Coarser	Rock
Percent of sample					
Local hillslope erosion	[0] insignificant	[1] minor	[2] serious		
Local gully erosion	[0] insignificant	[1] minor	[2] serious		
Bank erosion (% coverage)	minor	outside bends only		opposing banks	
	[0] insignificant (<10%)	[1] minor (10-30%)	[2] mod-high (30-100%)	[3] minor (10-30%)	[4] mod-high (30-100%)
Erosion type	[1] Subaerial	[2] Fluvial scour	[3] Mass failure	[4] Slump	
Present/ absent					
Incision	[0] not obvious	[1] minor	[2] serious		

Figure 3-10. Rapid field geomorphological assessment field sheet page 1.



Bars	[0] not present	[1] small	[2] large	[0] Not vegetated	[1] Vegetated	[2] LWD
Islands	[0] not present	[1] small	[2] large	[0] Not vegetated	[1] Vegetated	[2] LWD
Bed stability	[0] Not vegetated	[1] Vegetated	[2] LWD			
Sand slug	[0] Not present	[1] Present				
Vegetation	[0] not present, [1] sparse 0-25%, [2] moderate 25-75%, [3] dense 75-100%					
	Organic	Grass	Macrophyte	Shrub	Tree	
Bed/ bench/ bar						
Banks						
Riparian zone						
	No. per 300 m	Mean depth (m)	Max depth (m)	Mean length (m)		
Pools						
	No. per 300 m	[1] weak	[2] strong			
Riffles (coarse)						
	No. per 300 m	[1] weak	[2] strong			
Rock outcrops						
	No. per 100 m	[1] mostly not spanning	[2] mostly spanning			
LWD						
Hydraulic control	[1] bed and banks	[2] bedrock	[3] riffles	[4] LWD		
Low flow						
	[5] vegetation	[6] geological constriction	[7] artificial structure (in reach)	[8] backwater (downstream control)		
Low flow						
	[1] bed and banks	[2] bedrock	[3] riffles	[4] LWD		
High flow						
	[5] vegetation	[6] geological constriction	[7] artificial structure (in reach)	[8] backwater (downstream control)		
High flow						
Artificial stabilisation (% of reach length)	Rock beaching	Bed paving	Groyne	Other		

Figure 3-11. Rapid field geomorphological assessment field sheet page 2.

Geometry	Top width	Depth	Bank angle	Depth to toe	Floodplain width
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Pebble count	1 - 20	21 - 40	41 - 60	61 - 80	81 - 100
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Figure 3-12. Rapid field geomorphological assessment field sheet page 3.

3.8 Comparison of existing, broad scale geomorphic data sets

3.8.1 Background

There are two recent assessments of the sediment dynamics in streams within the North Central CMA region. The first was the National Land and Water Resources Audit (NLWRA) which reported sediment budgets for each of the major rivers and tributaries (Prosser et al., 2001). The second was a detailed study of the upper Loddon catchment using an enhanced version of the SedNet model developed for the NLWRA (SKM, 2002a).

These two projects produced predictions of geomorphic condition for a large number of North Central CMA streams. An analysis was undertaken to determine how the results of the Australia-wide NLWRA study compared with those of the more detailed Loddon-specific SedNet study. If the comparison holds, then the greater detail produced for small streams by the upper Loddon study could potentially be used to infer the condition of similar streams in other nearby catchments.

3.8.1.1 National Land and Water Resources Assessment

The NLWRA applied a uniform approach for the calculation of sediment budgets through river networks. The budgets include the storage of sediment on floodplains, in the bed of the river and in reservoirs. Calculations were made of the sediment output from each river link and the contribution of sediment to the coast, or any other receiving body, from all sub-catchments. The budgets treated two types of sediment: suspended sediment and bedload. These budgets were calculated using a suite of programs that were subsequently brought together and called the

SedNet model: the Sediment River Network Model (Prosser et al, 2001, p.1).

3.8.1.2 SedNet investigation of the Upper Loddon catchment

A fluvial geomorphological assessment of the Upper Loddon catchment was coordinated by Sinclair Knight Merz (SKM 2002a; SKM 2002b). The investigation brought together three lines of evidence: previous data via a literature review; a snapshot of current condition via field inspections; and a numerical assessment using an enhanced (by comparison with the NLWRA technology) SedNet model.

At the time, the study was considered to represent the benchmark for developing a comprehensive understanding the fluvial geomorphologic condition of a region. However, the approach is expensive and, in the years since publication, the report has not had a great deal of influence on the management of the Upper Loddon region.

The results from the SedNet geomorphic process model present a consistent interpretation of the geomorphology of the upper Loddon region. In the previous application, the SedNet data was used to "determine the spatial distribution of sediment supply and movement through the catchment and to identify the relative importance of different geomorphic processes in different parts of the catchment" (SKM 2002, p.13).

In this project the intention was to put the data to two uses:

1. A primary source of data to define sediment supply and movement within the Upper Loddon region, and
2. A contiguous data set to assist with infilling fluvial geomorphic gaps in other North Central catchments.

3.8.2 Method

Data was sourced for each of the SedNet studies. Details of the predicted sediment budget were attached in each case to stream links as a series of attributes. Comparing the predictions required a two step process:

First, as the stream networks the two studies employed were different, a relationship between each reach in the NLWRA and an equivalent reach (or often reaches) in the Upper Loddon study was developed. Essentially this involved developing an equivalence table which defined a cross-reference using the unique reach ID numbers from each study.

Second, the geomorphic data attached to equivalent reaches was compared. Both studies used SedNet to undertake the analysis (although the software versions were different) so common parameters could be compared. Of particular interest were predictions of river bank erosion, gully erosion and hillslope erosion. These predictions were compared for each common stream link between the NLWRA and Upper Loddon study.

3.8.2.1 Data sources

Stream links and the associated sediment budget components constructed for the NLWRA were downloaded via the Audit data library (http://nlwra.gov.au/Data_Library/).

Output from the SedNet models were provided as an ArcView package delivered by SKM with the Upper Loddon River Geomorphologic Study. The SedNet results were attached as attributes to stream reaches called 'bstreams'.

3.8.2.2 Stream reach cross-referencing

The SedNet model is based on a stream network and hydrological parameters derived from a Digital Elevation Model (DEM). The UL stream network was compared to the FIS stream network (derived from the Hydro-25 'blue line' streams) and to the stream network employed for the National Land and Water Resources Audit (Prosser et al., 2001). The NLWRA stream network was derived from the AUSLIG 9" digital elevation model of Australia using a threshold supporting area of 50 km^2 with short links removed (where the catchment area had not reached 75 km^2 by the next downstream link). Unfortunately, the report by SKM (2002) did not provide any detail on the resolution of the DEM employed nor on the threshold supporting area used to define the reaches for the Upper Loddon study.

A field was added to the Upper Loddon (UL) bstream data table to record the Object ID of the NLWRA reach with which the UL reach was associated. One of three values was written to the field during manual processing of the data:

- NLWRA object id - providing a one-to-one link
- '-1' indicating that no equivalent NLWRA reach exists
- '-2' indicating that the UL reach was fictitious (i.e. the DEM had generated a spurious link that could not be associated with a NLWRA reach nor was there an equivalent reach in the Hydro-25 layer)

This cross-reference table allowed comparisons to be made between the data associated with the same reach in each of the two data sets.

3.8.3 Results Part 1: stream network comparison

A comparison of these three networks of stream reaches (Figure 3-13) showed that the FIS stream nework was more detailed than either of the other data sets; that is the FIS networks extends further toward the divide (e.g. Carmanual Creek and Green Hill Creek) and include more reaches (e.g. Blind Creek and Flat Creek). The UL streams are clearly derived from a DEM with superior resolution to the NLWRA streams, and, although they are slightly offset from the Hydro25 streams, in general they reproduce the stream meanders. The NLWRA streams have the lowest resolution and extent. For example in the region depicted in Figure 3-13 the NLWRA network does not include four creeks that the UL stream set does include.

A statistical summary of the three representations of the Upper Loddon stream networks (Table 3-1) supported the observations above. The total stream length of the UL streams was only 25 percent greater than the NLWRA streams, a smaller difference than might have been expected. In fact only 16 percent of UL streams could not be associated with an equivalent NLWRA reach.

In summary, the FIS stream coverage was significantly more detailed than either of the two DEM-based representations. In some places the connectivity was different. Mostly the stream junctions were displaced and in a number of cases there were a number of short reaches in the vicinity of the junction. Overall, even though the UL streams were at a higher spatial resolution (more reaches) they had a reasonably similar coverage (total stream length) to the NLWRA network. Finally, the FIS data set was clearly superior to both the UL and NLWRA networks in terms of the total reach length, number of reaches, and mean reach length.

3.8.4 Results Part 2: comparison of geomorphic assessments

Three key geomorphic indices were compared to indicate the similarity of the predictions from each study. These indices were:

- Bank erosion rate (metres per year) - Figure 3-14
- Gully erosion rate (tonne per stream kilometer per year) - Figure 3-15
- Hillslope erosion rate (tonne per stream kilometre per year) - Figure 3-16

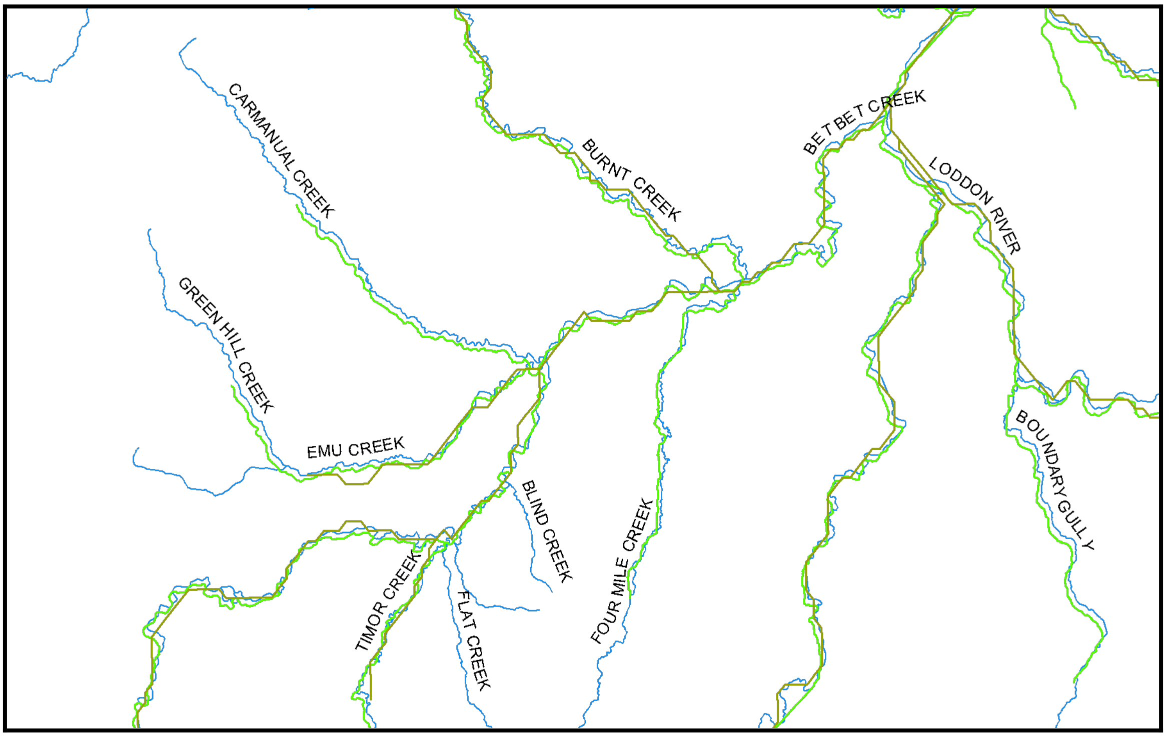


Figure 3-13. Comparison of three stream networks: Blue = FIS streams (based on Hydro25 data); Brown = National Land and Water Resources Audit reaches (AUSLIG 9" DEM); and Green = streams for the Upper Loddon River Geomorphological Study (source not stated).

Table 3-1.
Statistical comparison of three stream networks for the Upper Loddon Catchment.

Stream Set	Total Reach Length (km)	Number of Reaches	Mean Reach Length (km)
FIS (Hydro25)	2,400	567	4.2
UL streams	1,134	158	7.2
NLWRA reaches	835	58	14.4

Note that in order to provide a fair comparison between the statistics for Gully erosion and Hillslope erosion, which are expressed as a total input to a particular stream reach, the erosion rates were non-dimensionalised by reach length. Thus, the erosion rates (tonne/year) per kilometre of stream length were compared.

3.8.4.1 Goodness-of-fit measures

Three quantitative statistical measures were calculated to indicate the goodness of the relationship between the two data sets. First, the square of the Pearson’s correlation coefficient, the coefficient of determination (r^2), which indicates the amount of variance explained. Second, the bias between the two data sets, which essentially measures the difference between the mean value of one data set and the other. Finally, following Legates and McCabe (1999), the goodness-of-fit between the UL data and the NLWRA predictions was quantified using the Modified Coefficient of Efficiency (mCOE). This coefficient measures (in a single number) how different one set of data is from another set of data. If the data are identical, then mCOE will equal 1.00. Poor fits have small or negative values.

In order to assist with the visual interpretation of goodness of fit, two lines are shown with the data on each chart: (i) a linear regression line (indicating the relationship between one data set and the other) and (ii) the line of perfect agreement. If the geomorphic predictions from each data set are similar, then the data points should fall close to the line of perfect agreement.

3.8.4.2 Commentary on comparison

Inspection of each of the three charts (Figure 3-14, Figure 3-15 and Figure 3-16) revealed very poor relationships exist between the NLWRA and UL predictions.

For bank erosion (Figure 3-14) the coefficient of determination was satisfactory (at 0.85), but the bias and the mCOE values were poor. Comparison of the regression line with the line-of-perfect-agreement revealed that these were visibly dissimilar (causing the poor bias and mCOE which are sensitive to such differences). However, the estimates from each study were within the same order of magnitude, and reaches with large rates tended to have large rates in both data sets. The NLWRA estimates were almost universally greater than the Upper Loddon study estimates. Given that SedNet estimates bank erosion principally as a function of bankfull stream power, this result suggests that stream power estimates tended to be higher for the NLWRA assessment.

The gully erosion rate plot (Figure 3-15) showed even greater scatter than that for bank erosion, as demonstrated by the low value for the coefficient of determination (0.35). Bias and mCOE were also poor. Again, the NLWRA predictions tended to be significantly higher than the Upper Loddon estimates. Although for this parameter there were more cases where the Upper Loddon study predicted a larger rate (i.e. data points below the line-of-perfect agreement).

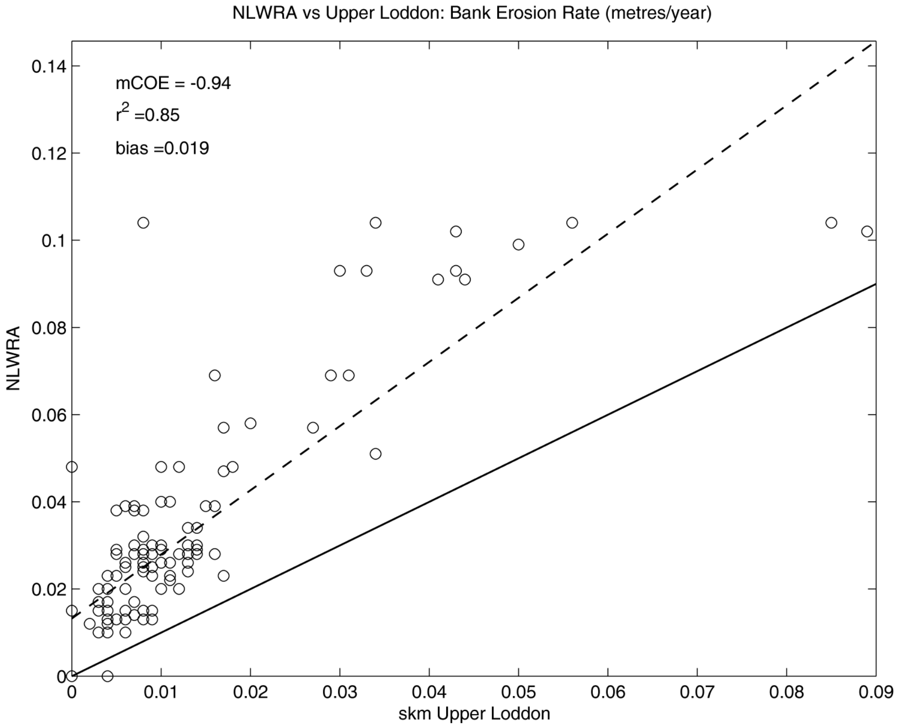


Figure 3-14. The open circles indicate the bank erosion rate (metres per year) predicted by the NLWRA compared to the rate predicted for the Upper Loddon study. Three goodness of fit measures are shown as well as the line-of-perfect-agreement (solid line) and the linear regression line (dashed line).

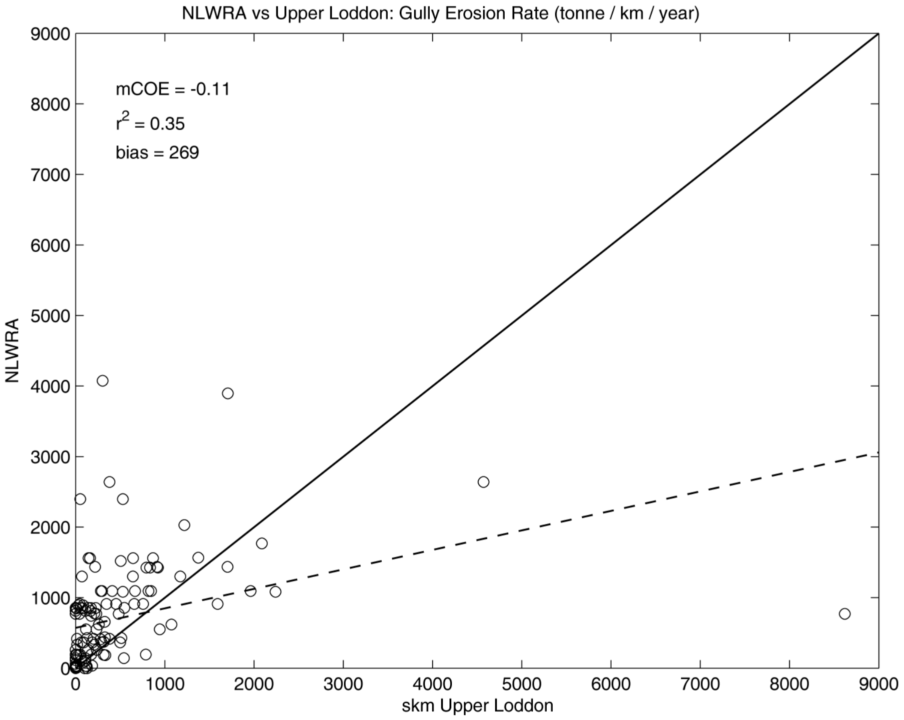


Figure 3-15. The open circles indicate the gully erosion input (tonne per year per stream kilometre) predicted by the NLWRA compared to the rate predicted for the Upper Loddon study. Three goodness-of-fit measures are shown as well as the line-of-perfect-agreement (solid line) and the linear regression line (dashed line).

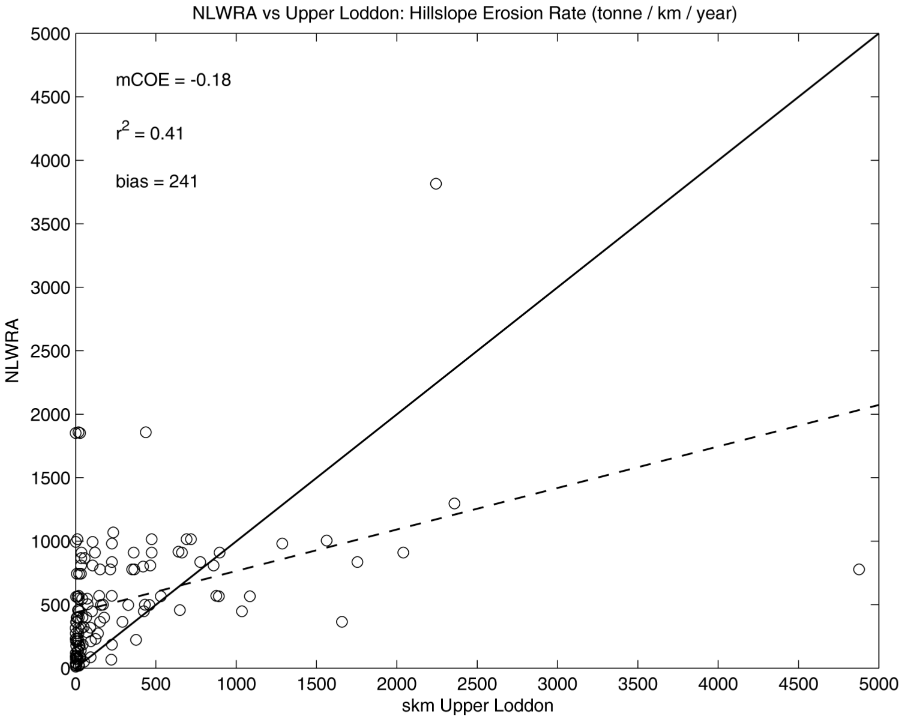


Figure 3-16. The open circles indicate the hillslope erosion rate (tonne per year per stream kilometre) predicted by the NLWRA compared to the rate predicted for the Upper Loddon study. Three goodness-of-fit measures are shown as well as the line-of-perfect-agreement (solid line) and the linear regression line (dashed line).

The hillslope erosion rate plot (Figure 3-16) indicated a similar result as obtained for gully erosion. The coefficient of determination was low (0.41), bias was high and mCOE was negative (very dissimilar to 1.0). It is noteworthy that while the bias was positive (269) the slope of the regression line was shallower than the line-of-perfect-agreement. This occurred because there were quite a number of reaches in which the Upper Loddon study predicted a much greater rate of hillslope erosion than did the NLWRA data.

3.8.5 Discussion

The NLWRA study and the Upper Loddon detailed study produced different estimates of the rates for key geomorphic parameters. Predicted bank erosion rates were consistently higher for the NLWRA assessment, although the relationship between the variables (as measured by r^2) was reasonable. However it is likely that this simply reflected the fact that reaches with high stream power (under the SedNet methodology) would naturally show high bank erosion rates (and vice versa for low stream power reaches).

Comparison of estimated hillslope and gully erosion rates were very poor. This was surprising given that the estimates were made with very similar software (different versions of SedNet). There was not even a reasonable regression relationship between the two sets of results.

The lack of consistency between the NLWRA data and the Upper Loddon study raises serious questions regarding the use of these data for the present study. Some differences were expected given the different versions of the software used and different input data sets submitted to the program. However, such poor correlations suggest that the SedNet algorithms changed radically between 2000 (the NLWRA) and 2002 (Upper Loddon). The algorithms were overhauled during this time (Ian Prosser and Scott Wilkinson, pers. comm., May 2007), however, the fundamental process relationships did not change. Possible explanations for the differences include: (i) differences in the input data set; (ii) error in the modelling process; or (iii) error in interpreting and comparing the data (this study). Which of these explanations is most likely was unable to be determined.

3.8.6 Conclusion

The principal outcome of this analysis was that neither the NLWRA data nor the Upper Loddon data can be relied upon to provide geomorphic process data. The consequence for this study is that other geomorphic data sources must be used in order to: (i) indicate geomorphic condition; and (ii) determine whether a reach in one location is similar to another. Finally, the poor correlation between the results of these two very similar studies, whatever the cause, calls into question the value in undertaking such numerical studies to derive geomorphic information. Repeatability is a key criterion in order to have confidence in an assessment methodology and this analysis shows that in this case SedNet's repeatability was poor.

4 Defining Assets and Geomorphic Threats

4.1 Objectives

The main objective of this project was to establish a cost effective methodology for assessing the fluvial geomorphology of the North Central CMA streams. Geomorphological investigations are only sensitive to ecological assets if they are initially directed to focus on pre-defined assets or target areas. Definition of ecological assets requires considerable value judgment, while definition and description of geomorphic character (including the various forms and processes) is a comparatively value-free process. The geomorphological character of a stream has no inherent value; a geomorphologist has no fundamental reason to value one river, or river reach, or river feature, over another, whether they be close to geomorphic reference condition or highly modified. The geomorphic character of a stream has value only when considered with respect to how the character relates to an external value, such as aesthetic value, economic value, or ecological value. The process of characterization of the geomorphology of a stream would ideally be undertaken as a value-free exercise, with values placed on the information as a secondary step. The reason for this is that fundamental geomorphological information is robust, while management priorities change over time. If the collection of geomorphological data is driven by management priorities, it could potentially become obsolete, or not relevant to a revised management focus.

In this project, potential geomorphological variables were assessed according to a set of criteria that essentially required them to have relevance to ecological and management values. Thus, the variables are biased by the current management paradigm; the geomorphological assessment does not necessarily provide an insightful understanding of the fluvial geomorphology of the rivers of the North Central CMA region in the way that a comprehensive research project might.

It would be imprudent to allow geomorphic assessment to drive the setting of river management priorities, even if the geomorphic variables have been linked to assets and ecological processes. Consideration of geomorphic processes needs to be incorporated into a wider process of deciding appropriate management priorities. Prioritization is best undertaken by river managers, who are aware of all of the relevant factors. For this reason, in this project, the objective of the prioritization component was intentionally modest. Rather than recommend reach-by-reach priorities on the basis of incomplete information, the objective here was to develop a geomorphic-based methodology to assist river managers develop management priorities. The implementation of this prioritization tool is contingent upon acceptance of the underlying theory and practical aspects of the geomorphological assessment, and approval of the tool itself. The following section describes the suggested method for prioritization that was developed for this project.

4.2 Define assets

In order to be consistent with the objectives of the North Central Regional River Health Strategy, the same list of river-dependent assets (with some minor modifications) will be used to determine priorities for geomorphic actions in this project. The assets from the Regional River Health Strategy can be divided into environmental, social and economic values (Table 4-1).

The value of each of these assets has been assessed on a 1 - 5 scale, with 5 generally meaning a high value (e.g. presence of nationally listed species of flora or fauna, riparian vegetation greater than 40 m wide, popular swimming or camping sites, high value infrastructure such as a major bridge). Data to identify the value of the various assets were derived from Statewide databases, Index of Stream Condition (ISC) assessments, community workshops and local knowledge.

Value scores for each asset are stored in the North Central RiVERS database. However, these values are recorded at an ISC reach scale. For many assets, this will be the only scale available, as specific sites within a reach have not been identified. For others, it will be possible to re-interpret the available data to develop scores at the sub-reach scale. In particular, riparian vegetation asset values measured during the ISC assessment are based on the average of a number of monitoring sites within a reach. It is intended to disaggregate the average scores into individual site scores which can be used at the sub-reach scale.

Another modification to the list of assets will be to divide the significant flora, fauna and EVCs into subclasses. Within each of these assets, there are components that are in-stream (e.g. significant fish species), those that are riparian (e.g. some significant bird species that occur along rivers) and some that are floodplain dependent. A similar division will be made for the social asset of Flagship Species.

The different subclasses of each of these assets will react differently to different geomorphic threats. For example, fish species may be affected by upstream erosion that alters water quality (turbidity) or stream bed characteristics (pool infilling). Riparian and floodplain species are very unlikely to be affected by these threats (as the disturbance is upstream of the reach), although riparian species may be affected by bank erosion within the reach.

Table 4-1.
List of assets from North Central Regional River Health Strategy. Source: NCCMA (2005).

Environmental	Description
Significant flora	Presence of flora species with National or State conservation status within 200 m of the stream channel
Ecological Vegetation Class	Presence of EVC with National or State conservation status within 200 m of the stream channel
Significant fauna	Presence of faunal species with National or State conservation status within 200 m of the stream channel
Invertebrates observed/expected	"Naturalness" of invertebrate community compared with reference state
Width of riparian vegetation	Width of riparian vegetation strip along stream
Continuity of riparian vegetation	Number and proportion of gaps in continuous riparian cover along streams
Structural intactness of riparian vegetation	Presence of groundcover, understorey and overstorey compared to reference state
Native fish observed/expected	Number of native fish species present compared with expected number under reference condition
Proportion of introduced fish	Proportion of fish species present that are introduced
Native fish migration	Presence of species that require migration as part of their life cycle
Wetland significance	Presence of wetlands with International, National or State conservation status within 200 m of the stream channel
Wetland rarity and depletion	Percentage of wetland type in reach compared to Victorian total
Heritage river or Representative river	Classification of river as either a Heritage River (LCC, 1990) or representative river in the Victorian River Health Strategy (VRHS)
Sites of significance	Presence of sites of biological or environmental significance
Ecological river health	Classification of river as Ecologically Healthy (VRHS)

Social	Description
Fishing	Presence and extent of recreational fishing
Non-motor boat activities	Presence and extent of boating activities not involving a motor (e.g. sailing)
Motor boat activities	Presence and extent of boating activities involving a motor (e.g. water skiing)
Camping	Presence and extent of camping activities
Swimming	Presence and extent of swimming activities
Passive recreation	Presence and extent of passive recreation
European heritage	Presence of listed heritage buildings and sites
Listed landscape	Presence of landscapes listed on a planning scheme
Flagship species	Presence of species valued by the community (not necessarily with a formal conservation status)

Economic	Description
Water supply – irrigation	Channel used for the delivery of irrigation or domestic water supply
Water supply - proclaimed catchment	Catchment proclaimed for water supply
Infrastructure	Presence of significant infrastructure
Land value	Scaled economic value of different land use activities
Tourism	Presence and extent of different levels of tourist activities
Power generation	River used to produce hydro-electric power

The final list of assets to be assessed under the project therefore consists of 20 environmental assets, 11 social assets and 6 economic assets (Table 4-2). In each of the geomorphic sub-reaches identified in the North Central region, a value rating for each of the 37 assets will be established, and the risk to each asset from geomorphic threats will be evaluated.

The key outcomes required are:

- Agreed modified list of environmental, social and economic assets
- Value rating of each asset at the sub-reach scale.

Table 4-2.

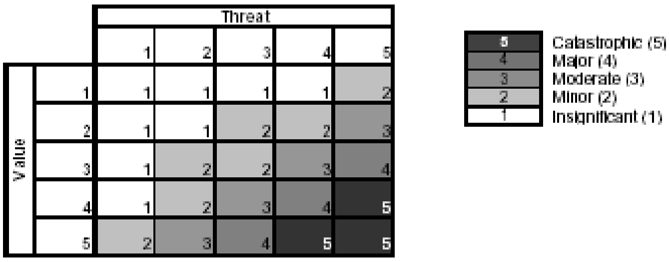
Assets to be used in the geomorphic investigation.

Environmental	Social	Economic
Significant in-stream flora	Fishing	Water supply – irrigation
Significant riparian flora	Non-motor boat activities	Water supply - proclaimed catchment
Significant floodplain flora	Motor boat activities	Infrastructure
Significant riparian EVC	Camping	Land value
Significant floodplain EVC	Swimming	Tourism
Significant in-stream fauna	Passive recreation	Power generation
Significant riparian fauna	European heritage	
Significant floodplain fauna	Listed landscape	
Invertebrates observed/expected	In-stream flagship species	
Width of riparian vegetation	Riparian flagship species	
Longitudinal continuity of riparian vegetation	Floodplain flagship species	
Structural intactness of riparian vegetation		
Native fish observed/expected		
Proportion of introduced fish		
Native fish migration		
Wetland significance		
Wetland rarity and depletion		
Heritage river or Representative river		
Sites of significance		
Ecological river health		

4.3 *Risk Assessment*

The basic aim of the risk assessment is provide some objective measure of the hazard to a particular asset (environmental, social or economic) by a particular geomorphic threat. In the North Central Regional River Health Strategy, risk analysis is expressed as a function of 'consequence' and 'likelihood'.

Consequence is a measure of the potential impact that a threat can have on a particular Asset. This can range from insignificant, through to a temporary small impact, through to a catastrophic impact (e.g. complete loss of the asset). The measure of consequence in the North Central Regional River Health Strategy was defined as a combination of the asset value rating, and the threat value rating (Figure 4-1).



		Threat				
		1	2	3	4	5
Value	1	1	1	1	1	2
	2	1	1	2	2	3
	3	1	2	2	3	4
	4	1	2	3	4	5
	5	2	3	4	5	5

5	Catastrophic (5)
4	Major (4)
3	Moderate (3)
2	Minor (2)
1	Insignificant (1)

Figure 4-1. Consequence scores from the North Central Regional River Health Strategy.

Hence, for a high value asset (rating of 5), under the influence of a high level of threat (rating of 5), the potential consequence of that threat is catastrophic. However, the consequence will only occur in reality if the threat can have a direct influence on the asset. This is evaluated using the likelihood measure.

Likelihood is a measure of the potential that a particular threat will have an actual impact on a particular value. It evaluates the connection, or association between a particular threat and a particular asset. Like the asset value and threat rating, likelihood is evaluated on a 1 - 5 scale (Table 4-3), with higher numbers representing a higher association between the threat and asset.

Table 4-3.
Likelihood scores and meaning.

Score	Meaning	Criterion
1	Practically Impossible	Practically impossible that the threat will impact on the asset.
2	Remotely possible	No evidence of threat impacting on asset, but it is remotely possible.
3	Unusual but possible	Moderate chance that the threat has an impact on the asset
4	Quite possible	Likely that threat has an impact on the asset
5	Almost certain	Almost certain that the threat always impacts on the asset

For example, a fish species influenced by upstream erosion is almost invariably adversely affected by the threat (by increased turbidity or pool infilling or sedimentation of egg-laying sites). Hence, the likelihood between the asset and threat is high (a score of 5). However, significant riparian vegetation is very unlikely to be affected by the same upstream erosion (as only water quality and in-stream habitats are affected), so the likelihood is low. It is conceivable that, say, pool infilling may alter the local riparian hydrology, leading to a change in species composition, so the likelihood rating can be described as remotely possible (a score of 2). A floodplain based significant flora species cannot be affected by upstream erosion, so would be evaluated with a score of 1.

A likelihood measure is evaluated for each possible asset/threat combination. The final risk rating is the product of consequence and likelihood, which can range from 1 – 25.

Therefore, for the combinations of a high level of upstream erosion (threat rating = 5) and significant fish species, significant riparian vegetation community and significant floodplain flora species (each with asset rating = 5), a risk table can be constructed (Table 4-4). Hence, even for the same level of consequence, there may be different levels of risk, according to the likelihood score.

Table 4-4.
Risk ratings for three assets under threat from a high level of upstream erosion.

Asset	Asset rating	Threat rating	Consequence	Likelihood	Risk Rating
Significant fish species	5	5	Catastrophic (5)	5	25
Significant riparian EVC	5	5	Catastrophic (5)	2	10
Significant floodplain species	5	5	Catastrophic (5)	1	5

The North Central Regional River Health Strategy identified three broad classes of geomorphic threat (bank erosion, bed erosion and channel modification) and provides likelihood values for each combination of asset and threat (examples in Table 4-5). The types of geomorphic threats will be modified and expanded as part of this project.

Hence, one of the key issues in this project will be to establish likelihood scores for each combination of the expanded list of significant assets (Table 4-2) and the revised list of geomorphic threats.

The key outcomes required are:

- Agreed modified list of geomorphic threats and rating scale
- Likelihood scores of each asset/threat combination.

Table 4-5.
Generic likelihood scores for environmental values in the North Central Regional River Health Strategy.

Asset	Bank erosion	Bed erosion	Channel modification
Significant flora	3	2	2
Ecological Vegetation Class	2	2	2
Significant fauna	4	4	2
Invertebrates observed/expected	5	5	3
Width of riparian vegetation	3	2	3
Continuity of riparian vegetation	5	1	3
Structural intactness of riparian vegetation	5	1	2
Native fish observed/expected	3	3	3
Proportion of introduced fish	3	3	3
Native fish migration	1	3	4
Wetland significance	3	3	3
Wetland rarity and depletion	4	2	4
Heritage river or Representative river	3	3	3
Sites of significance	5	4	4
Ecological river health	2	2	2

4.4 Setting Priorities

In each sub-reach identified from the geomorphic analysis, the risk rating of each asset for each geomorphic threat affecting that sub-reach will be calculated. This value describes the degree of risk to the asset from the level of threat.

No formal process exists to translate the risk rating to a priority rating (High, Medium, Low etc). In the North Central Regional River Health Strategy, a High Risk threat/asset combination was identified as a risk rating of 20 or 25 (North Central Regional River Health Strategy supporting documents) and so reducing the impact of the threat was given a high priority.

However, the raw risk rating does not necessarily determine the action response required, or the priority of those actions. Table 4-6 shows the various combinations of asset and threat ratings (and hence the consequence score) for high value assets (ratings of 4 or 5), under likelihood scores that have a medium to high possibility of having an adverse impact on the asset (scores of 3, 4 and 5). Four groups, or scenarios, can be identified, each of which would trigger a different management response, with different priorities.

Clearly, when the asset and threat ratings are both high (both 4 or 5 so that consequence = 4 or 5), and the likelihood is high (4 or 5), there is an urgent need to reduce the level of the threat - the high level of threat is almost certain to have an impact on the high value asset. The action response, to reduce the level of the threat, should therefore be given a High priority. Risk ratings for these combinations range from 16 – 20.

However, similar risk ratings (16 and 20) can be achieved from situations where the threat rating is actually medium (3 – see second group in Table 4-6). While there is some elevated chance that the asset may be affected, an argument could be made that these cases do not rate the same urgency of management response as the first group. Where financial resources are limiting, the appropriate action may well be to monitor the asset to determine any downward trend in their value before actions are required. At the very least, actions should be implemented to prevent the level of threat increasing (generally a cheaper option involving education and regulation rather than on-ground works). For these reasons, the priority in Table 4-6 is given as Medium.

A similar priority for management responses can be given to cases where the asset and threat ratings are both high, but the likelihood score is moderate (3 – meaning that there is a moderate chance that the threat has an impact on the asset - Table 4-3). In this case, a more suitable management response is to reduce the level of the threat where possible, although the urgency is not as great as for the first group. The priority in Table 4-6 is also given as Medium.

The final group of cases is where the threat level is, in fact, low, but any increase in the level would constitute a risk to the asset (due to the high likelihood score). In the sense of "protecting the best", these cases are also a priority for management – to prevent the level of threat increasing through education and regulation rather than on-ground works. The relatively low risk rating score, is therefore somewhat misleading.

Assigning priority levels between the three medium categories is unclear. Arguments could be made for any particular order, not related to the ultimate risk rating score. In our opinion, the last group may actually represent the best value for money – preventing an increase in threat level to protect a high value asset (in an area likely to be in good geomorphic condition). This requires further deliberation.

The key outcome required is:

- Agreed decision tree (as in Table 4-6) assigning risk and priority to different combinations of asset rating, threat rating and likelihood score.

Table 4-6.
Risk Ratings from various combinations of asset rating, threat rating and likelihood.

Asset Rating	Threat Rating	Consequence	Likelihood	Risk Rating	Priority	Action Response
High value, threat and Likelihood						
5	5	5	5	25	High	High Priority to reduce level of threat to protect the asset
5	5	5	4	20		
5	4	5	5	25		
5	4	5	4	20		
4	5	5	5	25		
4	5	5	4	20		
4	4	4	5	20		
4	4	4	4	16		
High value, medium threat and high likelihood						
5	3	4	5	20	Medium	Monitor assets. Prevent level of threat increasing.
5	3	4	4	16		
4	3	4	5	20		
4	3	4	4	16		
High value, threat and medium Likelihood						
5	5	5	3	15	Medium	Monitor assets. Reduce level of threat if opportunity arises
5	4	5	3	15		
4	5	5	3	15		
4	4	4	3	12		
High value, low threat and high likelihood						
5	2	3	5	15	Medium	Prevent level of threat increasing
5	2	3	4	12		
5	1	2	5	10		
5	1	2	4	8		
4	2	2	5	10		
4	2	2	4	8		
4	1	1	5	5		
4	1	1	4	4		

4.5 Incorporating multiple risk assessments and sub-reaches

The preceding discussion only deals with the assessment of a single asset and a single threat. Each sub-reach will have multiple assets (with potentially more than one high value) and multiple threats (with varying degrees of severity). These will need to be compared across different sub-reaches to determine an overall priority list of actions. As we have seen, the simple numerical approach (adding all the risk ratings for a sub-reach) as used in the North Central Regional River Health Strategy may not be appropriate. Other alternatives could include:

- Simply counting the number of High Priority results in a sub-reach. Sub-reaches could then be ranked according to the number of High Priority results;
- Counting the number of High Priority results, and weighting the number of Medium Priority results (as, say, half as important as High Priority results). An overall "count" could be calculated and sub-reaches ranked accordingly;
- Evaluating each individual threat (or preferably the management response required to address the threat). This could lead to priority lists for each type of management action

(grade control, education etc) based on the number of High Priority results for that action (or with weighting of Medium results);

- Weighting the "value" of the assets according to community aspirations. For example, significant fish species could be weighted more highly than significant flora species (so that a High Priority action to protect the plant species could carry the same weight as a Medium Priority result for the fish species). This would present some difficulties as the subjective assessment of importance would need to be justified.

This issue requires further deliberation.

The key outcome required is:

- Agreed protocol for comparing risk and priority results across different sub-reaches.

5 The Fluvial Information System

5.1 Overview

The Fluvial Information System (FIS) is a means of storing and using information related to the geomorphology of the North Central CMA region. FIS functions include:

- a means of navigating through the features of the catchment in a hierarchical manner, stepping between levels from:

  the whole region; to

  the 4 main catchments; to

  the 14 management units; to

  the 249 subcatchments; and finally to

  the 1,289 individual reaches;

- the ability to relate data entry forms (such as site photographs or scientific reports) to features at any level of the hierarchy; and
- the ability to enter and edit data entry forms (e.g. documents, images, custom forms) at any level of the hierarchy.

The page displayed for each feature permits the contents of any type of data entry form to be displayed by default, while all other data items (e.g. documents, images) are listed in a table from which they can be further inspected/sorted.

Standard users are presented with these basic features, as well as a page of queries/reports that can be used to summarise characteristics of the system (e.g. number of reaches defined as high priority). System administrators are presented with an additional tab on the menu, from which the functionality and display of the system can be tailored. This is expected to be locked down for NCCMA users, unless there is some level of ongoing customisation required. The administration module provides a more powerful set of functions and would require training for competent use.

5.2 Pages of the FIS

5.2.1 Home Screen

The Home screen (Figure 5-1) welcomes the user to the system and presents them with any necessary information. This page may also run default queries to alert users to particular aspects of the system, but this functionality is not currently implemented.

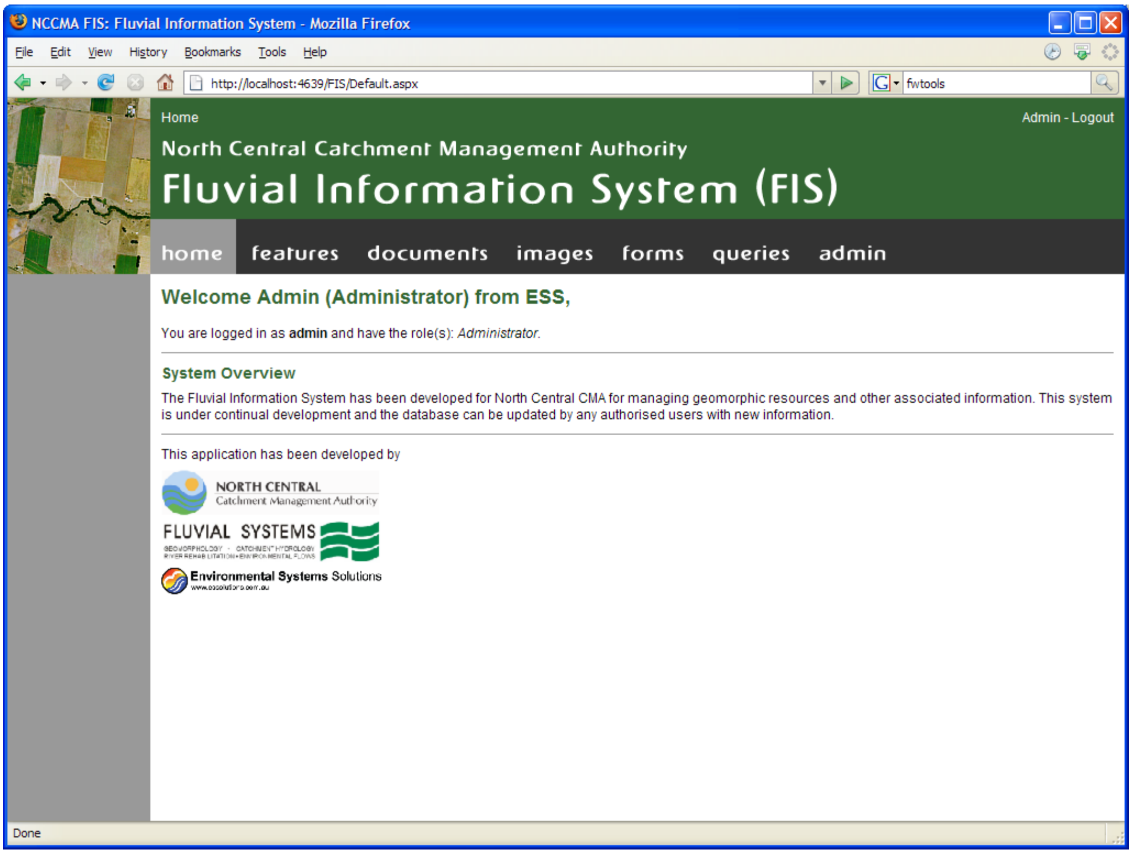
The main menu can be used to access:

- the default feature page;
- the listing of documents, images or forms;
- the queries page for running summaries of the system; or

- the administrative section (with appropriate user privileges).

The top-left of the menu bar shows ‘breadcrumbs’ for quickly finding where the user is located in the system and for jumping back to previous levels. The top-right corner displays the current user and can be used to logout.

The user name is stored in the database whenever items are added or edited. There are no ‘roll-back’ features for undoing edits. Items that are deleted are only tagged as deleted and could therefore be restored by a system administrator.



Welcome Admin (Administrator) from ESS,

You are logged in as **admin** and have the role(s): *Administrator*.

System Overview

The Fluvial Information System has been developed for North Central CMA for managing geomorphic resources and other associated information. This system is under continual development and the database can be updated by any authorised users with new information.

This application has been developed by

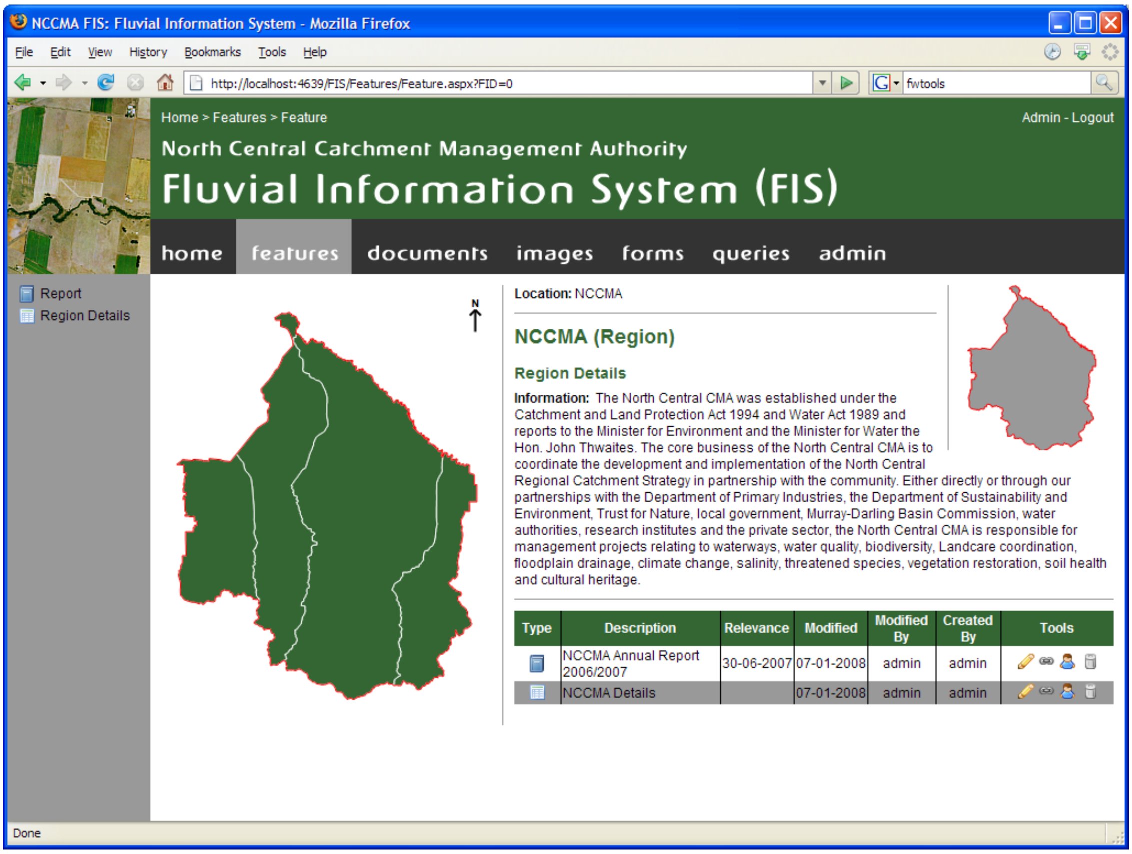
Figure 5-1. Fluvial Information System Home Screen.

5.2.2 Default Features page

The Default Features page (Figure 5-2) shows the entire region of interest, with a clickable map on the left and a locator map on the right. A default form is displayed, containing the ‘Region Details’. Below the form, a list of all data items entered for this feature is shown. This can be customised to communicate more relevant information about each data item.

The icons/buttons in the left panel are used to add further information. The icons/buttons within the list permit items to be edited or deleted (if the user has permission).

Clicking on the larger map allows the user to navigate through the catchment, with the location details updated accordingly (in the text section just below the main menu), thus providing quick hyperlink back to higher levels in the hierarchy.



Location: NCCMA

NCCMA (Region)

Region Details

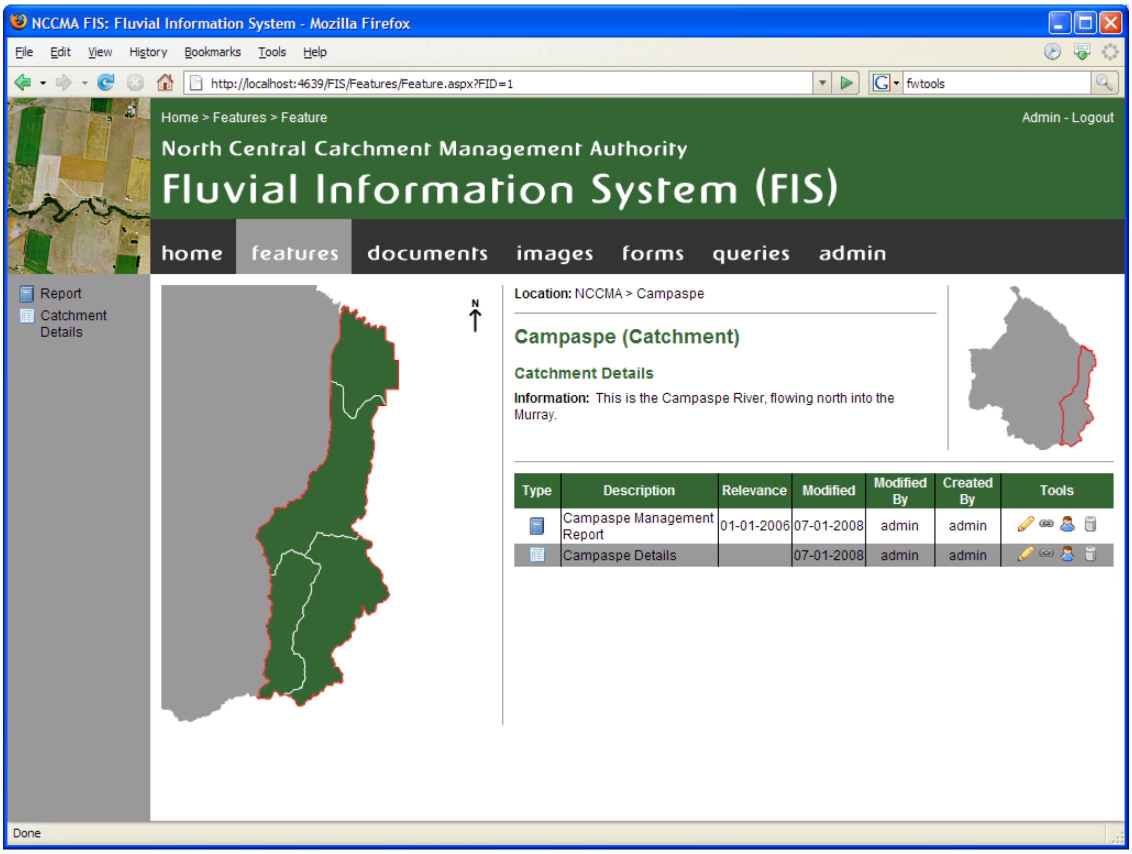
Information: The North Central CMA was established under the Catchment and Land Protection Act 1994 and Water Act 1989 and reports to the Minister for Environment and the Minister for Water the Hon. John Thwaites. The core business of the North Central CMA is to coordinate the development and implementation of the North Central Regional Catchment Strategy in partnership with the community. Either directly or through our partnerships with the Department of Primary Industries, the Department of Sustainability and Environment, Trust for Nature, local government, Murray-Darling Basin Commission, water authorities, research institutes and the private sector, the North Central CMA is responsible for management projects relating to waterways, water quality, biodiversity, Landcare coordination, floodplain drainage, climate change, salinity, threatened species, vegetation restoration, soil health and cultural heritage.

Type	Description	Relevance	Modified	Modified By	Created By	Tools
📘	NCCMA Annual Report 2006/2007	30-06-2007	07-01-2008	admin	admin	✎ 🔗 👤 🗑
▦	NCCMA Details		07-01-2008	admin	admin	✎ 🔗 👤 🗑

Figure 5-2. Fluvial Information Default Features page.

5.2.3 Catchment Features page

The Catchment Features page (Figure 5-3) is at one level lower in the hierarchy than the Default Features page. Different types of information are shown and different types of data items can be added. The information available on this page is relevant to the scale of the catchment. The link between the information item and its relevant scale is set by notations in the data entry phase.



Location: NCCMA > Campaspe

Campaspe (Catchment)

Catchment Details

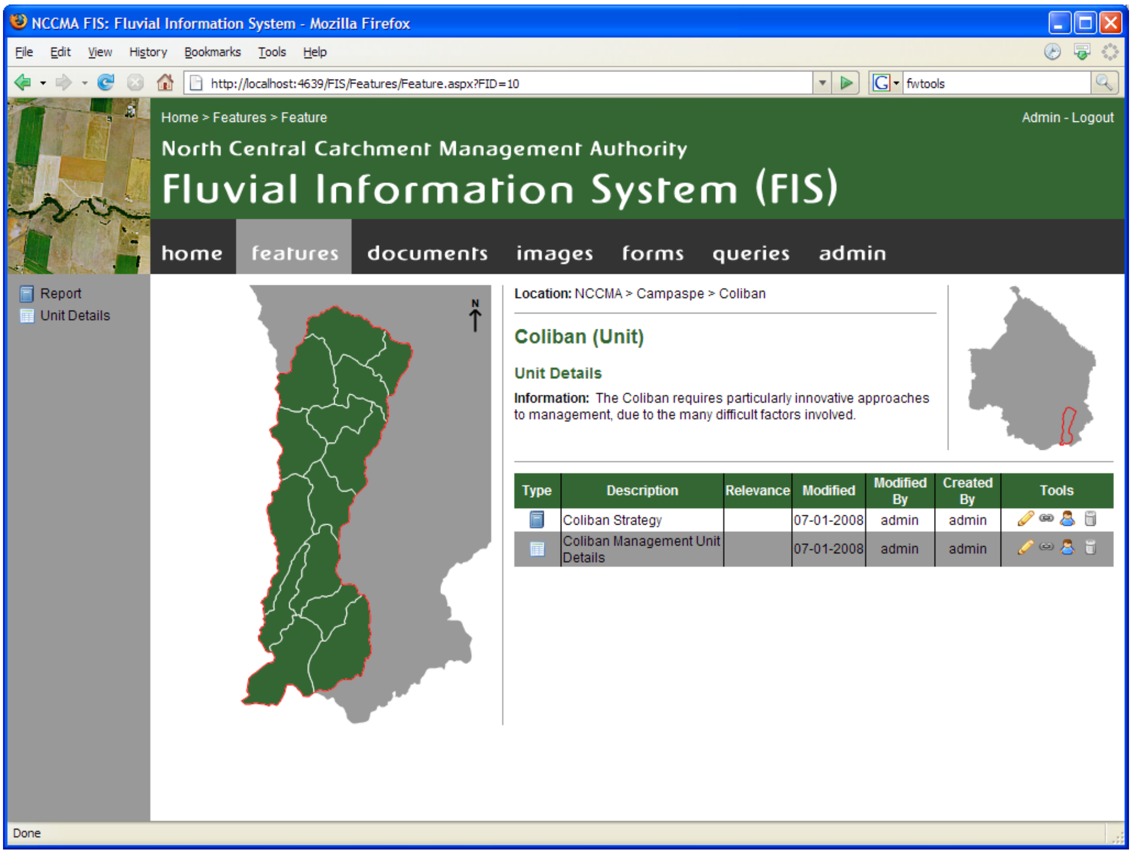
Information: This is the Campaspe River, flowing north into the Murray.

Type	Description	Relevance	Modified	Modified By	Created By	Tools
	Campaspe Management Report	01-01-2006	07-01-2008	admin	admin	
	Campaspe Details		07-01-2008	admin	admin	

Figure 5-3. Fluvial Information Catchment Features page.

5.2.4 Management Unit Features page

The Management Unit Features page (Figure 5-4) is at one level lower in the hierarchy than the Catchment Features page. The FIS Management Units are at one scale up from the NCCMA MUs. For example, the Campaspe catchment (Figure 5-3) has 13 NCCMA MUs, and 4 FIS Management Units. Different types of information are shown and different types of data items can be added. The information available on this page is relevant to the scale of the catchment. The link between the information item and its relevant scale is set by notations in the data entry phase.



Location: NCCMA > Campaspe > Coliban

Coliban (Unit)

Unit Details

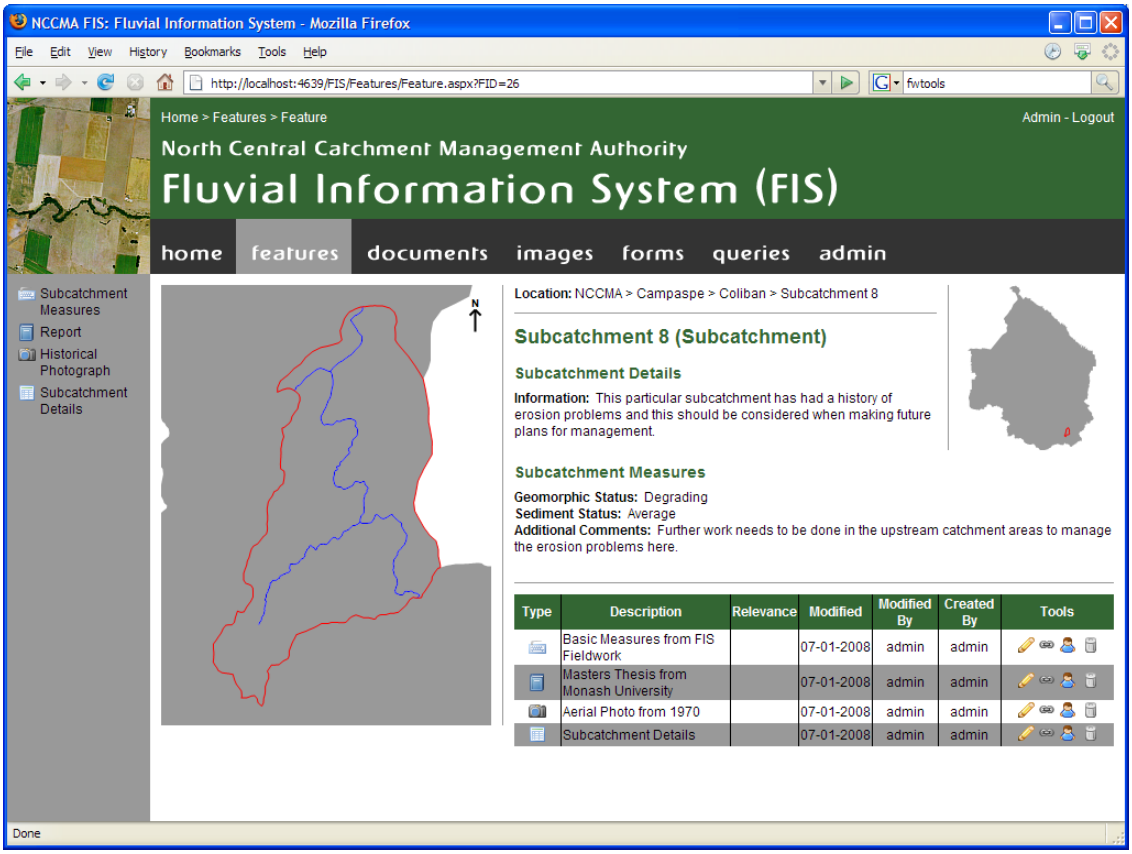
Information: The Coliban requires particularly innovative approaches to management, due to the many difficult factors involved.

Type	Description	Relevance	Modified	Modified By	Created By	Tools
	Coliban Strategy		07-01-2008	admin	admin	
	Coliban Management Unit Details		07-01-2008	admin	admin	

Figure 5-4. Fluvial Information Management Unit Features page.

5.2.5 Sub-catchment feature page

The Sub-catchment Features page (Figure 5-5) is at one level lower in the hierarchy than the Management Unit Features page. The FIS Sub-catchments mostly contain more than one stream reach, i.e. each identified stream tributary or link (reach between tributary junctions) does not have a separate sub-catchment. In the headwater areas the sub-catchments are in the order of 30 – 200 km^2 in area, while in the lowland areas, where stream density is lower, the sub-catchments tend to be larger and up to around 400 km^2. The information available on this page is relevant to the scale of the sub-catchment.



Location: NCCMA > Campaspe > Coliban > Subcatchment 8

Subcatchment 8 (Subcatchment)

Subcatchment Details

Information: This particular subcatchment has had a history of erosion problems and this should be considered when making future plans for management.

Subcatchment Measures

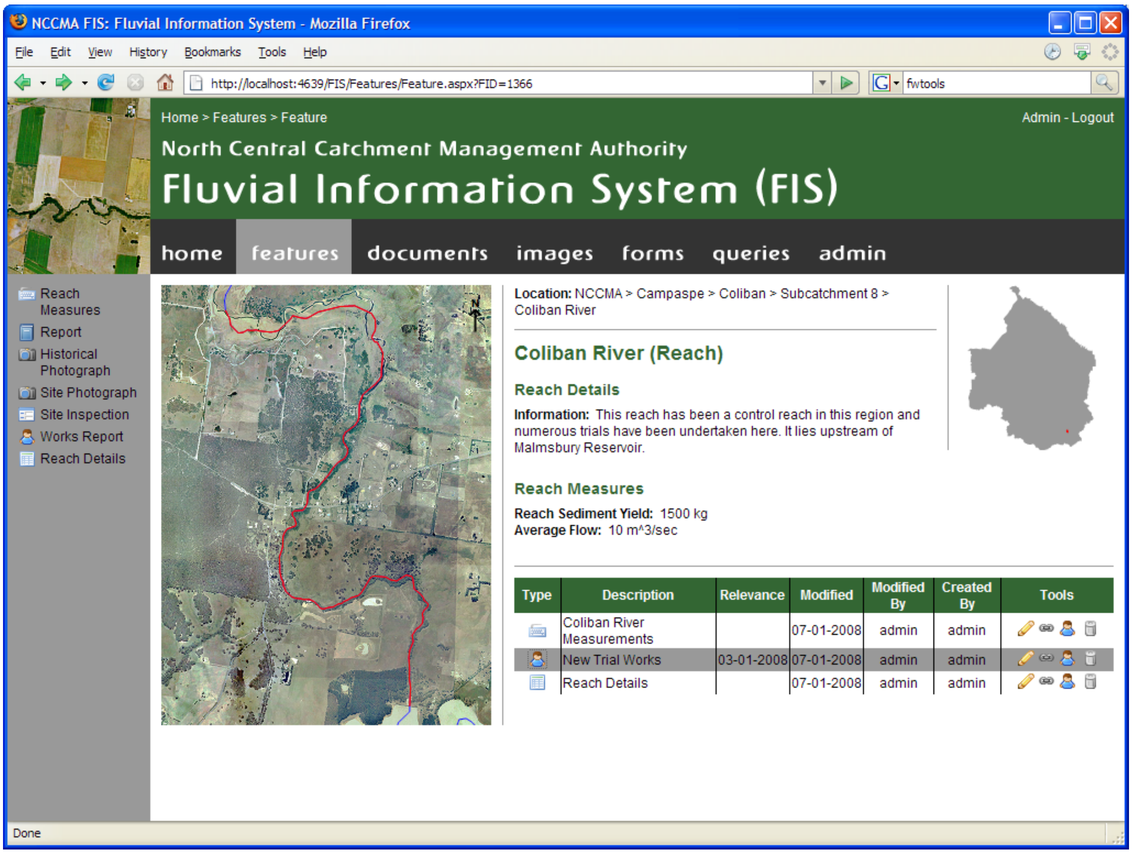
Geomorphic Status: Degrading
Sediment Status: Average
Additional Comments: Further work needs to be done in the upstream catchment areas to manage the erosion problems here.

Type	Description	Relevance	Modified	Modified By	Created By	Tools
	Basic Measures from FIS Fieldwork		07-01-2008	admin	admin	
	Masters Thesis from Monash University		07-01-2008	admin	admin	
	Aerial Photo from 1970		07-01-2008	admin	admin	
	Subcatchment Details		07-01-2008	admin	admin	

Figure 5-5. Fluvial Information Sub-catchment Features page.

5.2.6 Reach Features page

The Reach Features page (Figure 5-6) is at one level lower in the hierarchy than the Sub-catchment Features page. Reaches are of varying lengths, up to 20 km long, but with most less than 8 km long. A satellite imagery basemap is displayed at the Reach scale. Other spatial datasets of relevance could be displayed as required. The Reach page also shows more data items relevant to this scale of interest, and each of these could be clicked on for display/editing.



Location: NCCMA > Campaspe > Coliban > Subcatchment 8 > Coliban River

Coliban River (Reach)

Reach Details

Information: This reach has been a control reach in this region and numerous trials have been undertaken here. It lies upstream of Malmsbury Reservoir.

Reach Measures

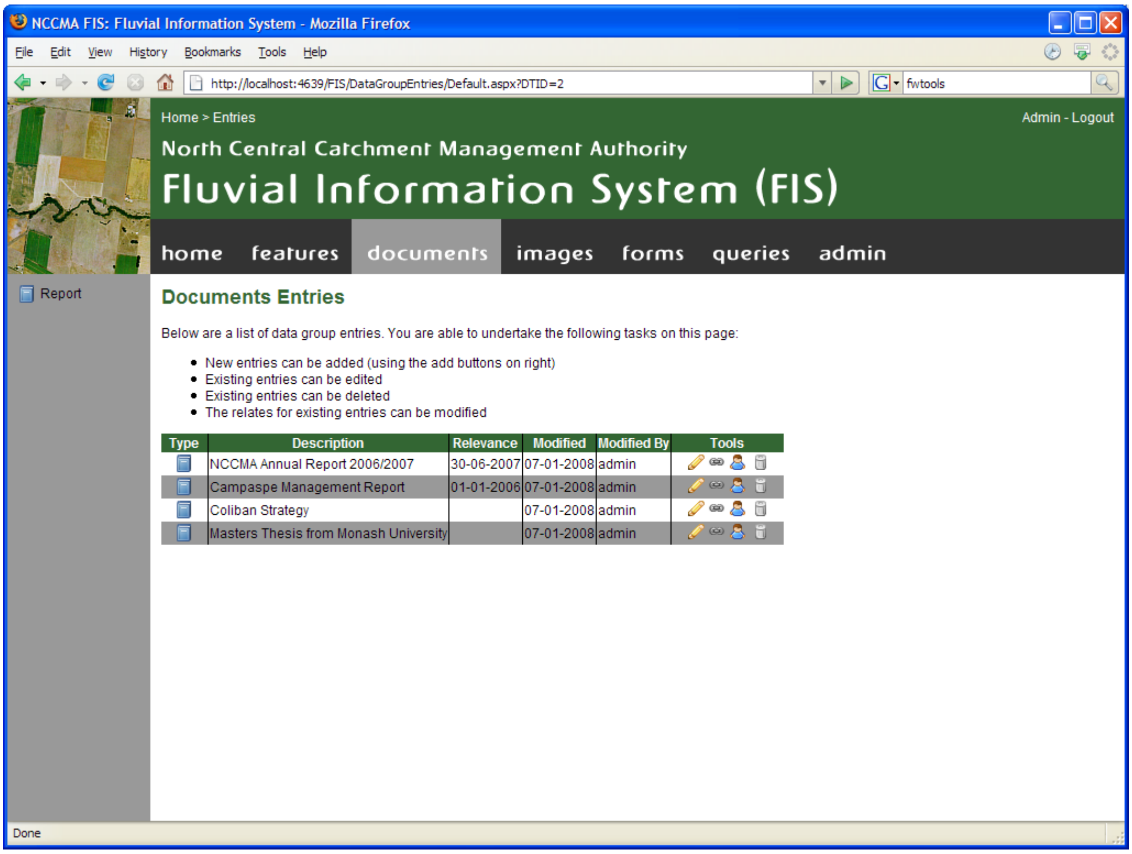
Reach Sediment Yield: 1500 kg
Average Flow: 10 m^3/sec

Type	Description	Relevance	Modified	Modified By	Created By	Tools
	Coliban River Measurements		07-01-2008	admin	admin	
	New Trial Works	03-01-2008	07-01-2008	admin	admin	
	Reach Details		07-01-2008	admin	admin	

Figure 5-6. Fluvial Information Reach Features page.

5.2.7 Documents, Images and Forms pages

As data is entered for each feature within the NCCMA region, the Documents, Images and Forms pages (Figure 5-7) are populated. These can be searched/sorted interactively by accessing them via the main menu. All three of these pages look the same, but show different types of data items. These may be displayed in a more descriptive manner if required.



Documents Entries

Below are a list of data group entries. You are able to undertake the following tasks on this page:

- New entries can be added (using the add buttons on right)
- Existing entries can be edited
- Existing entries can be deleted
- The relates for existing entries can be modified

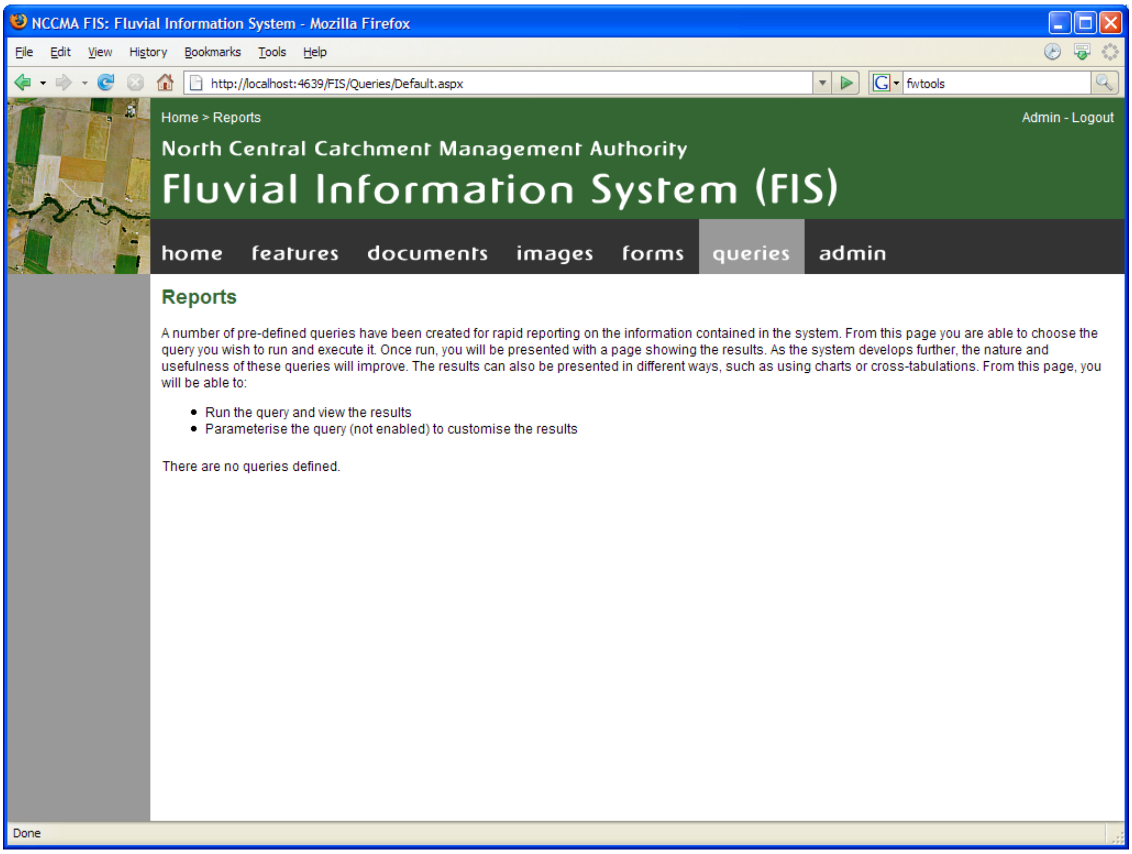
Type	Description	Relevance	Modified	Modified By	Tools
▤	NCCMA Annual Report 2006/2007	30-06-2007	07-01-2008	admin	✎ 🔗 👤 🗑
▤	Campaspe Management Report	01-01-2006	07-01-2008	admin	✎ 🔗 👤 🗑
▤	Coliban Strategy		07-01-2008	admin	✎ 🔗 👤 🗑
▤	Masters Thesis from Monash University		07-01-2008	admin	✎ 🔗 👤 🗑

Figure 5-7. Fluvial Information Documents page.

5.2.8 Search/queries page

The items within the current listings can be sorted by clicking on the headings. When a large number of items exist in the database, the listing will be ‘paged’, so that not all items are displayed at once.

The Queries page (Figure 5-8) does not currently contain are reports, but displays a list of pre-specified SQL queries than can be run on the FIS. These searches/queries return various tables of data or listings of relevant data items.



Reports

A number of pre-defined queries have been created for rapid reporting on the information contained in the system. From this page you are able to choose the query you wish to run and execute it. Once run, you will be presented with a page showing the results. As the system develops further, the nature and usefulness of these queries will improve. The results can also be presented in different ways, such as using charts or cross-tabulations. From this page, you will be able to:

- Run the query and view the results
- Parameterise the query (not enabled) to customise the results

There are no queries defined.

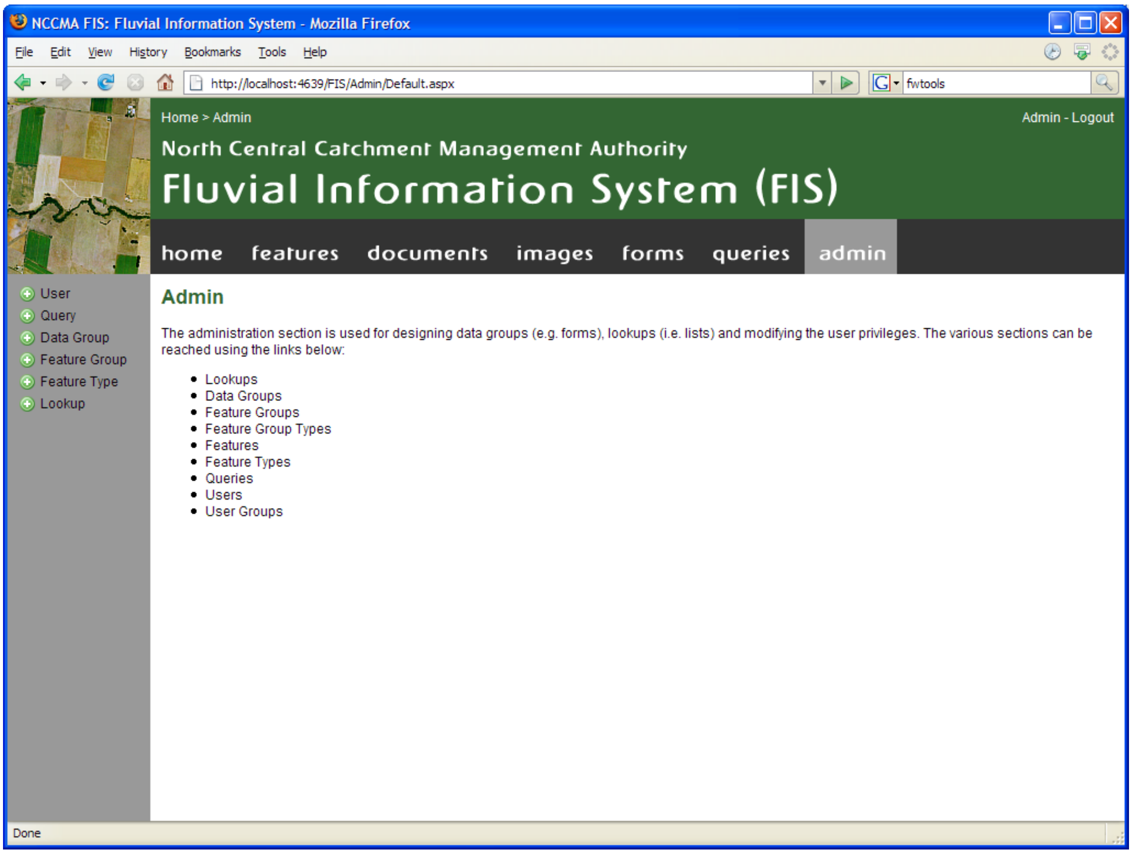
Figure 5-8. Fluvial Information Queries page.

5.2.9 Administration pages

The administration pages (Figure 5-9) are designed for use by trained system operators who understand how the application has been designed and works. These pages permit various tasks to be undertaken, including:

- Designing new forms for entering information about features in the database
- Modifying selection lists and relationships between data items entered
- Adding additional queries into the FIS for reporting on the system status

Much of the functionality listed here is used in designing and populating the system and will not be required by NCCMA staff in the day-to-day use of the FIS. If there are particular capabilities that are considered necessary, then two levels of administrative privileges may be implemented to ensure there is sufficient ability to customise without contacting the system developers.



Admin

The administration section is used for designing data groups (e.g. forms), lookups (i.e. lists) and modifying the user privileges. The various sections can be reached using the links below:

- Lookups
- Data Groups
- Feature Groups
- Feature Group Types
- Features
- Feature Types
- Queries
- Users
- User Groups

Figure 5-9. Fluvial Information Administration page.

5.3 Data integration

The initial version of the FIS is populated with a basic set of data, loaded into the system via data import tools developed by ESS. These data were collected during the course of the fluvial geomorphology investigation project.

6 Conclusion

It was hypothesized here that the North Central CMA already possesses sufficient information on sediment dynamics to inform management in a reliable way. This hypothesis was investigated because the CMA was not in a position to undertake detailed sediment modelling over their entire region, and was seeking a more cost effective way of delivering similar or even better outcomes (better in terms of how the outcomes link to management recommendations). A critical review and comparison of two SedNet studies undertaken in the Loddon catchment revealed additional concerns regarding catchment-scale sediment models. These models, although ostensibly using the same model structure, produced results that were not comparable.

Prior to gathering data on the geomorphology of the North Central CMA region, a framework was established. This framework was grounded in a thorough review of the global literature. The preferred variables will provide a useful description of the main geomorphic processes relevant to management of stream health.

A wide range of contrasting data sources were utilized in this investigation. Terrain analysis produced broad spatial patterns in certain variables that may be useful at the broadest scale of geomorphic classification. It was found that gully density corresponded well with slope steepness, and the areas of the region with high gully density showed a distinct signature in the long-term turbidity data. The 2006 Waterway and Catchment Descriptions, which obviously required a major investment on the part of the North Central CMA, produced a surprisingly comprehensive set of geomorphic information. It was possible to convert this textual form of information into numerical data that described the relative geomorphic condition of over 2,500 km of river channels. The broad patterns revealed in the data supported the other sources of information used in this project. A field methodology, grounded in geomorphic theory, was developed to collect data compatible with the variables proposed for the Sustainable Rivers Audit, and compatible with the data derived from the Waterway and Catchment Descriptions. This field assessment procedure was mainly developed as a tool for the CMA to use for regular data collection into the future. All of the data can be used to assist the setting river management priorities. A methodology was presented for accomplishing this step.

One problem with the CMA commissioning a diverse range of investigations concerning particular locations or issues is that the investigators do not report their findings in a consistent way that would allow easy comparison between studies. Secondly, written reports tend to have a short life-span, with the information often becoming forgotten or lost before too long. In this project we developed a Fluvial Information System for convenient storage and utilization of information related to the geomorphology of the North Central CMA region. This system is expected to encourage more consistent reporting of geomorphological information, and its memory is independent of any staff changes.

7 References

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