

River Styles® in the Upper Hunter Catchment

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Preface and acknowledgements

This work was produced under the UHRRI umbrella, and was supported by an ARC Linkage grant. UHRRI is the Upper Hunter River Rehabilitation Initiative – a collaborative partnership among the Hunter Catchment Management Trust, NSW Department of Infrastructure, Planning & Natural Resources and Macquarie University. The ARC Linkage Grant, entitled “Complex System Dynamics; Restoring Riparian and Riverine Ecosystems” is a five year project (2003 - 2007) sponsored by Bengalla Mining Company, Mt. Arthur Coal, and Macquarie Generation (Chief Investigator: Gary Brierley; Project Manager: Craig Miller). This study was completed with the assistance of the GEOS391 class from Macquarie University 2003 (Convenors: Gary Brierley & Kirstie Fryirs). A registered trademark for the River Styles framework is held by Macquarie Research Limited and Land & Water Australia. Nick Cook and Allan Raine (DIPNR) are thanked for their insightful review comments.

1. SECTION ONE: BACKGROUND TO THE RIVER STYLES FRAMEWORK

1.1 Introduction to the River Styles Framework

A remarkable transition in Australian land and water management practice has taken place over the past few decades. Accompanying, and in part underpinning, this transition have been changes to the value systems, perspectives and perceptions of landowners, agribusiness interests, environmental practitioners and others involved in land and water management, and the ways in which institutional structures have promoted and facilitated these changes. Over time, a distinctive approach to river management has developed that is characterised by extensive on-the-ground involvement of community groups in land management and rehabilitation practices. Adoption of participatory rather than regulatory approaches to river management has presented significant opportunity for research, development and incorporation of new ideas into best management practice. These initiatives also provide education and communication tools which can be used by local groups to assist in assessments of how their catchment works, how site-specific issues fit within a total catchment context, and how complexities and the inherent uncertainties of many environmental outcomes can be managed.

Among the many challenges faced by physical/natural scientists in addressing these issues is the need to develop appropriate information bases with which to support this transitional process. This requires the delivery of structured sets of biophysical information, ensuring that 'best available data' are meaningfully inter-linked and communicated in coherent packages. Adoption of adaptive management principles, whereby commitment to a 'process of learning' is maintained, ensures that sufficient consideration is placed on auditing of outcomes, such that lessons can be learnt from past experiences, thereby furthering the enhancement of environmental management and information-delivery processes.

It is in this context of social, institutional and intellectual change that the River Styles framework has been developed and applied as a tool for catchment-scale information management and communication in the river management arena. It is a trite but often understated fact that implementation of best management practice requires effective use of the best available information. Indeed, any endeavours at notionally *sustainable* environmental management must, by definition, build upon sound insights into the nature of the resource that is being managed. Viewed in this context, it is remarkable to consider how little we actually know about our rivers – their diversity and rarity/uniqueness, their sensitivity to disturbance, measures of their condition/health, their functionality and associated patterns/rates of activity/change, and their physical, ecological, aesthetic, recreational and spiritual values. Working within an ecosystem approach to natural resources management, the interconnected nature of these factors is recognised explicitly. The challenge is to convey best available insight on these 'baseline' principles in a structured and coherent manner.

Obviously, any individuals or group of individuals who set out to address these kinds of concerns are limited by the constraints of their own background experiences and understanding. In addressing questions such as: What are we managing our rivers for?, and What do we want our rivers to be like?, this report seeks to explain the diversity of river forms and processes in light of their landscape context, appraising spatial and temporal patterns of adjustment, and highlighting their physical linkages within a catchment. This mindset also seeks to address underlying causes of river diversity and behaviour, providing the baseline information atop which assessments of 'environmental condition' or 'health', and associated notions of recovery potential can be added.

The River Styles framework is built on the premise that assessments of river 'health' or condition that underpin many river rehabilitation strategies cannot be developed *independent from* an understanding of the geomorphic structure of a river reach and the catchment context within which those processes occur. The effective explanation of catchment-scale patterns and trends, and design/implementation of conservation/rehabilitation programs to address these management concerns, can not be developed without geomorphological understanding of the type of river under investigation, its relation to landscape setting, associated sets of catchment linkages, and interpretations of how the river adjusts (in both a contemporary sense, and in terms of likely trajectories of change). Similarly, it is naive to believe that sustainable management strategies can be adopted if principles do not 'work with nature' by building on a catchment-framed understanding of river character and behaviour, and ultimately condition and recovery potential. These premises are the key underpinnings of the River Styles framework, namely:

- Respect diversity
- Work with change (planning for average conditions or circumstances is inappropriate)
- Work with catchment-scale linkages
- Use a geomorphic platform to integrate biophysical processes, presenting a coherent physical template for management activities.

In the River Styles framework, the nature, range and rate of geomorphic adjustments are noted for each type of river. Applications of this framework provide catchment-specific understanding of geomorphic river forms and processes, their linkages, and system dynamic. Such insights can then be extended to identify regional level patterns with which to appraise the uniqueness, rarity and representativeness of river types. With this information in hand, comprehensive planning programs for river conservation/rehabilitation can be developed in a way that respects diversity of natural systems. Ultimately, this needs to be tied to appraisals of river condition (and the associated 'remnant' status of any given reach). If we wish to maintain a truly 'natural' river character, with naturally adapted flora and fauna, target conditions in management programs must replicate the natural variability and changing nature of river structure and flow inherent to the landscape setting.

The River Styles framework strives to establish a coherent, tightly structured package of geomorphologically-based insights that is applied at the catchment-scale. This 'learning tool' provides a meaningful basis for river *description*, an *explanatory* basis with which to assess how rivers behave, and a *predictive* framework to interpret how rivers are likely to adjust in the future. These insights provide a physical basis to compare like with like, summarising baseline information on the character, behaviour, and patterns of rivers of different types across a catchment. They do NOT pigeon-hole reality based on static assessments of river morphology. In endeavouring to move beyond prescriptive strategies that manage rivers to some 'type' or 'norm', the generic, open-ended nature of the River Styles framework allows new variants to be added as they are characterised, enabling the real world diversity of river morphology to be meaningfully captured.

The River Styles framework therefore operates as a flexible 'learning package', whereby sets of questions are posed to develop a system-wide set of information. Just as individual catchments may have 'unique' types of rivers, the distribution of river types in any one catchment and their patterns/rates of response to human disturbance are almost certainly unique. Understanding these catchment-specific responses, and associated perspectives on future trajectories of change, are considered to be prerequisites for effective management programs. Applications of the River Styles framework prompt river practitioners to focus attention on the underlying causes of problems associated with river changes, rather than their symptoms. To achieve this, investigators apply a systematic process of enquiry to evaluate and interpret their own river system. The underlying catchcry in applications of the River Styles framework is "KNOW YOUR CATCHMENT".

1.2 How this work fits into the Australian Research Council (ARC) Linkage Project and the Upper Hunter River Rehabilitation Initiative (UHRRI)

Various initiatives have been developed in Australia that merge research and managerial perspectives with community values/attitudes, providing a basis to implement participatory approaches to environmental management. Shared engagement and commitment not only promote an increased capacity to maintain environmental initiatives, they also provide a basis to collectively learn from ongoing adjustments. Through this, collective responses to successes and failures can be orchestrated, enabling us to strategically modify our practices. When applied effectively, this commitment to experimentation promotes sustained learning. This is one of the key aims of the Upper Hunter River Rehabilitation Initiative (UHRRI), a strategic partnership between Macquarie University, NSW Department of Infrastructure, Planning and Natural Resources and the Hunter Catchment Management Trust. Three key conceptual notions underpin the collaborative efforts and endeavours of this type of group, namely:

- Landscapes as integrators.
- Communities as implementers.
- Adoption of adaptive management principles and practices.

This report was produced as a milestone component of an ARC Linkage Project that forms an integral part of the UHRRI umbrella. Emphasis in this report is placed on the first of the three principles highlighted above. Ultimately, the Upper Hunter ARC Linkage Project aims to assess the effect of river rehabilitation practices on the operation and condition of biophysical fluxes along an 8km stretch of the Hunter River at Muswellbrook. Successful attainment of this goal requires that this reach is placed within its catchment context, framing what can be realistically achieved in river rehabilitation terms. The nature and operation of various catchment-scale biophysical linkages dictate from where, and over what timeframe, changes or impacts elsewhere in the catchment will affect the study reach. The catchment-scale work presented in this report represents the first step in understanding these catchment fluxes by providing a geomorphic template atop which a range of other biophysical interactions can be assessed.

This report presents application of **Stage One** of the River Styles Framework in the Upper Hunter catchment. This geomorphic information base provides a baseline template for a range of other research projects occurring within the ARC Linkage Project, and for river management and rehabilitation initiatives within UHRRI and the Hunter Catchment Blueprint. Sedimentary fluxes, weed sources, and fish habitat assessments are just a few of the research projects that will use this work to frame the selection of field sites and to assess inputs into the UHRRI study site at Muswellbrook. The template will be used to integrate a range of scientific perspectives and skills, striving to establish coherent cross-disciplinary knowledge of how rivers work and the linkages within the Upper Hunter catchment.

Significant developments have been made towards achieving this primary initial objective. The information presented here provides a coherent, first-rate framework for ongoing and future research and management. Along with the strategic initiatives developed through this ARC Linkage Project, which includes 3 industry partners (Bengalla Mining Company, Mt Arthur Coal and Macquarie Generation) and direct support from NSW Department of Infrastructure, Planning and Natural Resources, formal approval has been granted through a Memorandum of Understanding (MoU) that has facilitated direct on-the-ground support to implement the river rehabilitation initiatives. This MoU represents a collaborative program among Macquarie University, the NSW Department of Infrastructure, Planning and Natural Resources, and Hunter Catchment Management Trust.

1.3 Communicating the River Styles framework: a comment on report structure and terminology

The coherent and consistent template presented by the River Styles framework presents an ideal basis to **integrate** a host of management activities. The structure of this report follows the format by which River Styles reports are produced through Macquarie University. The format follows the structure of the River Styles framework and includes *all* components of Stage One. Maintaining a consistent reporting format and terminology (particularly in River Styles naming) is critical, not only for communication but for meaningful cross-catchment or regional scale analyses that compile reports produced by different practitioners. In all applications of the River Styles framework, however, definition of River Styles must be undertaken in a rigorous and consistent manner across a catchment.

The intended target audience for this report extends across the range of river practitioners. This always presents significant challenges, as there is significant divergence among river practitioners in use of terminology and how information is presented. Given the diverse array of potential end-users, all endeavours have been made to present this report in a user-friendly and easily communicable manner using graphics and photographs where applicable. In many instances, concepts have been adapted in a distinctive manner in the River Styles framework. Various key terms used in this report are defined in **table 1**.

Table 1 Definition of terms used in Stage One of the River Styles framework

Term	Definition
River Style	River Styles are classified at the scale of river reaches in a catchment-specific and scalar independent manner. A River Style is defined as a section of river where boundary conditions are sufficiently uniform along a reach of river (i.e. there is no change in the imposed flow or sediment load) such that the river maintains a near consistent structure. Individual River Styles have diagnostic features or unique combinations of features (measured in terms of channel planform, geomorphic units, and bed material texture).
Landscape unit	Different compartments of similar topography within a catchment are referred to as 'landscape units'. These topographic features comprise a characteristic pattern of landforms. Landscape units are differentiated on the basis of physiographic setting (landscape position) and morphology (elevation and slope). Examples include tablelands, uplands, escarpment, base of escarpment, rounded foothills and lowland plains. Landscape units generally form a characteristic downstream sequence. The extent and character of relief variability, manifest primarily through the imposed slope and confinement of the valley floor trough, are key determinants of the <i>valley-setting</i> in which a river is formed.
Valley-setting	The <i>confined valley-setting</i> has no floodplain or isolated pockets of floodplain. Over 90% of the channel margin abuts the valley margin. The <i>partly-confined valley-setting</i> contains discrete but discontinuous floodplain pockets that can alternate in a downstream direction. Between 10-90% of the channel abuts the valley margin. The <i>laterally-unconfined valley-setting</i> is characterised by rivers with continuous floodplains along both channel banks. Less than 10% of the channel margin abuts the valley margin.
Geomorphic unit	Geomorphic units are the building blocks of river systems. These landforms represent specific associations between landscape morphology and the set of processes that produce that form (termed the form-process association). Geomorphic units are differentiated into instream and floodplain types. Each River Style is comprised of a distinct set of geomorphic units.
Hydraulic unit	Patches of relatively homogeneous flow and substrate character, nested within geomorphic units. Hydraulic units are identified on the basis of surface flow type and dominant substrate composition (Thomson et al., 2001).
Imposed boundary condition	<i>Imposed boundary conditions</i> determine the relief (landscape dissection), slope and valley morphology (width and shape) within which rivers adjust. In a sense, these factors influence the potential energy of a landscape, and the capacity to perform geomorphic work. They also constrain the way that energy can be used, through their control on valley width and hence the concentration (or dissipation) of flow energy.
Flux boundary condition	<i>Flux boundary conditions</i> are catchment-scale controls that exert an influence over river character and behaviour through their role in determining the operation of biophysical fluxes in landscapes, namely flow and sediment transfer regimes (and their interactions).

1.4 What is the River Styles framework?

River Styles record the character and behaviour of a river, providing a geomorphic appraisal of what a river system looks like and how it adjusts. As the capacity for a reach to adjust varies for each River Style, management issues and associated rehabilitation programs differ for different River Styles. The River Styles framework also assesses geomorphic river condition and recovery potential, framed in terms of the evolutionary pathways of differing River Styles. When analysed within a catchment context, the framework provides a unified baseline upon which an array of additional information can be added, thereby generating a consistent platform for decision-making for a range of river management activities. As individual catchments comprise unique patterns of River Styles, in which reaches have differing character, behaviour, condition and recovery potential, planning for river conservation and rehabilitation is a catchment-specific exercise.

The River Styles Framework is structured as a nested hierarchy that differentiates among five scales: catchments, landscape units, River Styles, geomorphic units and hydraulic units. Catchment-scale conditions dictate the type and configuration of landscape units (i.e. topography), which in turn control the range of River Styles formed along river courses. River Styles are characterised for differing valley-settings. Distinction is made among confined (no floodplain), partly-confined (discontinuous floodplain) and laterally-unconfined (continuous floodplain) valley-settings. Nested within these valley-settings, River Styles are defined at the reach scale (hundreds or thousands of metres of river course), whereby boundary conditions are sufficiently uniform along a stretch of river (i.e. there is no significant change in the imposed discharge or sediment load) such that the river maintains a near-consistent geomorphic structure. River Styles comprise assemblages of geomorphic units (i.e. channel and floodplain landforms such as pools, riffle, levees, backswamps, etc.). Analysis of these landforms is used to interpret the behaviour of each River Style. Hydraulic units, which are areas of homogenous substrate and flow type, are nested within instream geomorphic units and are considered to provide key habitats for a range of aquatic flora and fauna.

In applications of the River Styles framework, spatial and temporal linkages of biophysical processes in rivers are appraised within a catchment context, assessing linkages between differing reaches, tributary streams and the trunk stream. Downstream patterns of River Styles are explained. Morphodynamic perspectives on the geomorphic make-up of catchments are tied to appraisal of system evolution to provide a predictive context with which to interpret how changes in one part of the catchment have impacted elsewhere, over what time frame, and what the likely future river condition will be. This provides an appropriate context with which to frame management responses to future catchment disturbance. Such applications require integration of Stages 2 and 3 of the River Styles framework, and are not considered in this report. Key attributes of the River Styles framework as a whole are summarised in **Table 2**.

Table 2 Key attributes of the River Styles Framework

The River Styles framework:

- Works with the ***natural diversity*** of river forms and processes. Due recognition is given to the continuum of river morphology, extending from bedrock-imposed conditions to fully alluvial variants (including unincised valley floors). The River Styles framework can be applied in any environmental setting.
- Is framed in terms of ***generic, open-ended*** procedures that are applied in a catchment-specific manner. Reaches are not 'pigeon-holed' into rigid categories; rather, new variants are added to the existing range of River Styles based on a set of discrete attributes (i.e. the valley setting, geomorphic unit assemblage, channel planform and bed material texture).
- Evaluates ***river behaviour***, indicating how a river adjusts within its valley setting. This is achieved through appraisal of the form-process associations of geomorphic units that make up differing River Styles. Assessment of these building blocks of rivers, in both channel and floodplain zones, guides interpretation of the range of behaviour within any reach. As geomorphic units include both erosional and depositional forms, and characterise ALL riverscapes, they provide an inclusive and integrative tool for classification exercises.
- Provides a ***catchment-framed*** baseline survey of river character and behaviour. Application of a nested hierarchical arrangement enables the integrity of site-specific information to be retained in analyses applied at catchment or regional levels. Downstream patterns and connections among reaches are examined, demonstrating how disturbance impacts in one part of a catchment are manifest elsewhere over differing timeframes. Controls on river character and behaviour, and downstream patterns of River Styles, are explained in terms of their physical setting and prevailing biophysical fluxes.
- Evaluates recent river changes in context of longer-term landscape ***evolution***, framing river responses to human disturbance in context of the 'capacity for adjustment' of each River Style. Identification of reference conditions provides the basis to determine how far from its 'natural' condition the contemporary river sits and interpret why the river has changed. Ergodic reasoning is applied to interpret the stage and rate of adjustment of reaches of the same type.
- Provides a meaningful basis to compare type-with-type. From this, the contemporary ***geomorphic condition*** of the river is assessed. Analysis of downstream patterns of River Styles and their changes throughout a catchment, among other considerations, provides key insights with which to determine geomorphic ***river recovery potential***. This assessment, in turn, provides a physical basis to predict likely future river structure and function.

The River Styles framework comprises four stages, each with a series of steps (see **Figure 1**).

Figure 1 Stages and steps in the River Styles Framework

STAGE ONE: Catchment-wide baseline survey of river character and behaviour

Stage One, Step One: Assess regional and catchment setting controls
Stage One, Step Two: Define and map River Styles across the catchment
Stage One, Step Three: Interpret controls on the character, behaviour and downstream patterns of River Styles

STAGE TWO: Catchment-framed assessment of river evolution and geomorphic river condition

Stage Two, Step One: Determine the capacity for adjustment of the River Style
Stage Two, Step Two: Assess river evolution as a basis for identifying irreversible geomorphic change and a reference condition
Stage Two, Step Three: Determine and explain the geomorphic condition of the reach

STAGE THREE: Assessment of the future trajectory of change and geomorphic river recovery potential

Stage Three, Step One: Determine the trajectory of river change
Stage Three, Step Two: Assess river recovery potential: Place reaches in their catchment context and assess limiting factors to recovery

STAGE FOUR: River management applications and implications: Catchment based vision building, identification of target conditions and prioritisation of management efforts

Stage Four, Step One: Develop a catchment framed physical vision
Stage Four, Step Two: Identify target conditions for river rehabilitation and determine the level of intervention required
Stage Four, Step Three: Prioritise efforts based on geomorphic condition and recovery potential
Stage Four, Step Four: Monitoring and auditing improvement in geomorphic river condition

Stage One of the River Styles framework entails identification, interpretation and mapping of River Styles throughout a catchment. This provides a baseline survey of river character and behaviour. **Stage Two** uses evolutionary insights to determine whether the reach is in good, moderate or poor geomorphic condition. **Stage Three** assesses geomorphic river recovery potential which determines whether the condition of rivers will improve over the next 50-100 years. Insights from application of the River Styles framework are used to identify target conditions for river conservation and/or rehabilitation of each reach, framed in context of a catchment-wide vision (**Stage Four**). Less impacted sections of a River Style are used to guide the target conditions for river structure in more degraded reaches of river of the same type, replicating the 'natural' character

of rivers for equivalent landscape settings. Using this baseline information, a physically-based procedure is then applied to prioritise catchment-framed river conservation and rehabilitation strategies based on where the greatest likelihood of success and most cost-effective measures can be implemented. This provides a rational basis with which to structure and implement conservation and rehabilitation programs. Management applications of the framework are summarised in **Table 3**.

Table 3 Key management applications of the River Styles Framework

The River Styles framework:

- Provides a basis to ***order physical information*** in a consistent, coherent and integrative manner, presenting a systematic and meaningful basis for communication. From this, information gaps, and/or the need for more detailed assessments of biophysical information, can be determined. Catchment-framed assessments present a template onto which finer scale resolution work can be added, providing more detailed insights into reaches of particular concern, without compromising the integrity of the information base for the catchment as a whole.
- Shows how the physical structure of a river throughout a catchment provides a ***template*** upon which the interaction of biophysical processes can be evaluated. This presents a consistent basis upon which issues of uniqueness, rarity, naturalness, geodiversity and representativeness can be appraised.
- Helps to develop ***proactive***, rather than reactive, management strategies that work with nature, ensuring that site-specific strategies are linked within a reach and catchment-based ***vision***.
- Determines realistic ***target conditions*** for river rehabilitation, focusing management attention on underlying causes of problems, rather than the symptoms of change. This also enables the most appropriate river rehabilitation treatment to be selected (or designed).
- Can be used to more effectively ***prioritise*** resource allocation to management issues, balancing efforts at river conservation and rehabilitation. This requires differentiation of reaches of high conservation value (in terms of the geodiversity and/or rarity of River Styles) and degraded or stressed rivers. Priorities can be determined within- and between-catchments, presenting an open and transparent physical basis for decision-making.
- Can be used to select representative or reference sites across the range of River Styles in programs to ***monitor*** river condition and audit the effectiveness of river management strategies. These benchmarking and monitoring procedures can be applied at scales ranging from within-catchment programs through to regional, State or even National river management programs. For example, wild and scenic river classification can be undertaken to determine the best remaining reaches of different types of rivers.

1.5 Practical considerations in application of the River Styles Framework in the Upper Hunter catchment

The River Styles framework is a comprehensive yet adaptable approach that allows differing users to derive data on river character and behaviour that can be utilised in a meaningful manner by other practitioners. Obviously, the way in which River Styles reports are utilised should be innately tied to the quality of the data that has been recorded. The reliability of a River Styles report will depend on:

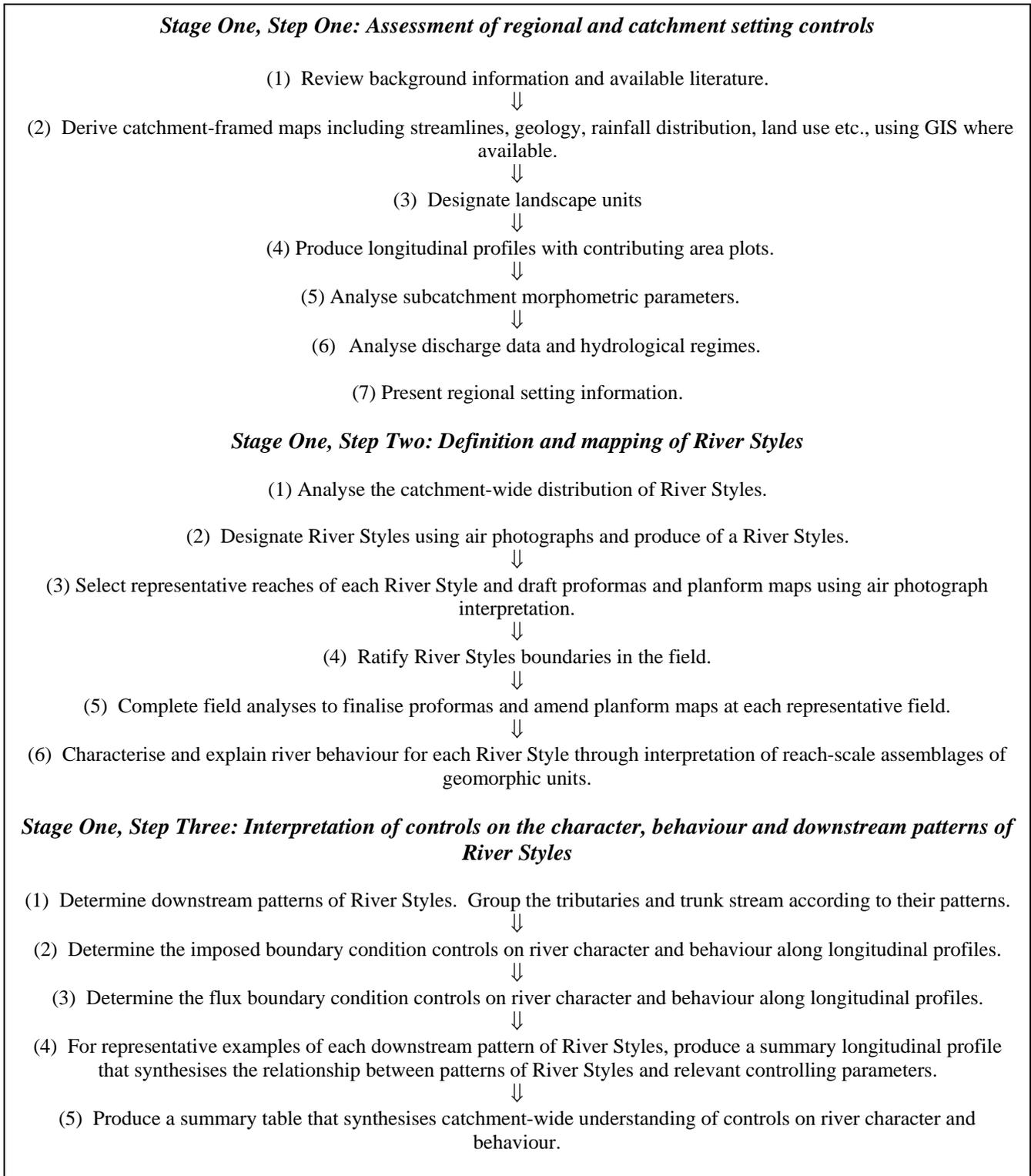
- ***The skills base of the practitioner and user.*** The combination of air photograph interpretation and field analytical skills requires some basic geomorphology training. The River Styles framework is not a prescriptive black box exercise that places each reach into a limited range of categories, but a way of reading the landscape. Each river operator must understand and document the limitations imposed by the scale/resolution of the work they are completing. This report has been completed by practitioners trained in the River Styles Framework in close collaboration with the developers of the framework (Gary Brierley and Kirstie Fryirs).
- ***The timeframe in which the study is completed.*** In general terms, the time available to complete a River Styles analysis dictates the scale at which data can be collected and compiled. As cross-catchment consistency is critical, careful judgement must be made on the scale of inquiry and related time management issues at the outset of a project. A large proportion of analysis in the River Styles framework is field-based. Application of Stage One of the framework in the Upper Hunter catchment has taken a year, culminating in this report. During this year, significant time was spent in the field. The office-field ratio is about 2:1.
- ***The scale at which data are reported and analysed.*** For many management applications, broad reconnaissance knowledge of the catchment as a whole may suffice. In many instances, initial catchment-framed assessments at a coarse resolution present a template onto which finer scale work can be added. In this manner, more detailed insights can be gained for reaches of particular concern, but the integrity of the information base for the catchment as a whole is not compromised. The scale of analysis integrated into the final River Styles maps must be consistent across the entire catchment. This report covers a catchment area of around 4000 km² and 13 river courses. Initial, coarser analysis of valley-settings was completed at 1:100,000. Identification of River Styles was completed at 1:25,000 scale using maps and air photographs. This provided the basis for finer resolution work and more detailed analysis of River Styles boundaries and attributes in the field.
- ***Splitting versus clumping.*** The resolution of analysis undertaken in the River Styles framework is dependent on the purpose to which the information is to be utilised. The assessment of 'near-uniform' river character and behaviour in a reach will vary dependent on the scale at which the River Styles framework is applied. There will be no definitive, final statement on variants of River Styles, as no magic number can meaningfully summarise the diversity of natural river forms and processes. Different end users will prefer a clumped rather than a split approach to the differentiation and labelling of River Styles. Much deliberation will be encountered over whether reaches should be split into individual River Styles, or clumped together as a broader reach of a single River Style in which there is a range or alternating patterns of river character and behaviour (sometimes referred to as a segment). Alternatively, localised features inevitably get buried in broader-scale analyses, but may be very important considerations in finer resolution work (e.g. assessments of geodiversity). In this report, a cross-catchment consistency in the scale of application, and documentation of adopted procedures has been applied. River Styles extend over the scale of kilometres, and many incorporate finer scale. For example, along Rouchel Brook, the Confined valley with occasional floodplain pockets River Style contains alternating sequences of gorge-like sections and areas where floodplain pockets occur. These small scale reaches that span several tens or hundreds of metres have been clumped into the one River Style.

- ***Boundaries between River Styles.*** The boundaries between River Styles are defined by a change in the diagnostic features of a Style such that a change in geomorphic structure results. These boundaries can be distinct or gradual. Distinct changes often coincide with tributary-trunk confluences, changes in valley gradient (e.g. at bedrock steps) or sudden changes in valley width and morphology associated with lithological or structural changes. Gradual changes are less easily pinpointed. These transition zones are often coincident with gradual downstream changes in valley width and morphology, or valley slope. For example, a change from occasional to discontinuous floodplain pockets may occur over several kilometres of river course. In this report, the boundaries between these sorts of river reaches is placed in the middle of this transition zone.
- ***Labelling River Styles.*** Particular problems emerge in putting labels onto River Styles, striving to achieve a balance between consistency, while maintaining an interpretive meaning and ease of communication. At times this has proved impossible, and borders on the farcical as a dozen or more terms are merged into the label. Putting boxes, boundaries or labels on nature is NOT the underlying message of the framework. Much remains to be learned from the ongoing debates about how to define a reach, assess how it looks and behaves, interpret how it is likely to change, and apply a label to it. Overall, the fundamental premise of the River Styles framework, and the intent with which it has been developed, is to provide a learning tool through which geomorphologists can summarise river character, behaviour, condition and recovery potential and convey these insights across to a range of practitioners from other disciplines, with a management focus. In essence, the River Styles framework provides a series of systematic procedural steps with which to guide observations on river geomorphology in a meaningful, coherent and consistent manner.
- ***A cautionary note on practical applications of River Styles insights in river rehabilitation programs.*** As any given reach represents a summary of a range of river character and behaviour, a precautionary approach to management applications should always be adopted, such that suggested management treatments are appropriate to the specific problem to be addressed. In addition, such applications must be cognisant of local river dynamic and potential off-site (upstream and/or downstream) considerations. The coherent catchment-framed basis of the River Styles framework is NOT intended to replace detailed field-based analytical enquiry and interpretations of local river history and change. However, applications of the framework provide a consistent and meaningful manner to order and organise insights into river character and behaviour such that analyses and interpretations of river forms and processes can be translated from one field situation to another, over an array of spatial scales. Hence, site- or reach-specific insights are framed and evaluated in light of their catchment context in a manner that enables cross-catchment comparisons to be meaningfully undertaken.

2. SECTION TWO: METHODS USED IN APPLICATION OF STAGE ONE OF THE RIVER STYLES FRAMEWORK IN THE UPPER HUNTER CATCHMENT

Methods used to undertake Stage One of the River Styles framework in the Upper Hunter catchment are summarised in **Figure 2**.

Figure 2 STAGE ONE: Catchment-wide baseline survey of river character and behaviour



2.1 Historical analyses and assessment of regional setting

In the River Styles framework, landscape units are readily identifiable topographic features with a characteristic pattern of landforms. Identification and mapping of landscape units is undertaken on the basis of physiographic character, landscape position, geology and relief. Examples of landscape units include: tablelands, uplands, mountains, escarpment, rounded foothills, low lying hillslopes and lowland plain. A map showing the distribution of landscape units in the catchment is produced. Elevation, longitudinal valley slope and valley width are tabulated to characterise each landscape unit. These descriptors represent fundamental controls on river character and behaviour.

Longitudinal profiles record the downstream changes in elevation, and hence slope, along a river course. Given that slope is a primary control on river character and behaviour, changes in slope along a longitudinal profile often coincide with landscape unit and/or River Styles boundaries. Overlaying longitudinal profiles from different subcatchments can be used to compare downstream changes in slope and assess tributary-trunk relationships. This is a key basis upon which to analyse and interpret controls on the downstream patterns of River Styles in Stage One Step Three. In the River Styles framework, contributing area is superimposed onto the longitudinal profiles. This defines the area draining into each section of the river course, which is a fundamental control on downstream changes in discharge. It also defines the relative contributions of area from different parts of the catchment, and provides a quick, visual overview of changes in catchment area (and hence discharge) at tributary confluences. It is often instructive to note (and explain) whether the character and behaviour of the trunk stream changes downstream of tributaries.

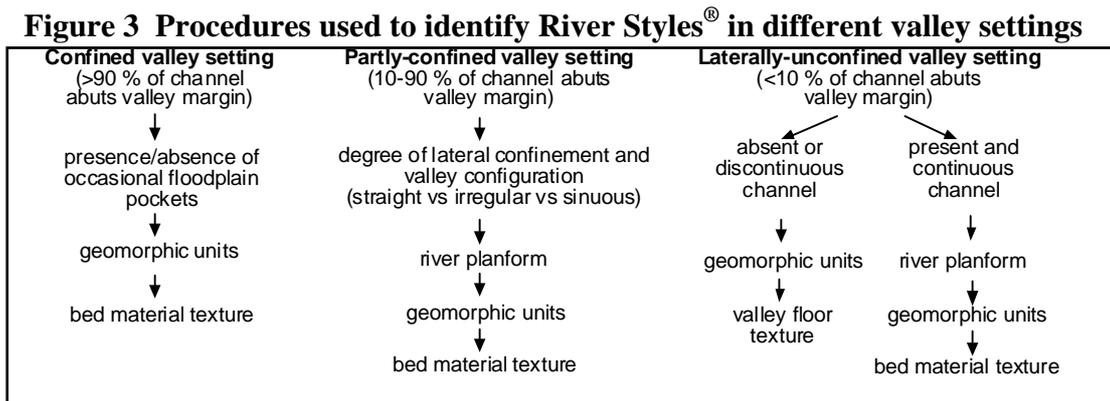
The timing and frequency of flows dictate the capacity of a river to adjust its morphology, while the sequencing of floods affects the geomorphic effectiveness of the flow (i.e. the capacity of a given flood to do geomorphic work, that is, transport sediment). The hydrological analyses undertaken in the River Styles procedure are used to gain an appreciation of what scale of event is the dominant control on river morphology, and how frequently that type of flood occurs.

For the Upper Hunter catchment, regional setting analyses involved compilation of significant historical and archival information (sourced from the Mitchell Library in Sydney, that State Archives in Sydney, the Muswellbrook Office of the NSW Department of Infrastructure, Planning and Natural Resources (NSW DIPNR), the Hunter Catchment Management Trust and other standard library searches). These historical records proved invaluable in assessment of landuse changes, flood histories, vegetation changes since European settlement. Flood records and discharge data were analysed using the Pineena database compiled by NSW DLWC. All gauges with a record of greater than 10 year of continuous data were collated and catchment area-discharge relationships generated. Given the limited number of gauges in the upper Hunter catchment, this analysis was completed for the entire Hunter catchment. Given the variability in rainfall and climatic conditions across the catchment, unfortunately, these relationships represent a summarised assessment of magnitude-frequency relationships for the Hunter catchment and should be considered a guide only for the Upper Hunter catchment. These relationships are used to calculate stream power relationships along longitudinal profiles, to give some indication as to the energy conditions under which different River Style operate in the catchment.

A 25 m digital elevation model (DEM) was used to construct the longitudinal profiles for each primary river course in the catchment. GIS databases were also used to attain maps of, vegetation cover, geology, landscape units etc. Local anecdotal evidence was compiled from various sources including landowners and personnel in NSW DIPNR.

2.2 Air photograph interpretation and mapping of River Styles

The definition and interpretation of River Styles was initially undertaken as a desk top exercise using available maps and the latest set of aerial photographs. Fieldwork was then undertaken to collect relevant information on river character and behaviour for each River Style in the catchment and ratify boundaries between River Styles. River Styles are identified initially in terms of the **valley setting** in which a river operates (**Figure 3**). The primary trunk and tributary streams in each subcatchment are systematically analysed, identifying the distribution of floodplains along river courses to determine the range and pattern of valley-settings. Distinction is made among *confined* (no floodplain), *partly-confined* (discontinuous floodplain) and *laterally unconfined* (continuous floodplain) valley settings.



Within each valley setting, each River Style is characterised by a distinctive set of attributes, analysed in terms of:

- **channel planform** - the number of channels, sinuosity and lateral stability of channels as viewed from the air.
- **geomorphic units** that make up a reach - landforms that are the building blocks of rivers, e.g. bars, pools, levees.
- **bed material texture** - bedrock, boulder, gravel, sand or fine-grained variants.

Each River Style is initially identified on the basis of river planform and the assemblage of geomorphic units. Each River Style comprises a specific assemblage of geomorphic units. The identification and interpretation of geomorphic units provide insight into the range of formative processes that reflect the range of behaviour of a River Style. Bed material texture provides a finer level differentiation that is completed in the field. Dependent on whether the reach falls into a confined, partly confined or alluvial valley section, differing sets of procedures are used to identify the River Style (**Figure 3**). The importance of each parameter for assessing the character and behaviour of a river varies depending on the valley-setting in which it is found. A River Styles tree is constructed that outlines the specific identification criteria for each River Style in the catchment. Each River Style is given a diagnostic name and a draft catchment wide map showing the distribution of River Styles is produced and colour coded. Geomorphic planform maps are produced for representative reaches of each River Style and a River Styles tree is produced.

The identification of River Styles in the upper Hunter catchment was undertaken using the 1998 1:25,000 Muswellbrook, Murrurundi, Camberwell and Ellerston air photograph sets and accompanying topographic maps. Given the coverage required (over 4000 km²), a clumping approach was adopted, and near uniform river character and behaviour, or alternating sequences, was identified for reaches that were up to several kilometres in length. All streams greater than 4th order were assessed, leading to analysis along 13 river courses (the Hunter trunk stream to the confluence with the Goulburn River, Middle, Dart, Moonan, Stewarts, and Rouchel Brooks,

Kingdon Ponds, Pages and Isis Rivers, Brush Hill, Branch, Pages, and Davis Creeks) Planform maps were mapped directly onto the 1:25,000 air photographs. Representative reach maps were rectified in the field.

2.3 Field analysis

Each River Style boundary was checked in the field. In general, River Styles boundaries were distinct, marked by significant constrictions in valley morphology or a change in valley alignment. Numerous boundaries coincided with tributary confluences. In cases where a gradual transition between River Styles occurred, say over several hundreds of metres, the boundary was simply placed in the middle of the transition zone.

Representative reaches of each River Style along each river course were visited to rectify and finalise the geomorphic unit distribution and complete proformas for each River Style. Valley-scale cross sections were surveyed and sedimentological and vegetation analyses performed for differing geomorphic units. Representative photographs were also taken. The River Styles proformas presented in this report contain a summary of the character and behaviour of each River Style across the catchment. This entails synthesis of the range of geomorphic conditions found in each River Style. The best examples of planform maps, photographs and cross-sections are presented.

2.4 Assessing controls on river character and behaviour

One of the key components of the River Styles framework is the desire to understand how and why each reach looks and behaves in the manner that it does. River Styles, and their downstream patterns, are appraised in terms of their landscape setting and the spatial and temporal linkages of geomorphic processes. This is appraised within a catchment context, assessing linkages between differing reaches, tributary streams and the trunk stream, providing guidance into off-site impacts of change. To further this understanding a summary assessment of controls on the distribution of River Styles is presented.

Critical controls on river behaviour may vary from reach to reach. Controls on river character and behaviour are split into imposed and flux boundary conditions. Imposed boundary conditions are measures such as valley confinement, landscape unit and valley-setting. Flux boundary conditions are the water and sediment transfer regimes of a river course expressed in terms of the stream power and process zone distribution.

Initial insights into the array of controls on any given reach may be gained by plotting downstream patterns of River Styles onto longitudinal profiles. Analyses of slope and contributing area are combined with catchment area-discharge relationships to estimate gross stream power, from which stream power ranges are determined for each River Style. The critical role of downstream changes in valley confinement is explained at this stage, generally in terms of the geological imprint (structure and lithology) along with long-term landscape history.

To assess controls on the character and behaviour of each River Style in the Upper Hunter catchment, river courses were grouped according to their downstream pattern of River Styles. A representative example of each downstream pattern was chosen and River Styles and landscape unit boundaries placed on the longitudinal profile-contributing area plots. Gross stream power was calculated and overlaid on this plot. An interpretation was made of the contemporary process zones (source, transfer or accumulation) and sediment transport regime (bedload, mixed load, suspended load) of the river course. A visual diagram demonstrating downstream changes in each of the imposed and flux boundary condition controls is presented for representative examples of each downstream pattern of River Styles.

3. SECTION THREE: RIVER STYLES IN THE UPPER HUNTER CATCHMENT

3.1 STAGE ONE, STEP ONE: REGIONAL SETTING OF THE UPPER HUNTER CATCHMENT

3.1.1 General overview

The Hunter Valley covers a catchment area of around 22,020 km² of which the Upper Hunter Catchment covers about 20%. The Upper Hunter Catchment covers an area of around 4,480 km² from its confluence with the Goulburn River at Denman. In this report 13 river courses were assessed ranging in catchment area from 4481 km² (Hunter River) to 71 km² (Middle Brook). Figure 4 shows the Australian and NSW context of the Hunter Catchment and figure 5 is a general road map of the Upper Hunter area with many of the place names referred to in this report.

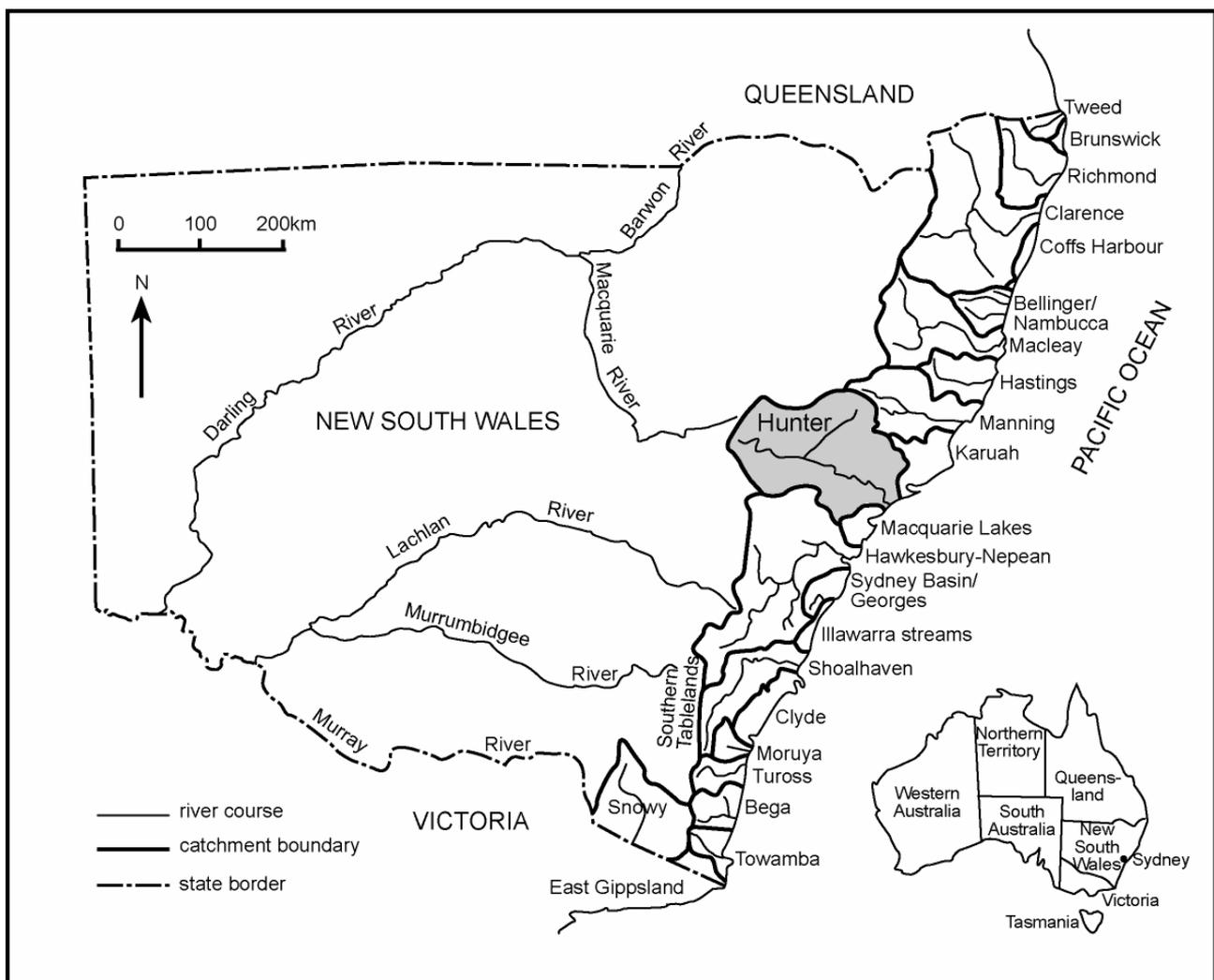


Figure 4: The location of the Hunter Catchment within Australian and NSW.



Figure 5: General road map of the Upper Hunter area with many of the place names referred to in this report.

3.1.2 Geology of the Upper Hunter Catchment

The rocks of the Hunter Valley reveal a history of the earth's tectonic life at the eastern edge of Gondwanaland. Part of this history is the Hunter – Mooki Thrust Fault. This fault is evident at the surface as it scribes a line westward from the coast, just north of Newcastle, swings around to the north and heads well into Queensland. The Upper Hunter straddles the Hunter – Mooki fault, from slightly east of Lake Liddel the fault arcs around until it is roughly parallel with the New England Highway. Where the highway crosses the Great Dividing Range at the saddle above Murrurundi (leaving the Hunter catchment) the highway is almost directly on top of the fault. The Hunter – Mooki Fault divides the upper Hunter catchment into two distinct geological regions, the folded strata of the New England Fold Belt, to the east, and the near flat lying strata of the Sydney Basin to the west. The Hunter – Mooki Fault marks the boundary where two bodies of rock were once

compressed together. The compressive forces were generated by the slow convection of the earth's mantle and caused folding and faulting in the rock strata. Along the ridges and plateaus of the Hunter Valley, where elevation is high, there is a basalt capping. Basalt is a rock formed as viscous lava flows over the landscape and then solidifies. This capping covers areas of both Sydney Basin and New England Fold Belt rocks and is another important component of the geology of the Upper Hunter Valley. The Hunter – Mooki Fault, the New England Fold Belt and the Sydney Basin are genetically related, whereas, the basalt flowed over the land long after the belt, basin, and fault were quiescent.

During the Devonian period (410Ma – 354Ma) the Pacific margin of Gondwanaland was an arc that would cross the present Australian coast line somewhere between Sydney and Newcastle and curve up into Queensland. This ancient coastline delineated a continental – oceanic convergent plate boundary (B-subduction, fig 6). Continent – oceanic convergent boundary complexes produce an elongated region of explosive volcanism approximately parallel to the coastline. This Devonian volcanism and the associated terrestrial and marine sedimentary complexes are the origin of a suite of lithologies which includes the oldest rocks found in the Hunter Valley. These oldest rocks occur at the top of the Isis and Hunter catchments. At these locations, during the Devonian, sediment was accumulating in a shallow marine environment along the continental margin. The limestone within which the Timor and Glenrock Caves have formed dates from the Devonian period. Devonian chert (a dense, very hard sedimentary rock consisting mainly of very fine quartz), is a common river gravel in the Hunter and Williams rivers. Fossils from the Devonian rocks suggest warm equatorial conditions.

Tectonic activity continued at the Pacific margin of the Gondwanaland through the Devonian, Carboniferous, Permian and Triassic Periods.

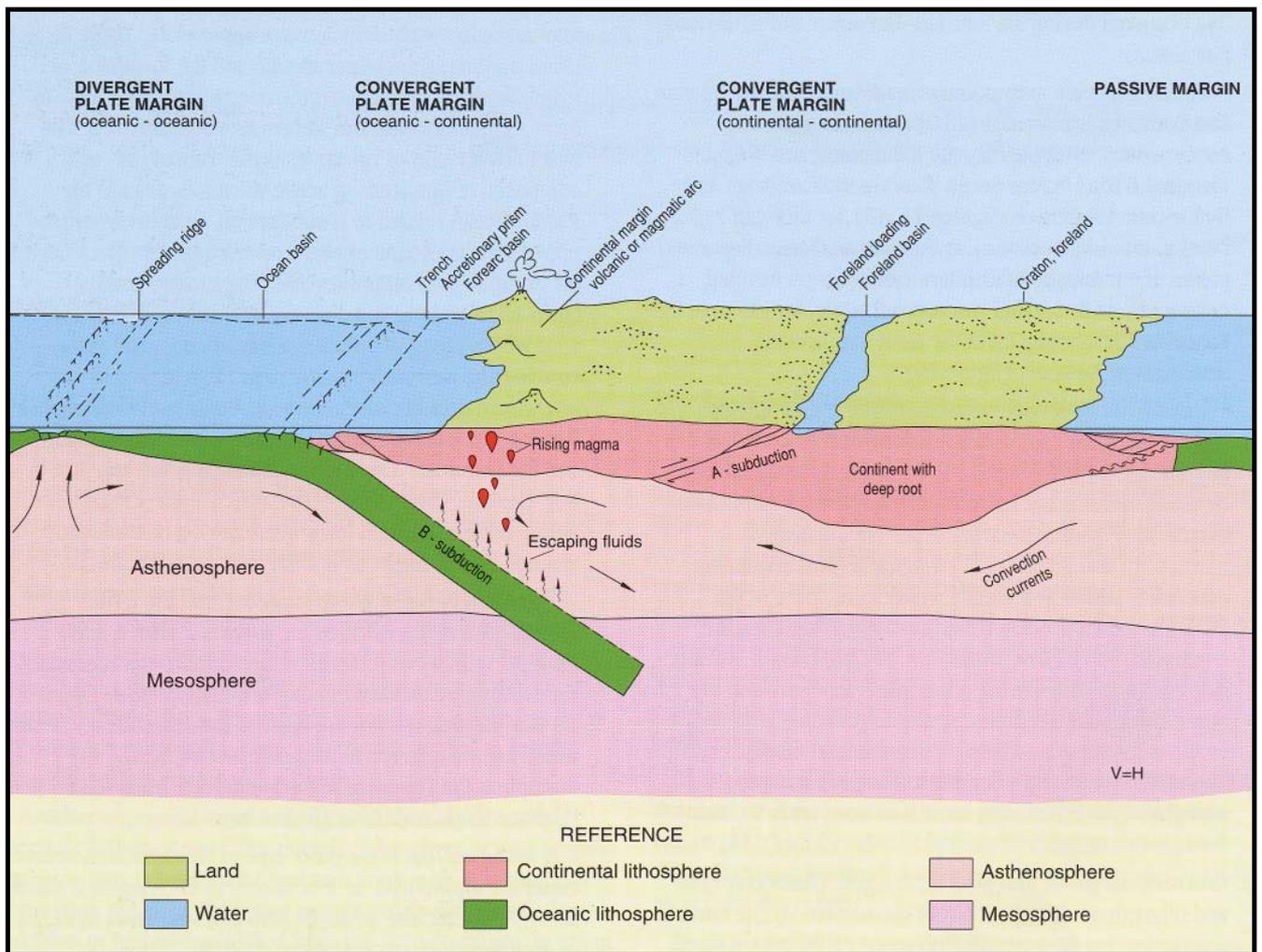


Figure 6: Subduction Model. In the context of the subduction along the east coast of Australia this diagram is drawn looking southward. (Source: Anon 1999, pp12)

During the Permian and Triassic periods (296 Ma to 251 Ma and 251 Ma to 205 Ma, respectively) what is now the Sydney – Bowen Basin was the site of a foreland basin situated toward the Pacific margin of Gondwanaland (Jones et al. 1984, pp243). The Pacific margin was a continental – oceanic convergent plate boundary (B-subduction, fig 6). The subduction of the oceanic plate produced explosive volcanism and compression. The enormous stresses and strains exerted by this compression caused folding and faulting (deformation) of the rock strata. As the crust is deformed it bulges, both, skywards and towards the earth’s center. The geological term for this mountain building process is orogeny. Deep below the surface the pressure and temperature produced during a mountain building episode creates a range of metamorphic rocks.

A foreland basin (see fig 6) is a depression that may form at the margin of a mountain range (orogenic belt) where the mountain range has been thrust (A-subduction, fig 6) onto the adjacent stable continental crust (craton). The weight of the overthrust material forces the edge of the stable continental crust down into the earth’s mantle (foreland loading) creating a basin (foreland basin).

The Sydney – Bowen Basin (Permian/Triassic in age) was a foreland basin formed as the New England Fold Belt was thrust onto the stable continental crust (the stable continental crust in this case was the remnants of the Lachlan Fold Belt, which was once a mountain range but had by the Permian Period been eroded down and become, and still is, stable continental crust). The movement of the New England Fold Belt as it was pushed onto the stable continental crust occurred in a zone along the Hunter – Mooki Thrust Fault.

Throughout the Permian and Triassic Periods the mountain building process uplifted Devonian and Carboniferous marine, fluvial, and volcanic rocks and created the highlands of the New England Fold Belt. During the mountain building process, at great depth below the earth surface, the oceanic crust that was force down into the earth's mantle partially melted. Over millions of years this molten material rises due to its buoyancy. This is represented in figure 6 as inverted teardrops of rising magma (red) above the subducting oceanic plate. If the molten rock rises close to the earth's surface there can be a spectacular explosive eruption. The eruption of Mount St Helens (May 18th 1980, Washington State, USA) is an example of this type of eruption. If the molten rock does not reach the surface but solidifies underground it forms granite or granite like rock. The Barrington Tops Granodiorite and the New England Granite were emplaced in this manner. The Barrington Tops Granodiorite is older than the New England Granite but they are both Permian in age.

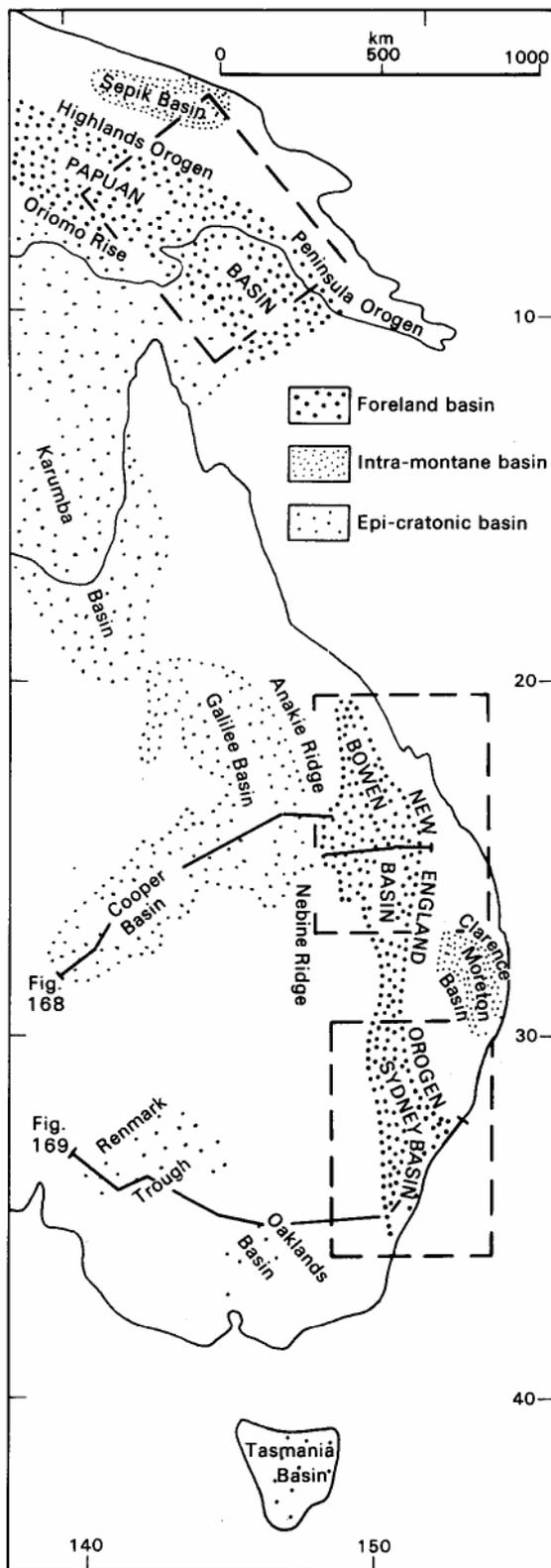


Figure 7: Australia – Papua New Guinea Analogue.
 (Source: Jones et al. 1984, pp258)

Jones et al. (1984) describes the Permian-Triassic Sydney – Bowen foreland Basin and the New England Fold Belt as analogous to the present tectonic setting of Papua New Guinea and the Australian mainland (see fig 7).

The contemporary Papua New Guinea region is a convergent continental – oceanic plate boundary. The boundary is roughly north east of and parallel to the Papua New Guinea land mass. The Indo-Australian tectonic plate is moving approximately northward, over the Pacific oceanic plate.

Within the analogy, the contemporary northwest-southeast aligned New Guinean Highlands equates to the north-south aligned Permian/Triassic New England Fold Belt. The New Guinean Highlands sheds sediment into the Papuan Basin, the New England Fold Belt would have shed sediment in to the Sydney Bowen Basin.

The New Guinean Highlands is a dissected plateau with active volcanism and peaks commonly over 3000 m (Jones et al. 1984, pp 245). In the Permian/Triassic Periods the New England Fold Belt would have been similar with very high peaks and active volcanoes.

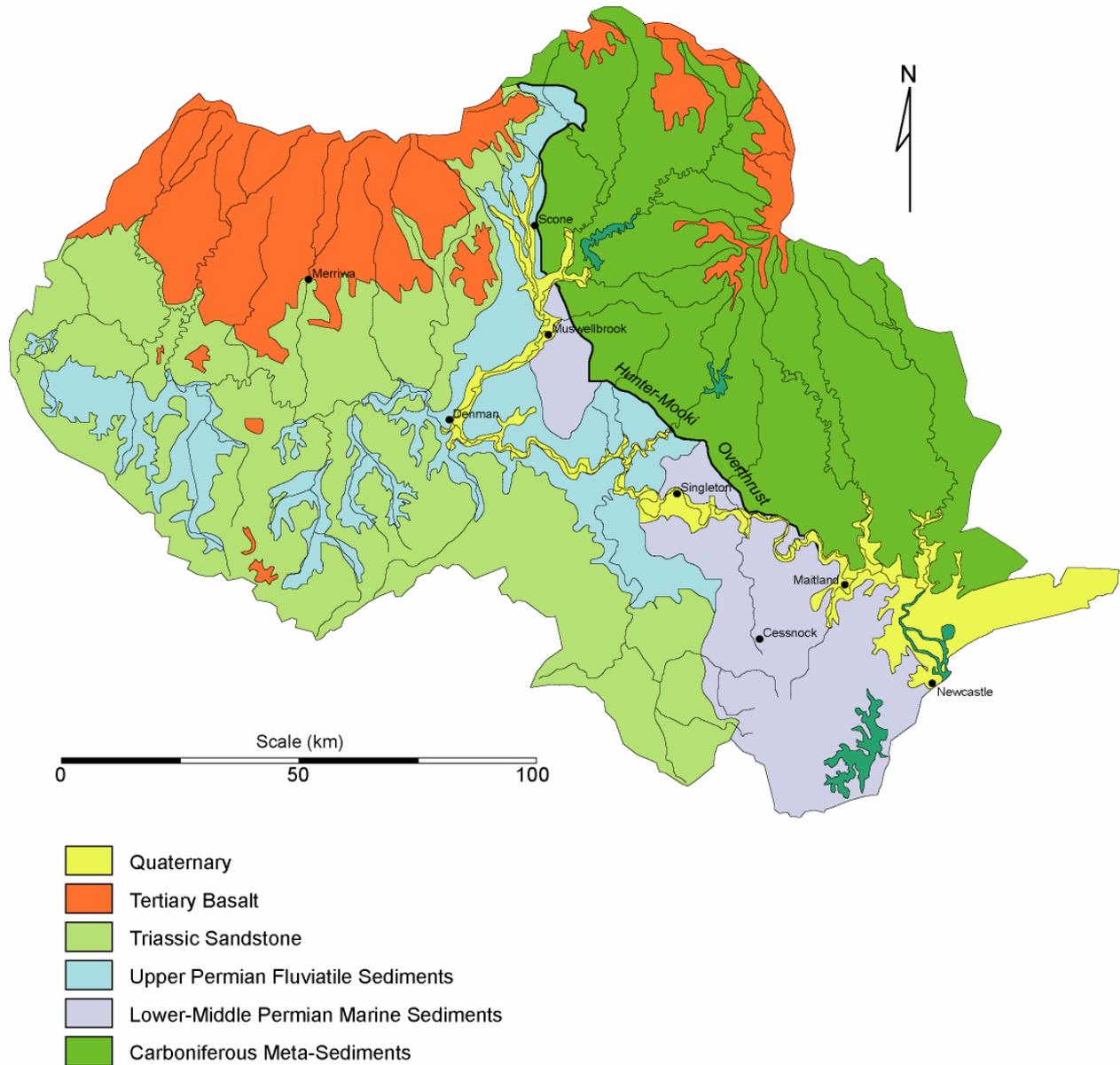
Since the Permian/Triassic Periods the New England Fold Belt has been eroded and worn until the volcanoes, mountains, and valleys of the highlands disappeared.

The New England Fold Belt is tightly folded and significantly faulted, while the Permian and Triassic strata proximal to the Hunter Mooki Fault are folded and faulted to a relatively mild degree. The deformation in the Permian and Triassic strata is important to the upper Hunter region as it repeatedly brings the coals seams to the surface or near surface (Glen & Beckett 1989, pp589).

Subsidence of the Sydney Basin (foreland basin) and the uplift of the New England Fold Belt occurred simultaneously (Jones et al. 1984, pp257), so that, as the New England Fold Belt grew sediment accumulated in the Sydney Basin.

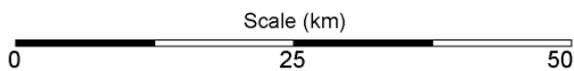
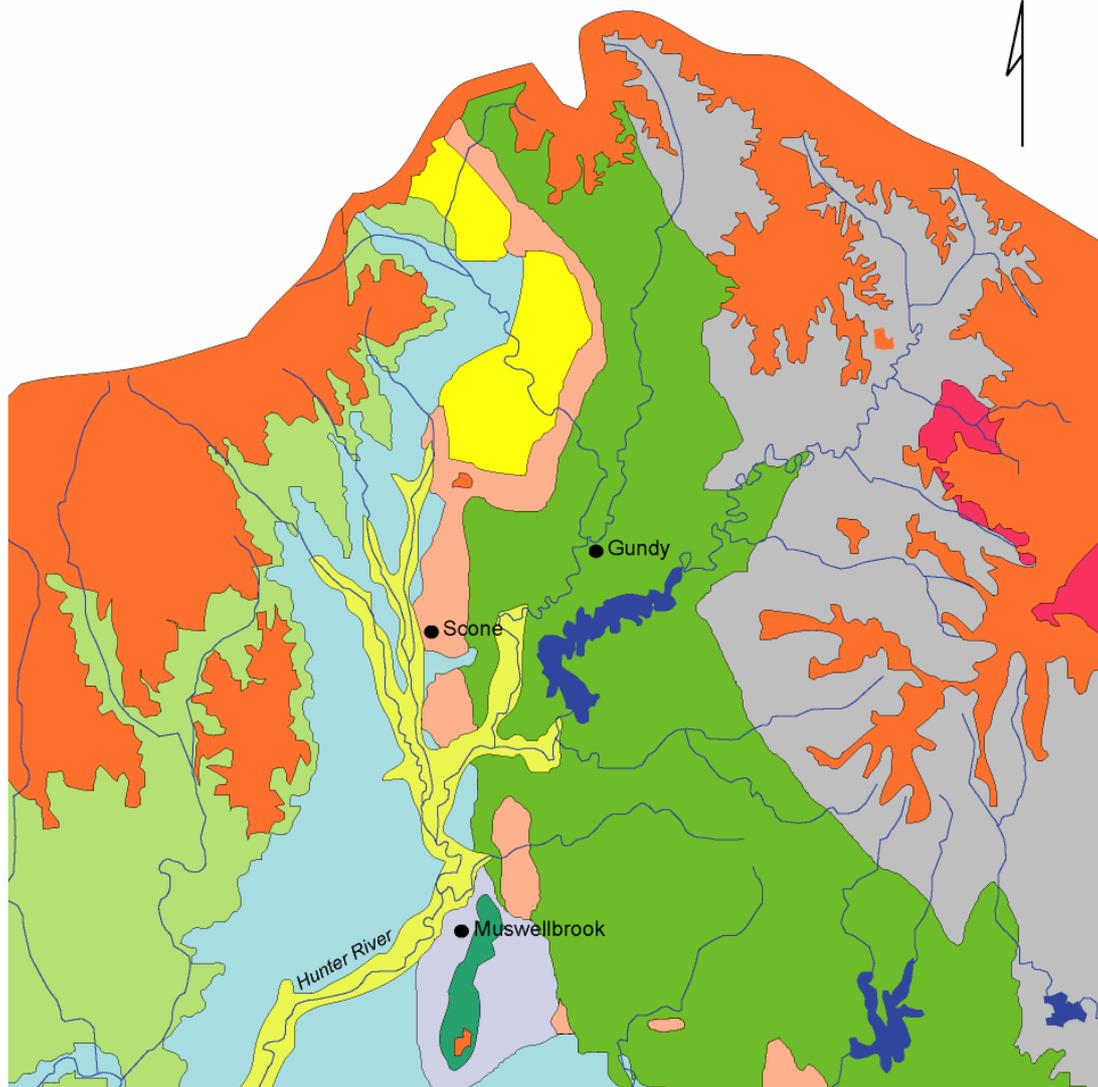
Figure 8 is a geological map of the Hunter Catchment and figure 9 is an excerpt of the upper Hunter. The geological map (fig 8) shows Permian sediments abutting the Hunter – Mooki Fault. These consist of coal measures, claystone, siltstones, sandstones, and conglomerates. Stratigraphically above the Permian sediments are the Triassic sediments. These consist of claystone, siltstones, sandstones, and conglomerates and include the Hawkesbury Sandstone. The Triassic sediments have a higher quartz content than the Permian sediments. Some of the differences between the Permian and Triassic strata are a consequence of their sources. When the rate of uplift of the New England Fold Belt was rapid, the sediments filling the basin were derived, dominantly, from the New England Fold Belt and when the uplift was in decline the sediments were derived, dominantly, from the stable continental crust (Jones et al. 1984, pp258 & Conaghan et al. 1982). The coal bearing sediments are among those that are derive from the New England Fold Belt.

FIGURE 8: GEOLOGY OF THE HUNTER CATCHMENT



Compiled from: Tamworth 1:250,000 Geological Series Sheet SH 56-13, First Edition 1971, and Singleton 1:250,000 Geological Series Sheet SH 56-1, First Edition 1969. NSW Department of Mines

FIGURE 9: GEOLOGY OF THE UPPER HUNTER

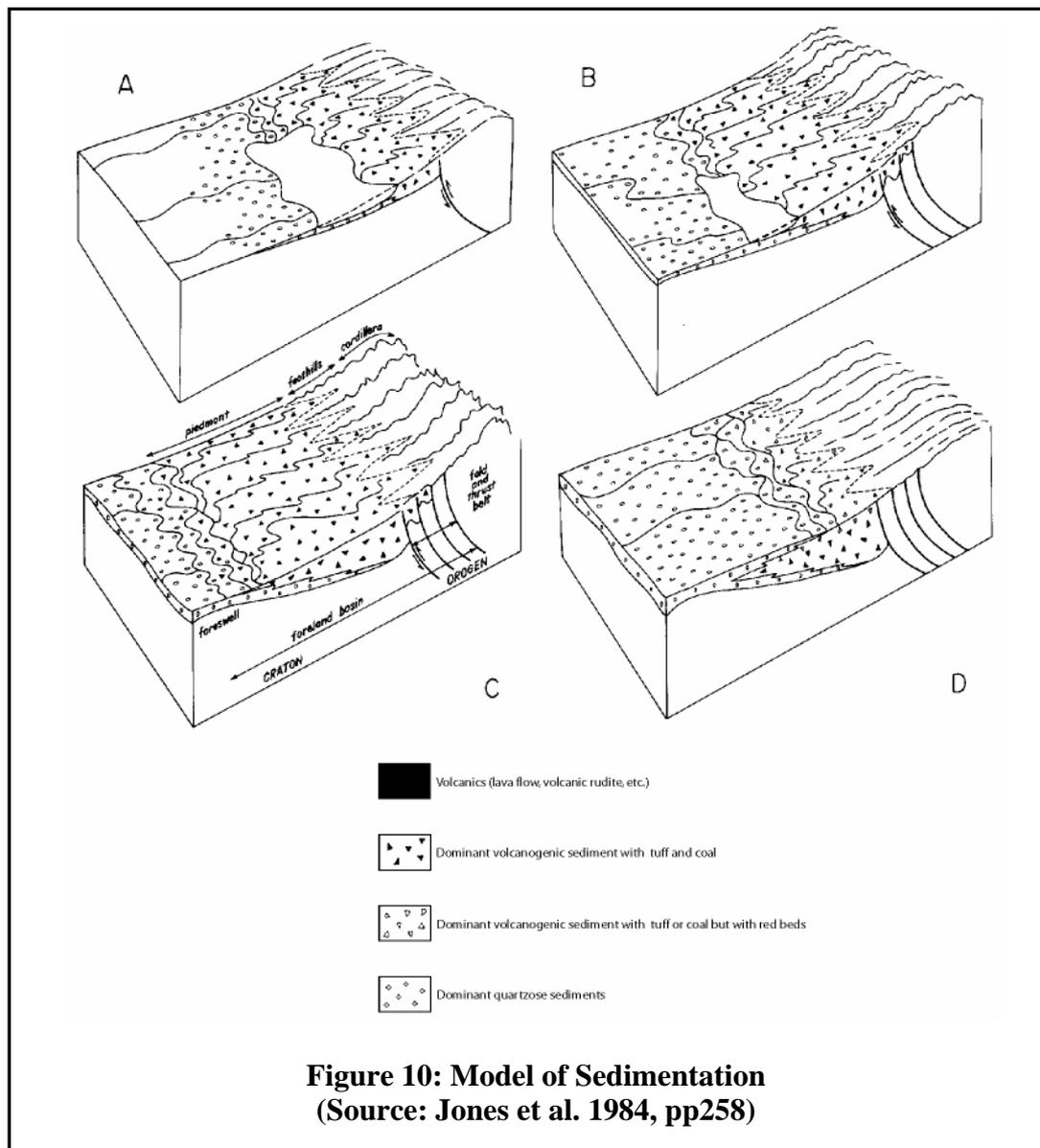


Quaternary		Alluvium (gravel, sand, silt, clay)
Tertiary		Olivine basalt with occasional sediment interbeds, dolerite, trachyte
Triassic		Sandstone, conglomerate, red and green claystone, shale
Upper Permian		Sandstone, shale, mudstone, conglomerate and coal seams
Middle Permian		Siltstone, sandstone and conglomerate
Lower-Middle Permian		Sandstone conglomerate shale and coal seams
Lower Permian		Basaltic lava and tuff, tuffaceous sandstone
Lower Permian		Granodiorite and quartz monzonite
Upper Carboniferous		Conglomerate, sandstone, shale, acid tuffs
Middle Carboniferous		Tuff, lavas, conglomerate, sandstone
Lower Carboniferous		Undifferentiated sediments and volcanics

Compiled from: Tamworth 1:250,000 Geological Series Sheet SH 56-13, First Edition 1971, and Singleton 1:250,000 Geological Series Sheet SH 56-1, First Edition 1969. NSW Department of Mines

Figures 10A to 10D show this model of sedimentation of the Sydney Basin. The left side of each figure is the stable continental crust and the right side is the mountains of the New England Fold Belt. In figure 10A mountain building is beginning, the Sydney Basin is still shallow, and sedimentation is relatively slow. In figure 10B mountain building and the down thrusting of the Sydney Basin is progressing strongly. Because the mountains are high and steep they supply sediment to the basin at a much faster rate than the stable continent and the basin is filled with sediment predominantly from the mountains (Permian Sediments). Sediment is deposited at such a rate that large amounts of organic matter is buried, this organic matter will one day become coal. In figure 10C the mountains are at their greatest height and the basin at its greatest depth. In figure 10D the mountain building has ceased and erosion has diminished the height and steepness of the mountains. At this stage the basin is being filled with quartz rich Triassic sediment derived predominantly from the stable continent.

Sedimentation in the Sydney basin continued into Jurassic period, the rocks currently exposed at the surface were not the last sediment to be deposited, a significant thickness of strata once covered the current surface.



It is generally believed that stable conditions, with some minor erosion, prevailed from the Early Cretaceous (141Ma) to the start of the Late Cretaceous (98Ma) (O'Sullivan 1996, pp425). During the Late Cretaceous the opening of the Tasman Sea lead to elevation of Eastern Australia (anon 1999, pp28). The elevated areas then begin to erode, producing a landscape of valleys and ridges. This landscape continued to erode into the Tertiary Period (65Ma – 1.8Ma), until the region was covered by vast fields of basalt erupted from local volcanic vents and fissures. This type of extensive out-flowing of lava is known as a flood basalt and created a vast plateau. The basalt plateau extended well beyond the upper Hunter catchment. This Tertiary igneous activity was associated with the opening of the Tasman Sea and the passage of the Australian continent over a mantle hotspot (anon 1999, pp29). The flood of basalt was not the result of a single eruption, but was the accumulation of basalt flows from many eruptions during the Tertiary Period.

After the basaltic eruptions ceased the landscape was once again a erosional landscape. The expanses of basalt eroded away and valleys were excavated. In some cases the erosion exhumed valleys that existed before the basalt flows and in other cases erosion created new valleys. The present basalt is a remnant of the once vast fields. The fields have been eroded back and reduced to a capping on areas of high elevation atop the Liverpool Range, Mount Royal Range, and Barrington Tops.

3.1.3 Landscape Units of the Upper Hunter Catchment

As an introduction to the landscapes of the Hunter Valley and to give some broader context to the landscape units identified for the purpose of this River Styles report, below is a brief summary of the land systems of the Hunter Valley as described by Galloway (1963).

Southern Mountains

The southern valley boundary is represented by an escarpment/plateau formed in strongly jointed Triassic sedimentary rocks. Hawkesbury Sandstone, the uppermost unit, weathers to steep, often precipitous cliffs that form a spectacular rampart along the southern valley margin. The underlying interbedded sandstones and shales of the Narrabeen Group have weathered to slopes of gentler grades. Although the lower hillslopes have formed from structurally weaker lithologies they exert control over the overlying massive-facies sandstone. The sandstone capping is removed by undercutting and mass wasting that often leaves blocky sandstone boulders strewn across the lower slopes. The isolated remnants of Tertiary basalt lava flows are found on a few scattered peaks in the Hunter Range.

Central Goulburn Valley

Within the southern and central Goulburn Valley the Triassic sandstone has been partially removed leaving an irregular series of steep-sided valleys and narrow gorges sharply abutting lowlands formed from softer exposed Permian strata. A number of the ridgelines and plateaux in this area are mantled by Tertiary basalt.

Merriwa Plateau, Liverpool Range

To the north of the Goulburn River, draining from the Liverpool Range, a series of parallel sub-catchments aligned north-south (including the Merriwa River) have cut through the Merriwa Plateau, a region of Mesozoic sandstone (Triassic-Jurassic) capped by Tertiary basalt. To the north, the Liverpool and Mt Royal range rise to elevations of over 1200 metres marking the catchment boundary.

Barrington Tops and North-eastern Mountains

The Hunter Valley is bounded in the north and east by the Barrington Plateau and Mt Royal Range. A series of concentric mountain belts radiate outwards from the Barrington Plateau decreasing in height towards the valley bottom. This region has formed from folded and faulted Devonian and Carboniferous sedimentary and volcanic rock complexes mantled with Tertiary basalt.

Central Lowlands

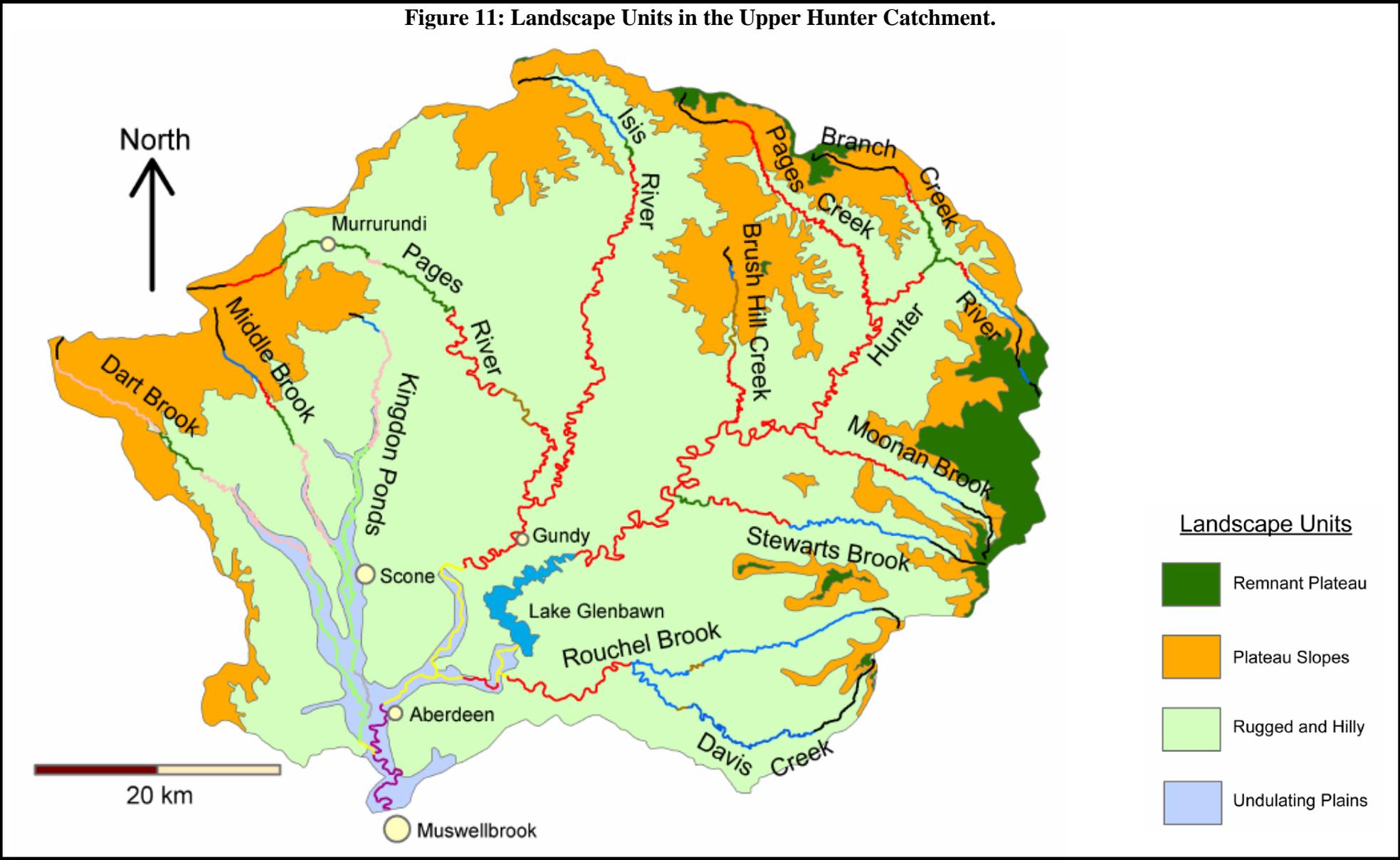
The central third of the Hunter Valley is characterised by an undulating belt of lowlands and rolling hills developed in comparatively weak Permian sedimentary rock. Along the central valley axis a number of conspicuous basalt capped hills such as Mt Arthur provide areas of localised high relief.

Within the landscapes of the Upper Hunter Catchment we have identified 4 key types of topography which are relevant to the purposes of this report. We refer to these types of topography as landscape units. They have been named the **Remnant Plateau**, **Plateau Slopes**, **Rugged and Hilly**, and **Undulating Plain** landscape units. Table 4 describes the characteristics of these landscape units and Figure 11 notes their distribution within the Upper Hunter Catchment. The landscape unit boundaries shown in figure 11 are estimates based on geological boundaries, with the exception of the Remnant plateau boundary which is based on the 1210m map contour.

Table 4: Parameters used to identify and describe landscape units in the Upper Hunter catchment.

	Remnant Plateau	Plateau Slopes	Rugged and Hilly	Undulating Plains
Physiographic character or landscape morphology	Dissected plateau with incised valleys.	Steep slopes incised with narrow valleys and gorge.	Steep to rolling hills with moderately deep valleys extending downstream from the plateau slopes to the undulating plains.	Relatively flat plains.
Landscape position	Top of catchment on plateau surface.	Near top of catchment, directly below remnant plateau.	Central parts of the catchment. Between the slopes of the plateau and the alluvial plains.	Lower section of catchment, downstream of the rugged and hilly landscape.
Geology	Tertiary Basalt.	Tertiary Basalt, Devonian and Carboniferous Meta-Sediments.	Devonian and Carboniferous Meta-Sediments, Permian and Triassic Sedimentary Rocks.	Quaternary Alluvium and Permian Sedimentary Rocks
Relief	~ 300m	~ 400m	~ 500 m	~ 100m
Elevation	~ 1200 to 1500 m	~ 800 to 1200 m	~ 800 to 200 m	~ 200 to 100 m
Valley width	Narrow confined valleys. (~ 40 to 100 m)	Narrow confined and partly confined valleys. (~ 40 m)	Narrow to moderately wide confined and partly confined valleys. (~ 50 to 500 m)	Very wide laterally unconfined valleys. (~ 200 m to 2 km)

Figure 11: Landscape Units in the Upper Hunter Catchment.



The **Remnant Plateau** landscape unit is a remnant of an extensive basalt plateau that was erupted during periods of Tertiary volcanism and once covered the area. This landscape unit has confined and partially confined valleys, relatively high elevation, and steep slopes reflecting the dissection of the plateau. Tertiary basalt is still present atop the areas of high elevation on the Liverpool and Mount Royal Ranges and Barrington Tops. This landscape unit is only prominent in the upper most 4 km of the Hunter River. The headwaters of the other subcatchments lie in the Rugged and Hilly landscape unit. Some streams (e.g. Moonan Brook) do reach an altitude that is slightly higher than the top of the Hunter River but do not extend on to the Remnant Plateau. This is because the plateau is not completely flat and featureless, it is higher in some places than others.

The **Plateau Slopes** landscape unit, as the name suggests, occupies the slopes that descend from plateau remnants and the higher elevation ridges. (In places, particularly to the west of the catchment, the plateau has been eroded back until there is only a ridge line. For the purpose of this report the Plateau Slopes landscape unit includes slopes below such ridge lines.) In this landscape unit the streams in the north-east of the catchment flow down through the basalt and into Devonian and Carboniferous meta-sediments, whilst the streams in the north-west of the catchment flow down through the Tertiary basalt and into the Triassic sandstone that here are the north-western rim of the Sydney Basin. The slopes are steep and the valleys are confined.

The **Rugged and Hilly** landscape unit occurs in the north-east of the catchment where the underlying strata is Devonian and Carboniferous meta-sediments. This landscape unit covers the central areas of the catchment and accounts for a large proportion of the catchment area. The slopes are low to moderate and the valleys are partly confined. The varying mechanical and chemical properties, and orientation of the Devonian and Carboniferous strata partially accounts for transitions between River Styles seen in this landscape unit.

The **Undulating Plains** landscape unit occurs through the center of the catchment approximately along the course of the New England Highway. The underlying strata is the Permian sedimentary rocks and Quaternary alluvium. The Permian sedimentary rocks are relatively soft rock. The slopes are low and the valleys are laterally unconfined. Other than the lower part of the Pages River and the Hunter River, only those catchments situated west of the Hunter-Mooki fault contain this landscape unit.

3.1.4 Longitudinal profiles of rivers in the Upper Hunter Catchment

The sum of the lengths of all 13 streams assessed in the Upper Hunter catchment is 793.65 km. Table 5 shows the length of each stream and the percentage it is of the total assessed stream length.

Table 5: Stream lengths and percentages of total assessed stream length

Stream	Stream Length (km)	Percentage of Total Assessed Stream Length
Branch Creek	20.477	2.58%
Brush Hill Creek	23.785	3.00%
Dart Brook	66.240	8.35%
Davis Creek	38.681	4.87%
Hunter River	223.385	28.15%
Isis River	77.997	9.83%
Kingdon Ponds	52.503	6.62%
Middle Brook	33.551	4.23%
Moonan Brook	26.896	3.39%
Pages Creek	38.200	4.81%
Pages River	104.570	13.18%
Rouchel Brook	51.104	6.44%
Stewarts Brook	36.257	4.57%

Longitudinal profiles and contributing area plots of all 13 river courses studied in the Upper Hunter catchment are presented collectively in figure 12 and separately in figure 13-1 to 13-13.

Figure 12: Longitudinal profiles of the 13 assessed streams in the Upper Hunter

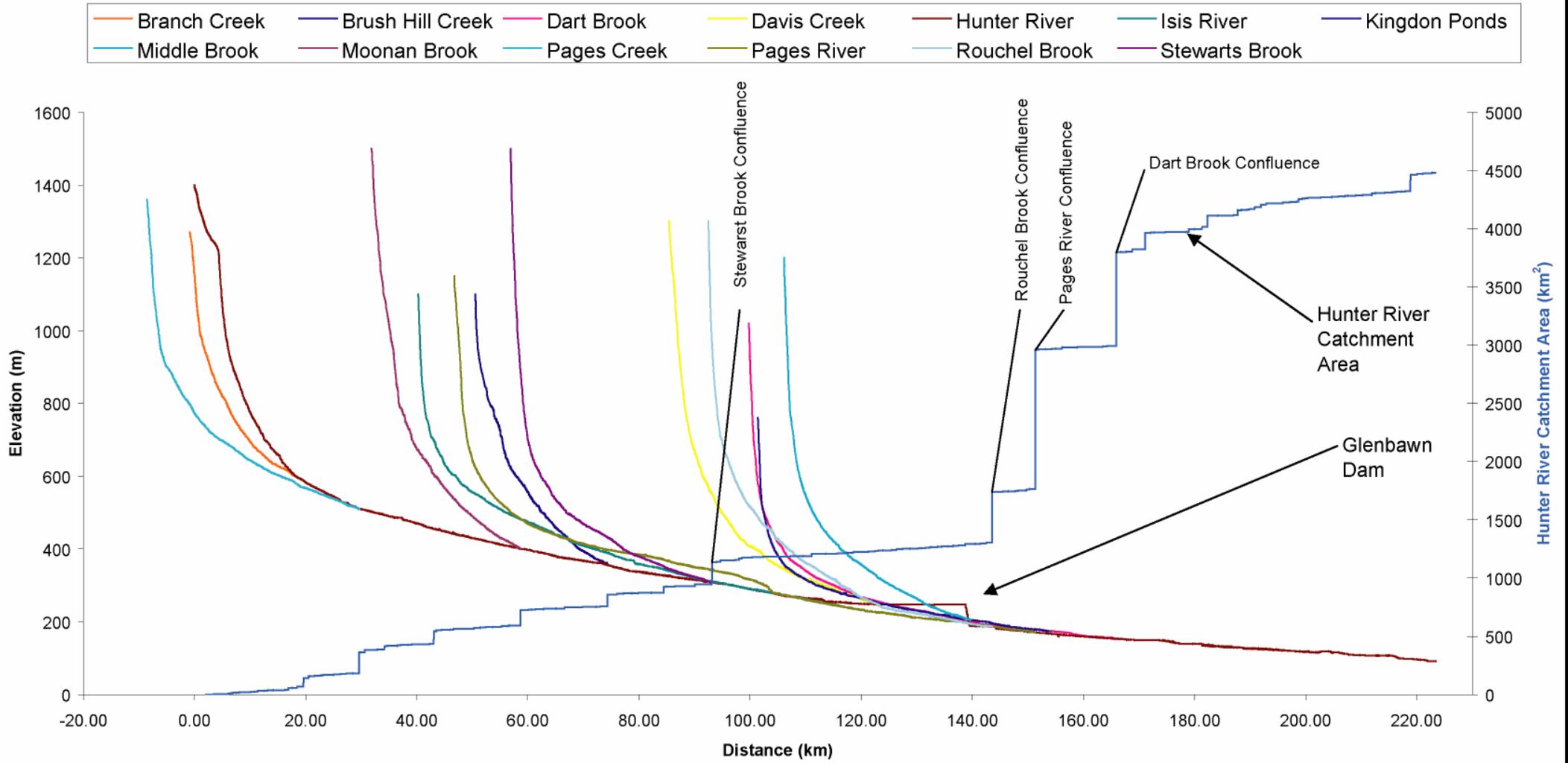


Figure 13-1: Longitudinal Profile Branch Creek

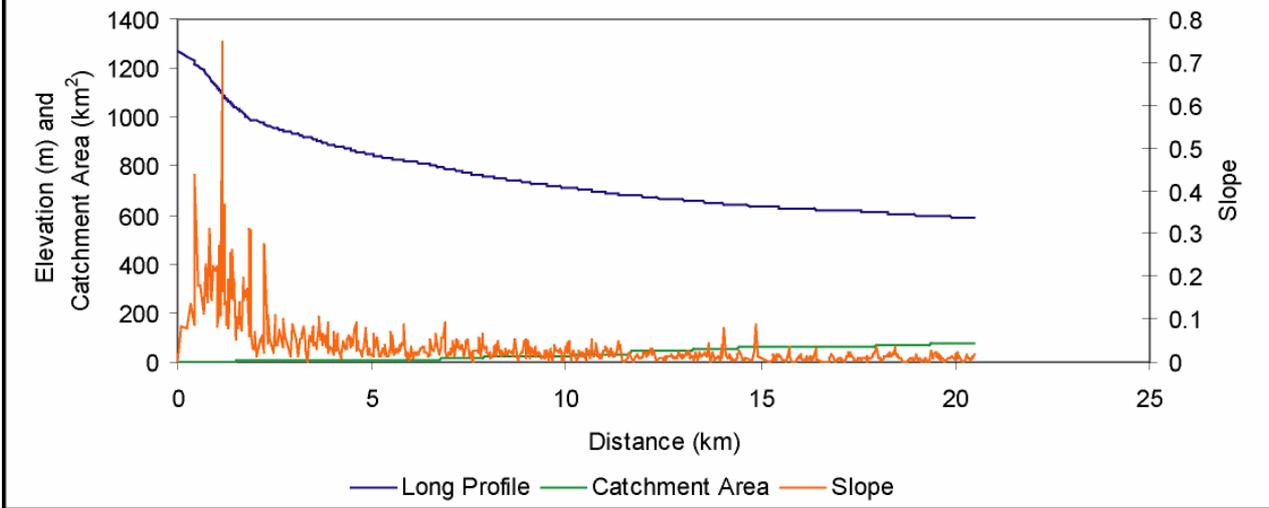


Figure 13-2: Longitudinal Profile Brush Hill Creek

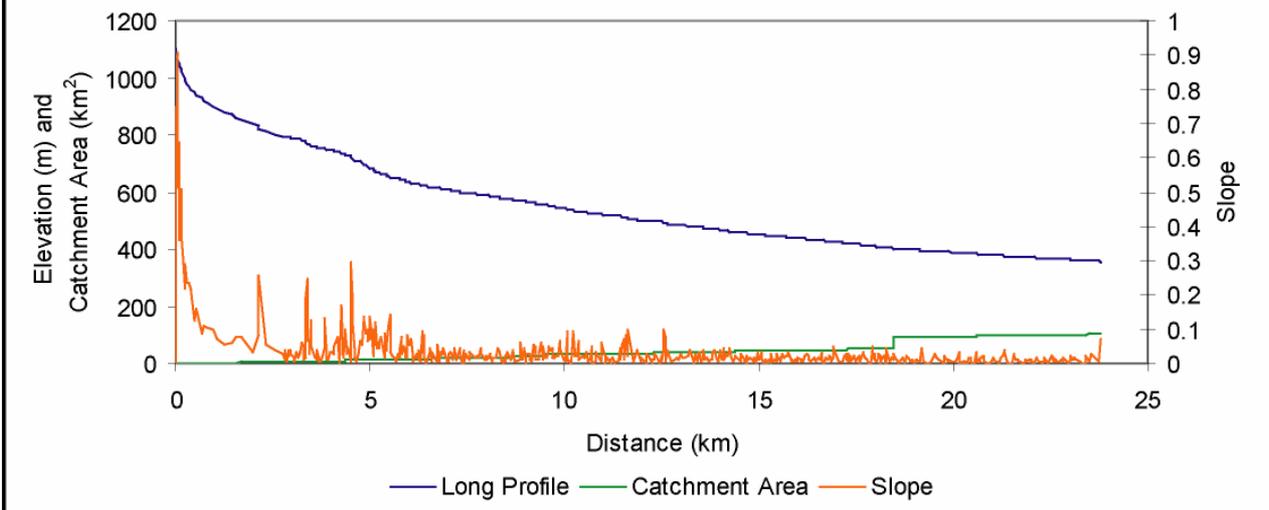


Figure 13-3: Longitudinal Profile Dart Brook

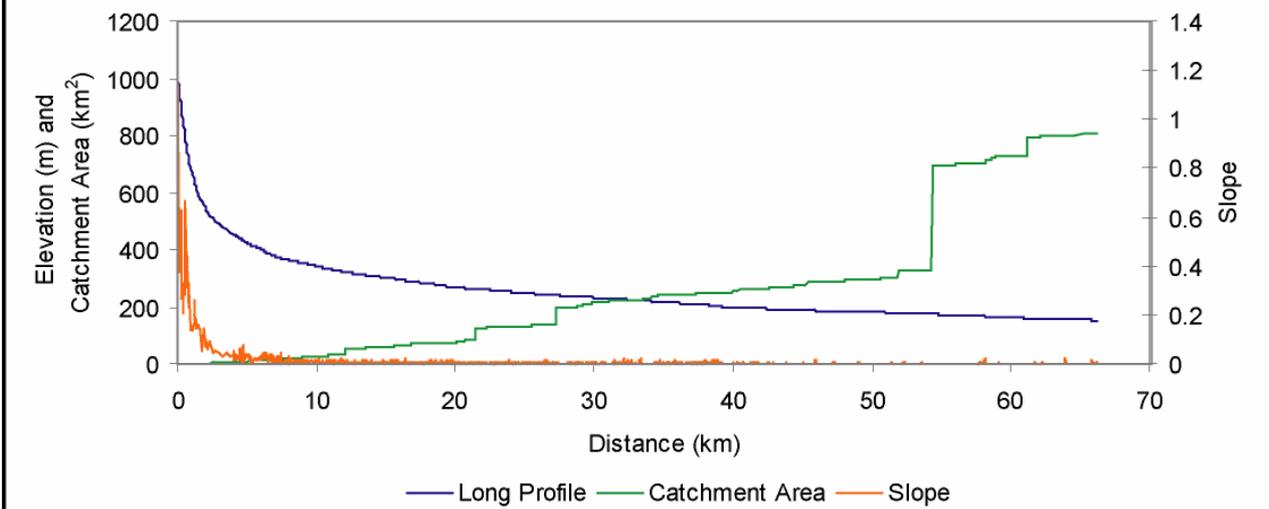


Figure 13-4: Longitudinal Profile Davis Creek

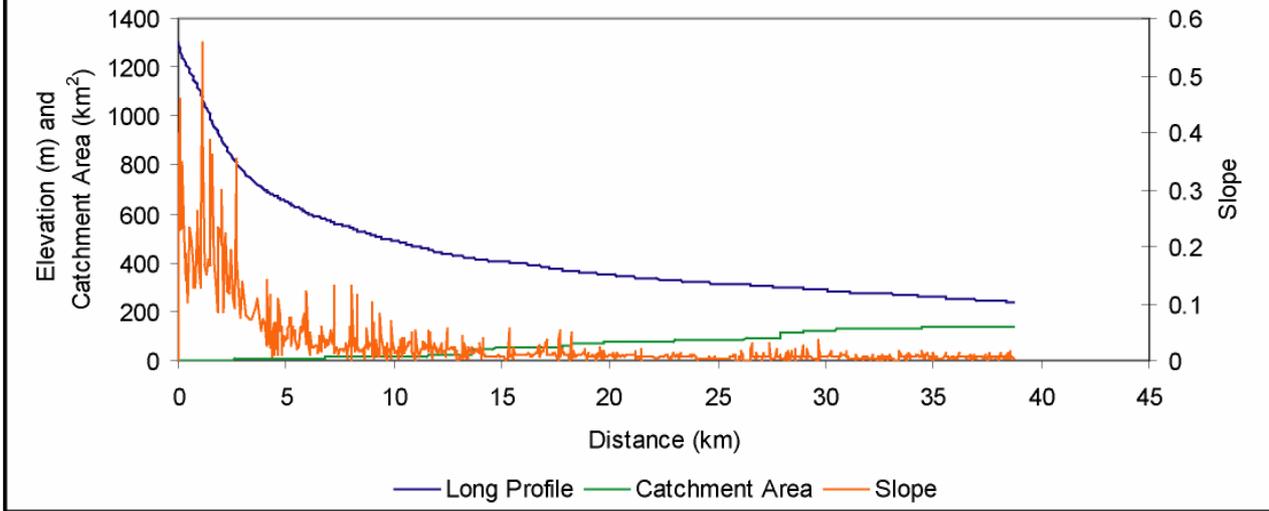


Figure 13-5: Longitudinal Profile Hunter River

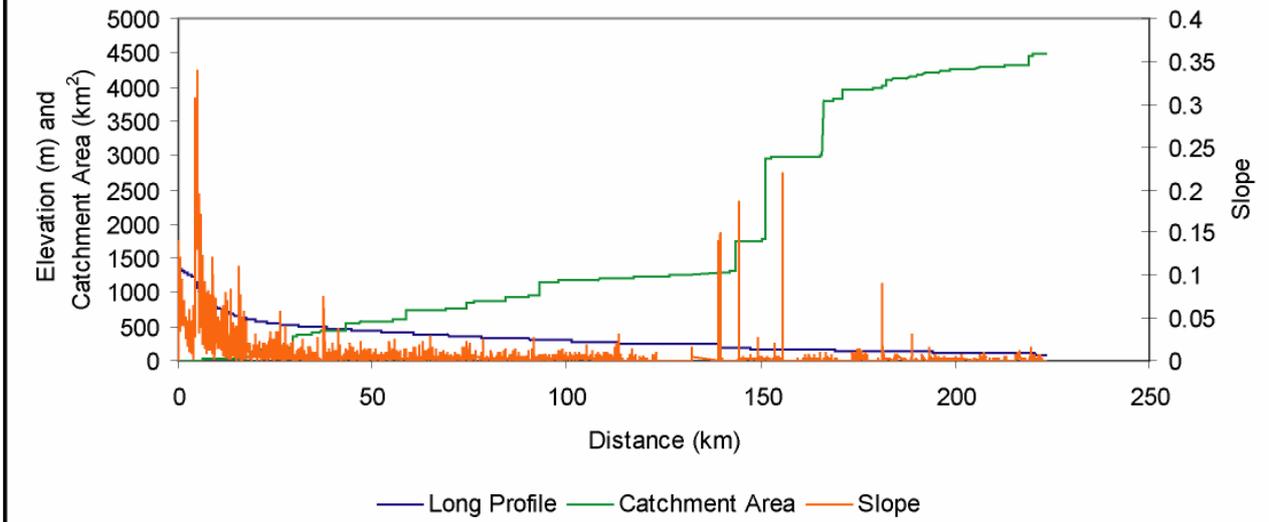


Figure 13-6: Longitudinal Profile Isis River

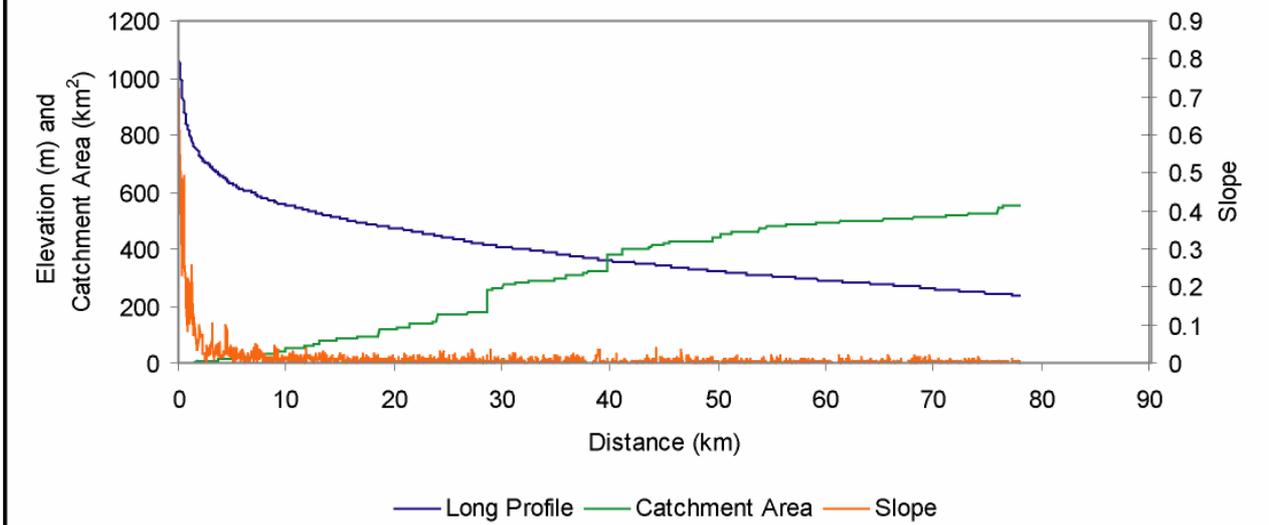


Figure 13-7: Longitudinal Profile Kingdon Ponds

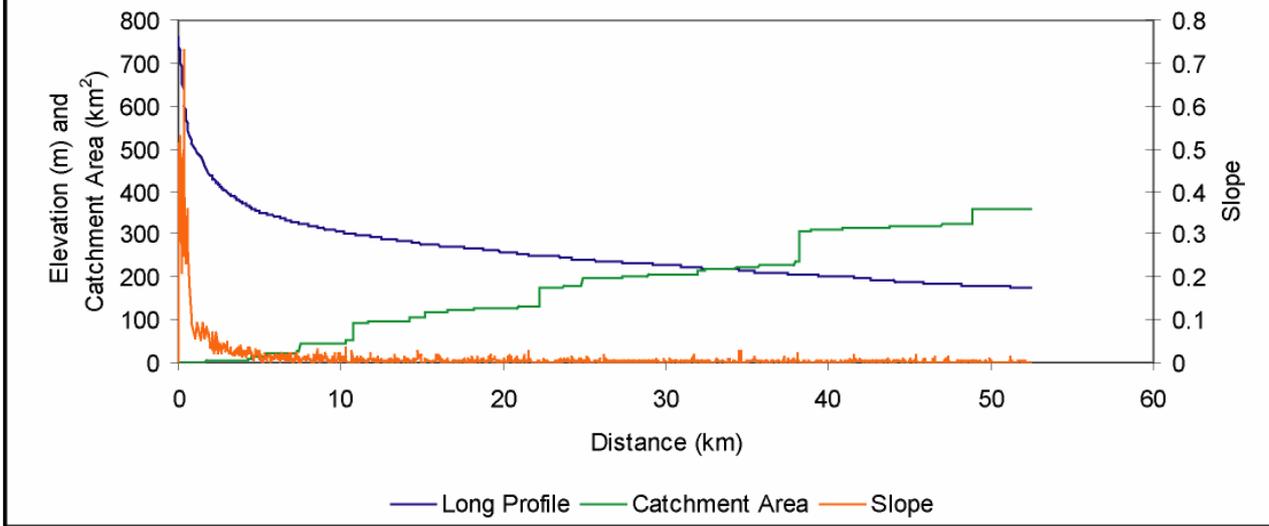


Figure 13-8: Longitudinal Profile Middle Brook

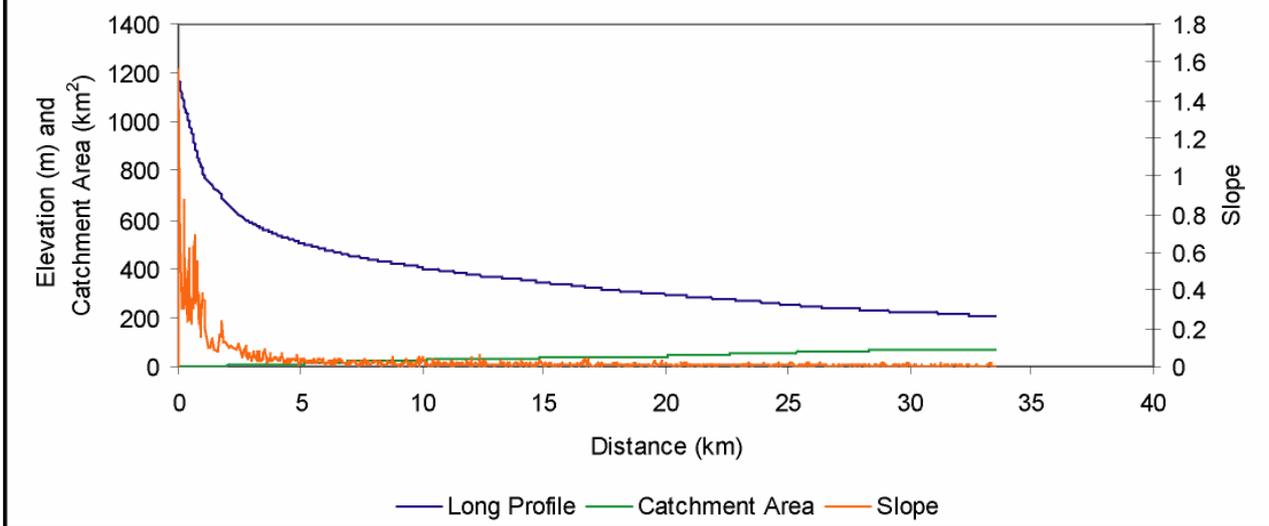


Figure 13-9: Longitudinal Profile Moonan Brook

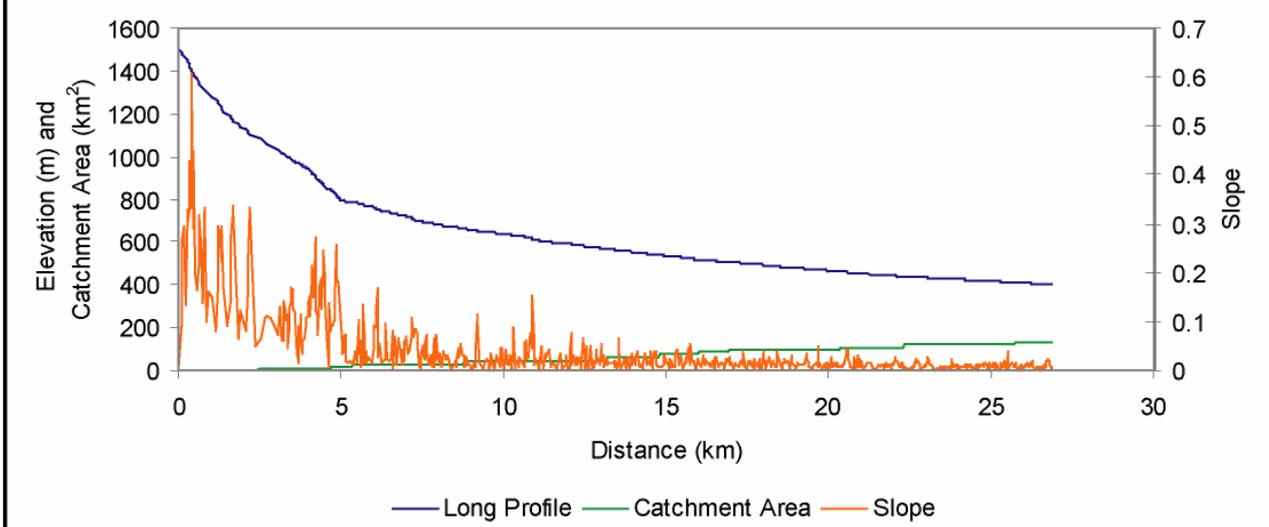
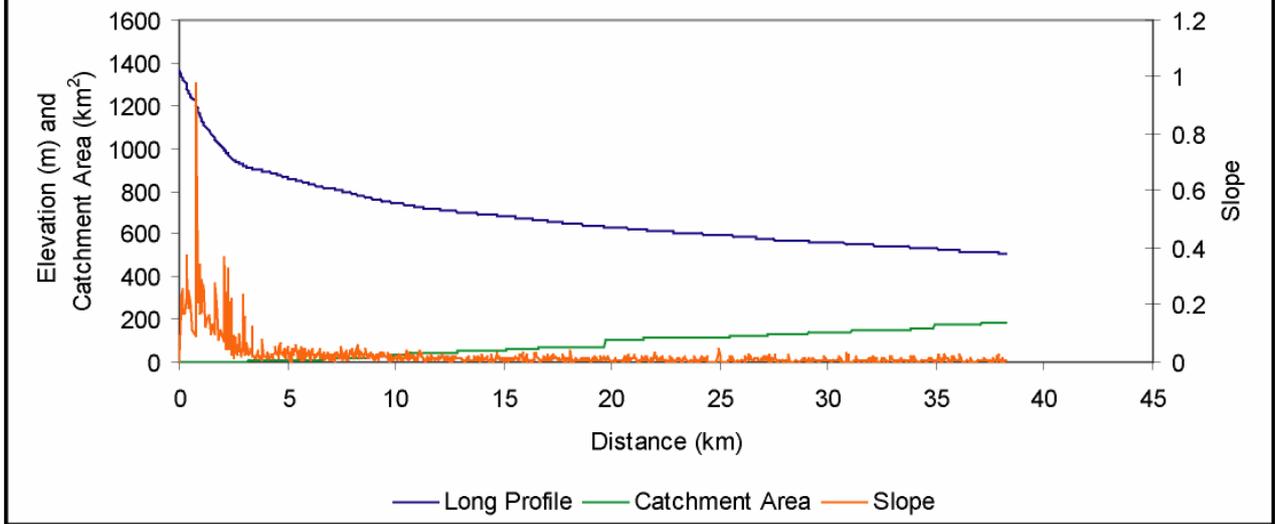
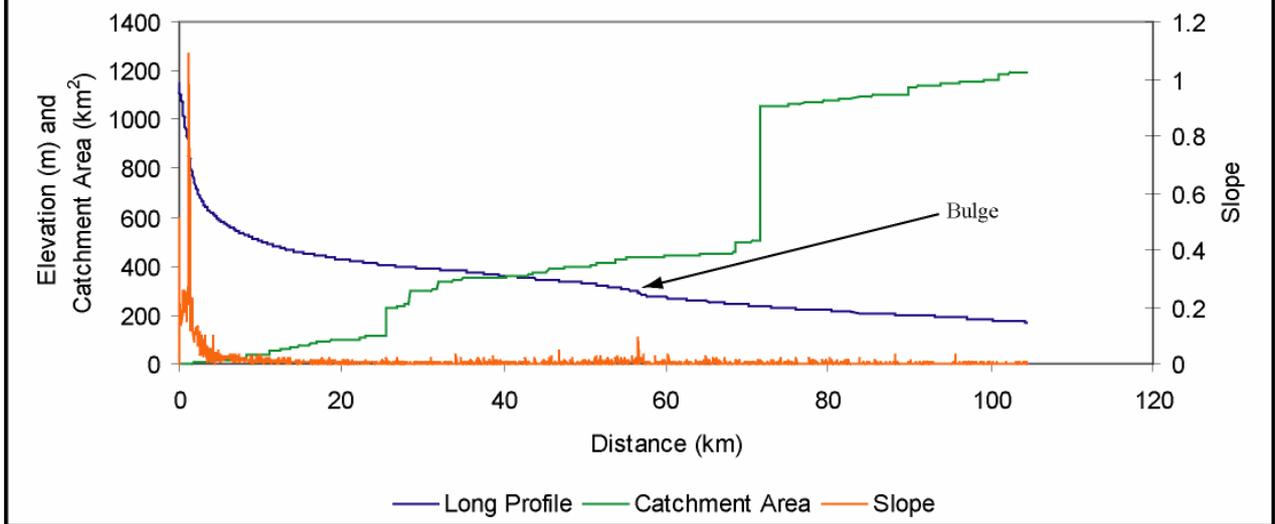


Figure 13-10: Longitudinal Profile Pages Creek



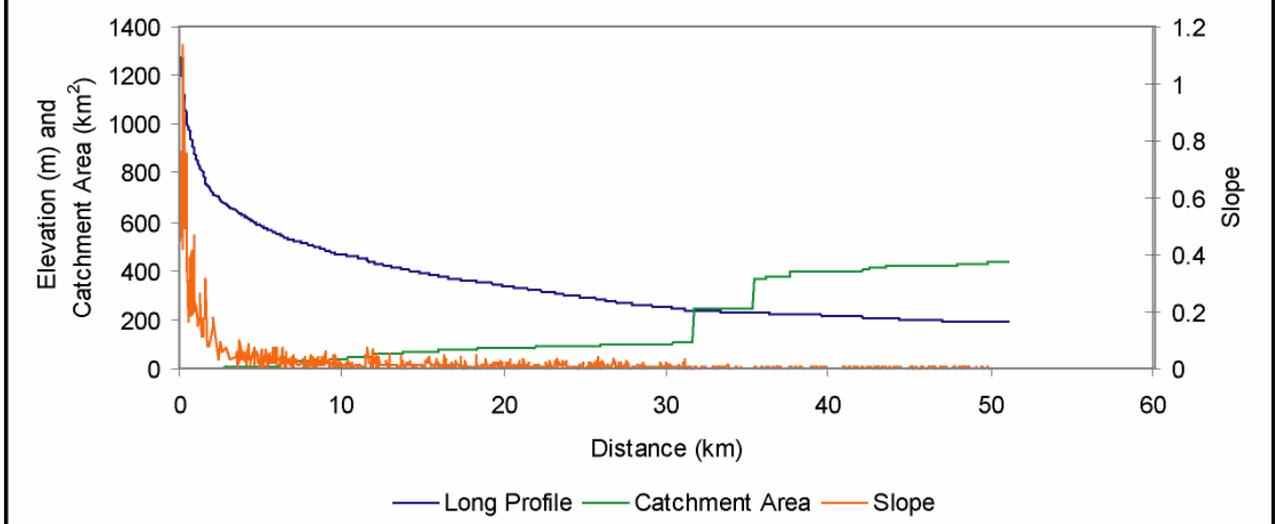
— Long Profile — Catchment Area — Slope

Figure 13-11: Longitudinal Profile Pages River

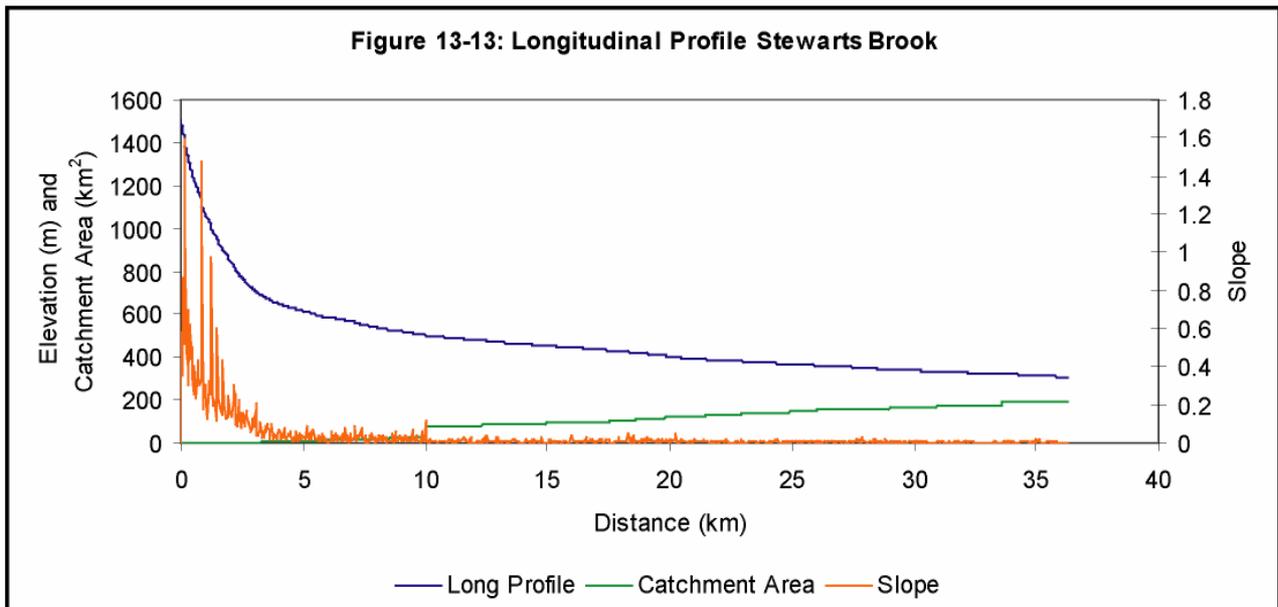


— Long Profile — Catchment Area — Slope

Figure 13-12: Longitudinal Profile Rouchel Brook



— Long Profile — Catchment Area — Slope



In general, the tributaries that flow into the upper sections of the Hunter River have short, relatively steep profiles and drain the steeper Plateau Slopes country. The tributaries that flow into the lower sections of the Hunter River have longer, shallower profiles and drain large areas of the Rugged and Hilly and Undulating Plain landscape units.

The upper sections of all rivers, except the Hunter, are within the Plateau Slopes landscape unit and have eroded deeply into the slopes of the remnant plateau. The shape of the Hunter River varies slightly as its headwaters are within the Remnant Plateau landscape unit. Along the Upper Hunter trunk stream, the slope decreases over the first 4 km as the river crosses the remnant plateau, slope then increases as the river plunges over the edge of the plateau into the Plateau Slopes landscape unit. This can be seen on the longitudinal profile as one small concave-up section at the start of the profile and another larger concave-up section that includes the remainder of the profile. At the base of the Plateau Slopes landscape unit a gradual decrease in slope is transitional to the Rugged and Hilly landscape unit.

The only other longitudinal profile with variability in its shape is the Pages River. A distinct ‘bulge’ occurs at around the 280 m elevation mark. This ‘bulge’ represents the downstream end of the gorge that occurs along middle reaches of this river.

3.1.5 Climate of the Hunter Catchment

3.1.5.1 Temperature and humidity

Temperature in the Lower Hunter is moderated by its proximity to the ocean. Summer extremes are often reduced by south-easterly sea breeze flow. The moderating effects of a sea breeze front can, on occasion, penetrate inland as far as Scone. However, in the Upper Hunter during daytime temperatures exceeding 40°C are fairly common. Winter temperature extremes are also mitigated by a coastal influence in the lower valley. Due to the heat storage capacity of the ocean, winter minimums proximal to the coast are rarely under 7°C. However, in the Upper Hunter, winter temperatures below zero are commonplace.

Like temperature, humidity is strongly influenced by proximity to the coast. Higher overall humidity along the coast reflects available moisture from the ocean. Hence, at locations further inland such as the Upper Hunter, humidity is typically lower with average summer values below 50%.

On occasion during the summer months, a large slow-moving pool of high pressure centred in the Tasman Sea, extending into the arid centre of the continent generates conditions of very low humidity (<15%) and hot north-westerly winds. This phenomenon, particularly when associated with a passing cold front (intensifying wind speeds) can establish conditions of extreme bushfire weather.

3.1.5.2 Wind

The Upper Hunter Valley, like much of the earth's surface is affected by seasonal, synoptic-scale circulation patterns and locally generated winds. Synoptic scale processes refer to large scale circulation and its influence on regional wind speed and direction. An important example includes the passage of cold fronts. At mid latitudes, such as the Hunter, synoptic weather patterns typically migrate west to east. Pre-frontal air is directed from the northwest, pushed along parallel to the leading edge of the colder, denser air mass, intensifying in speed closer to the pressure boundary. A rapid wind-shift to a south-westerly direction announces the arrival of the front, followed by a gradual shift to easing southerly winds. Due to the dominance of synoptic scale circulation, only under conditions of little regional wind can local-scale topographically controlled winds (anabatic & katabatic) and east-coast sea breeze circulation establish. Although subordinate to synoptic circulation, local winds still play an important role in mitigating summer temperature extremes in the middle and upper Hunter.

3.1.5.3 Rainfall and severe storms

Rainfall in the Upper Hunter, around Muswellbrook averages 600 mm/yr. For the valley as a whole there is a rainfall gradient from the coast with its average of around 1,100 mm/yr due to the influence of ocean, dropping to 550 mm/yr at Merriwa and Murrurundi. The Barrington Tops and north-eastern mountains intercept moist coastal inflow providing the regions highest overall rainfall with annual averages exceeding 1,400 mm/yr. There is a pronounced seasonal aspect to rainfall in the Upper Hunter with the greatest falls in the summer months due in a large part to thunderstorms.

The Hunter region has one of the highest occurrences of severe thunderstorms in Australia. Storms are formed by a range of processes that are responsible for inducing atmospheric instability and convection. A passing cold front, displacing lower-level moist air upwards, and broad low pressure troughs often result in mesoscale regions of severe storm development during the warmer months. Storm formation most often occurs in the afternoon due to the steeper vertical temperature gradient

resulting from terrestrial heating. Most individual storm-cells last for little more than an hour, disintegrating as the downdraft associated with precipitation intercepts and extinguishes the driving updraft. On occasion however, a suite of atmospheric conditions allow for a discrete, self-reinforcing pattern of circulation to develop whereby an individual storm cell, termed a supercell or mesocyclone, can persist for up to 5 hours. These rare events produce some of the most destructive weather effects known, such as heavy rain, flash-flooding, large hail, wind gusts exceeding 200km/hr and on occasion, tornadoes. One such storm, at Singleton in December 1996, produced 11cm-sized hail, seriously injured 6 people and caused damage in the millions. The vertical wind speeds required for hail of this size to form within the storms core exceed 300km/hr.

3.1.5.4 Flood weather

Two distinct weather patterns produce widespread heavy rain responsible for flooding in the Hunter Valley. Coastally generated synoptic scale circulation such as east coast extra-tropical cyclones are a recurrent cause of moderate to heavy flooding. Due to the proximity of the ocean and the orographic influence of the eastern highlands, the eastern subcatchments of the Hunter (e.g. Allyn, Paterson, Williams, Wollombi) tend to receive the highest rainfall from this type of weather system. East coast lows are most frequent during the cooler months when the land-sea temperature gradient is at its most extreme. The catastrophic flood of June 1949 along the Wollombi was triggered from a coastal cyclonic system.

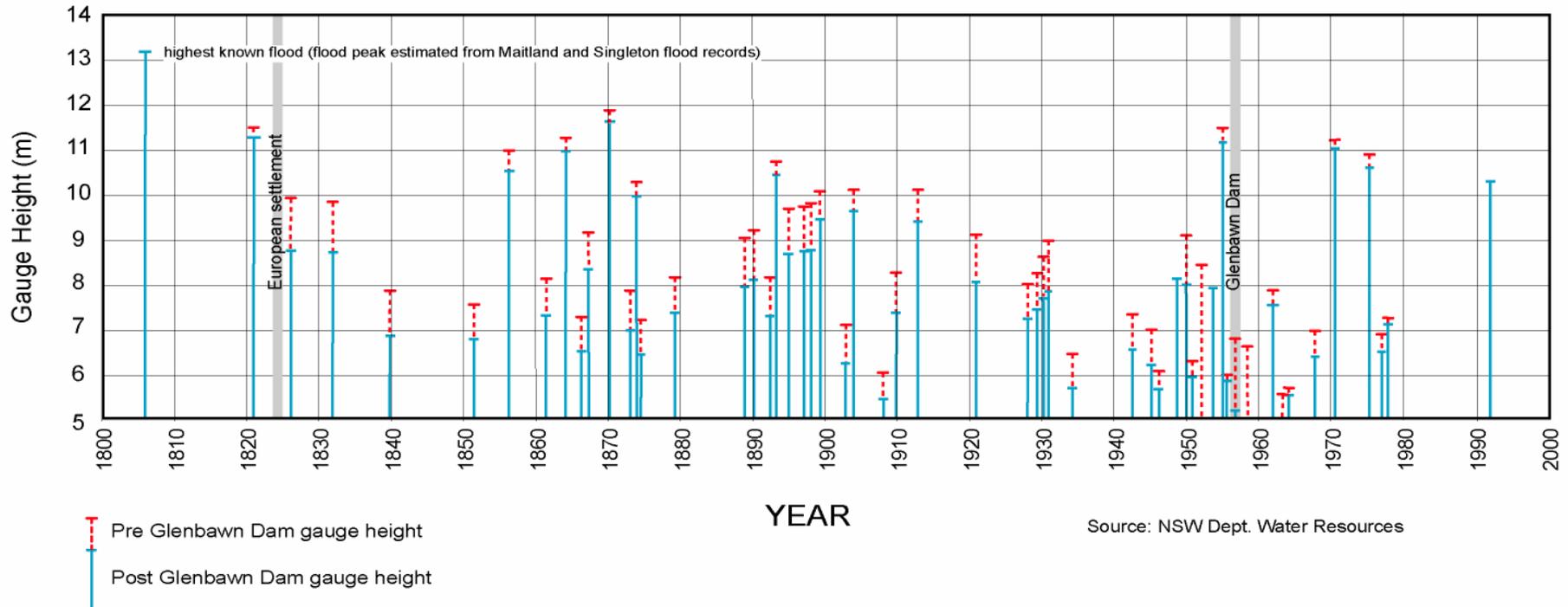
The second form of weather pattern responsible for flooding in the Hunter Valley involves the penetration of moist equatorial air inland to higher latitudes. Lifting of this air mass due to its interception with cooler, dense coastal inflow produces intense regional precipitation. This phenomenon tends to occur during the warmer months when the intertropical convergence zone is centred over northern Australia. The second largest, but most destructive flood on record in the Hunter occurred in February 1955 as a result of these meteorological conditions.

3.1.6 Hydrology of the Upper Hunter Catchment

3.1.6.1 Floods in the Upper Hunter Catchment

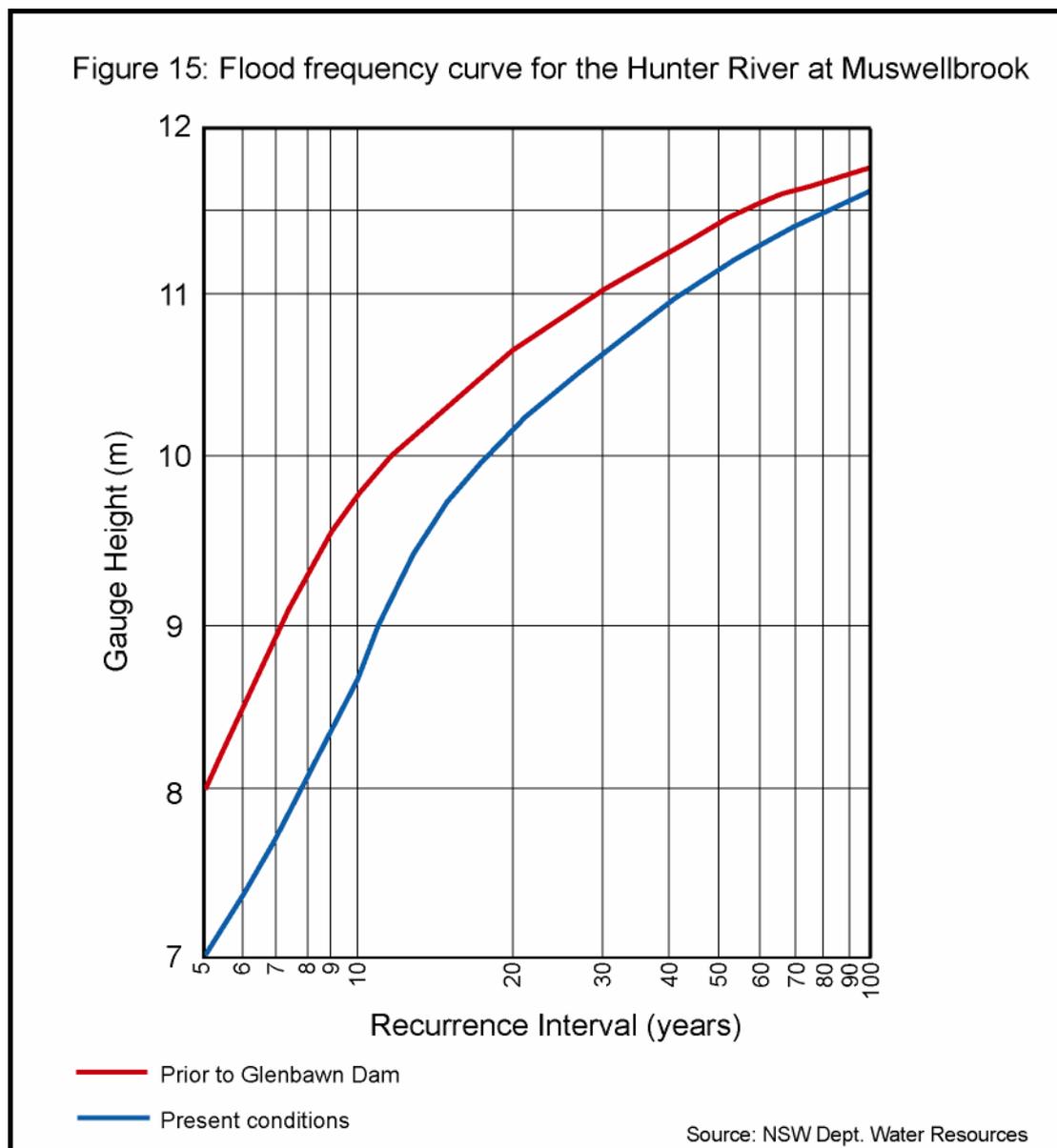
Since European settlement, 6 floods have reached heights of over 11 metres at Muswellbrook and a further 8 have exceeded the critical (bankfull) height of 10 metres (Figure 14). It is important to note however, that since European settlement the bankfull condition of the river at Muswellbrook has changed substantially (see later sections), meaning that floods that once went overbank now tend to be contained within an over-enlarged channel. Figure 14 shows the history of flood events at Muswellbrook. A series of large floods characterize the period from 1854-1875 and 1893-1913. These were interspersed with recurrent floods of small-moderate magnitude. An extensive periods of no major flooding, extending up to 42 years, was recorded in the first few decades of the 20th Century.

Figure 14: The History of Flood Heights at Muswellbrook.



The largest flood on record at Muswellbrook, since European settlement, occurred in 1870. However, the 1955 flood was considered more destructive, as parts of Muswellbrook were severely damaged (see later section). Since the construction of Glenbawn Dam (1957) the number of small-moderate flood events has decreased significantly. These flows are captured within Glenbawn Dam. Large floods however, did occur in 1971, 1976 and 1992 when flows along tributary systems not captured by Glenbawn produced overbank flooding at Muswellbrook. The last near-bankfull event occurred in 2000.

At bankfull, flow volume at the Muswellbrook gauge is around 175,000 ML/d. Prior to the construction of Glenbawn Dam, the floodplain became inundated at Muswellbrook in a 1 in 11 year event or greater (figure 15). The construction of Glenbawn Dam has resulted in the recurrence of overbank events decrease to a 1 in 19 year event (figure 15). Of interest, a 1 in 20 year flood (10.17m) is only 1.49 metres lower than a 1 in 100 year flood (11.66m) at the Muswellbrook gauge.



3.1.6.2 *The flood of February 1955*

The 1955 flood is a landmark event in the post-European history of the Hunter Valley. Rainfall of unprecedented intensity (around 270mm) fell over the entire catchment from Wednesday February 23rd to Sunday 27th February. A catastrophic flood of around 1¼ times the mean annual discharge for the catchment was generated. Peak discharge at Maitland was around 110 000m³/s with a maximum height of 12.2m. Peak discharge at Muswellbrook was more than 42 000m³/s, reaching a height of 11.66m at 11:30am on 24th February. A second smaller peak at Muswellbrook of 9.9m was recorded two days later at 8:30am on 26th February.

Fourteen lives were lost; over 5000 homes were inundated in towns along the river, leaving 20 000 homeless. At Maitland more than 40 homes were swept away in floodwaters, a further 103 were beyond repair and later demolished. At Muswellbrook, 370 homes were inundated, particularly along lower Hill, Brook, Ford and Scott Streets. South Muswellbrook was isolated from the rest of town due to water backing up Muscle Creek against the main stream, flooding the subway to around 1m below the railway bridge.

The intense low pressure cell responsible for the 1955 flood was centred over Dubbo in central western NSW. It has been estimated that if the storms core had been over the Hunter, up to 25% more rain may have fallen within the catchment. There is evidence that a flood larger than that of February 1955 may have occurred in the early 19th Century. The explorer, Allan Cunningham noted flood debris 50-60ft above river height near Denman in April 1825.

3.1.6.3 *Glenbawn Dam*

Glenbawn Dam is located on the Hunter River upstream of the Rouchel Brook confluence, 14 km east of Scone. A suitable site was selected in 1939, construction commenced in 1947. Glenbawn was officially opened in 1957 and began holding water in 1958. The dam is constructed of rolled earth-fill and rock. The original aim was to provide assured flows for agricultural and domestic purposes and for flood mitigation. The catchment area above Glenbawn is 1295 km², around 6% of the entire Hunter catchment and around a third of the Upper Hunter Catchment. Originally, of the 361 000 ML capacity, 24 650 ML was given as dead storage for sediment, 228 000 ML for water conservation and 133 000 ML for flood mitigation. The maximum outlet capacity is 7340 ML/d (Erskine, 1984).

A constant level of flow is maintained to the Hunter River, so that at least 50 ML/d reaches Maitland (Laurie *et al.*, 1979). The dam has a sediment trap efficiency of around 98.9%, with 100% trap efficiency for sand and gravel (Erskine, 1984).

The reduction in flood magnitude is estimated to be up to 0.5m at Muswellbrook, with negligible effect at Singleton. Most flows greater than 8 000 ML/d have been eliminated, however, extreme flood events are likely to be little effected due to the large area (~70%) of unregulated catchment above Muswellbrook. Flows greater than 700 ML/d have been reduced and flows less than 700 ML/d have increased in summer and decreased in winter (Erskine, 1984). At Muswellbrook, the daily flow is now less than 100 ML/day 11% of the time, compared to 22% of the time under conditions of no regulation (DLWC, 2000)

The capacity of the dam was increased to 750 000 ML in the late 1980s, making a further 48500 ML/year of shelf water available, with 120 000 ML flood storage (DLWC, 2000) A further addition included a small hydroelectric power station. The spillway capacity is 466 000 ML/day (495 000 ML/day aux). Water is also diverted into the dam from the Manning Valley by Macquarie Generation in the Barnard River Diversion Scheme. This has been designed to ensure adequate

supplies to Bayswater and Liddell Power stations. The scheme can divert 260 ML/day, or 20 000ML/year (DLWC, 2000).

3.1.6.4 Catchment area-discharge relationships for the Hunter Catchment

Catchment area-discharge relationships were constructed for the Hunter Valley using available gauge records from across the catchment. These gauges with a continuous record of greater than 10 years were extracted and catchment area-discharge relationships plotted. While very crude, these estimates allow analysis of gross stream power along river courses. We suggest that caution is exercised when using these numbers as the hydrological conditions of the Upper Hunter Catchment have been ‘summarised’ within the Hunter Valley plots. This analysis should be considered a guide only, from which generalized patterns can be extracted.

3.1.7 The character of the Hunter River at the time of European settlement

The Hunter Valley was one of the earliest regions in Australia explored and settled by Europeans. Valuable insight into the character of the river and changes observed over the decades following settlement has been catalogued in the diaries and records of those people.

3.1.7.1 Riparian vegetation

The bulk of the historical record refers to the Lower Hunter, particularly the estuary from Newcastle to immediately upstream of Maitland. The first Europeans that ventured up the river were confronted by a wall of rainforest upon first disembarking from their boats. Descriptions of this forest refer to massive red cedars (*Toona ciliata*) up to 27ft (8m) in circumference with the main trunk more than 50ft (15m) in height (Rusden, in Wood, 1972), a triangular buttressed fig at Maitland having a perimeter at its base of more than 60ft (18m) (Breton, in Wood, 1972) and tall smooth barked gums reaching high above the canopy. Reference is made to stinging trees, vines and epiphytes and “acre-wide camps of flying-foxes...hanging like large loathsome leaves from the high branches” (Wood, 1972, 2). In the cool, scattered light at the surface, ferns, mosses and mushrooms grew. The explorer Henry Dangar often referred to the dense brush along the Lower Hunter, forming an almost impassable palisade, preventing access to the high banks behind.

For the most part, this dense gallery forest was restricted to the river banks and land immediately adjoining. However, at Wallis and Paterson’s Plains (near Maitland) rainforest occupied most of the floodplain. George Boyle White commented in 1833 that to connect the Government township (East Maitland) with the Paterson River it would be necessary to cut through 2-3 miles of ‘brush’ from the Hunter River crossing (Wood, 1972). The language used in these early European accounts suggests substantially more than a passing appreciation for the lowland rainforest; a sense of wonderment and reverence is imparted. Although there was widespread acknowledgement of the forests beauty, it was not, however, sufficient to warrant its preservation. The great red cedars were soon identified as a valuable commodity as too was the rich floodplain alluvium. Clearing began in earnest.

European settlement of Paterson’s Plains began in 1813 with several settlers establishing farms upon the alluvial lowlands. The river flats were opened up into 30 acre lots and by 1820 there were 12 farms on Paterson’s Plains and 11 on Wallis Plains. An anonymous paper written in 1830 remarked that 12 of the best behaved convicts were permitted to occupy land at Wallis Plains conditional to their supply of a specified and continuing quantity of cedar to the Government. Typically, gangs of 30 convicts were tasked to clear 100 trees a month and get the logs to water. These were formed into rafts and floated to Newcastle. The journey from Wallis Plains to

Newcastle usually took around 8 days. Cedar parties ventured up the Hunter past the tidal limit at Wallis and Paterson's Plains and were cutting timber as far up the river as Melville. Although cedar getters were extracting logs from the headwaters of Dart Brook, Pages River and the southern slopes of the Liverpool Range, cedar appears not to have grown along the river banks above Glendon, around 42km (River Length) upstream of Maitland (Scott, 1825, in Wood, 1972).

The character of riparian vegetation in the Upper Hunter was briefly described by the explorer Allan Cunningham. In April 1825 he climbed Ogilvie's Hill, providing a commanding view of the Goulburn and Upper Hunter River and noted that the river was marked by a dark line of trees (Wood, 1972). In 1826, Peter Cunningham ventured along Twickenham Meadows, the land adjoining the Hunter between Denman and Muswellbrook "The flat alluvial lands spread out before you are matted with luxuriant herbage. Branching evergreens are scattered singly or in clumps, with the river winding through the midst; its steep and grassy banks bordered with a deep green fringe of dark foliated swamp-oaks" (Cunningham, 1826). These descriptions are consistent with a riparian corridor dominated by *Casuarina spp.*

The testimony from those who farmed the narrow strip of Hunter floodplain recorded in the Moriarty Report of 1870 (arising from the Colonial Commission into Floods in the Hunter), offers a more detailed account of early 19th Century vegetation and channel conditions than from the diaries of Cunningham and Danger. A number of witnesses giving evidence for the Commission were among the first Europeans to take up land by the river and provide a telling record of change over the decades following settlement. *Casuarinas*, noted as growing in abundance along the river, appear to have been recolonising sites of localised erosion in the early 1830s, possibly as a result of the large flood of March 1832. Robert Scobie described a thick growth of *Casuarina* seedlings and small trees on the banks and bed of the river when he first settled by the Hunter in 1839, upstream of Maitland. By 1857 these had grown to trees of 40-50ft tall, prior to their removal in the catastrophic flood of that year. The regrowth trapped woody debris forming a sizable dam, diverting flow and causing localised erosion. Alexander Mc'Dougall, noted that oaks (*Casuarina spp.*) only began to grow in the channel and on a 'beach' next to his property after the 1832 flood.

Upstream of Maitland repeated reference is made to a thick 'scrub', quite distinct from *Casuarina* forest, occupying bights (John Eckford) or false-shelves (John Brown) closer to the level of low flow. The scrub was likened to the extensive brush or lowland rainforest of the Maitland area, although around Singleton was only found growing on pockets of land closer to water level. The brush-land around Singleton was progressively cleared from the early 1820s and the land farmed.

3.1.7.2 Channel morphology

Although accounts of the morphology of the Hunter River above its estuary at the time of first settlement are limited, there are several descriptions from early European explorers that allow a reasonable picture to be established.

From many accounts, it is likely that the channel was considerably narrower. There were gravel bars and bedrock steps (cascades). The upper limit of the estuary was marked by a conspicuous gravel bar called 'the falls' which was used as a crossing point for many years prior to the construction of a bridge (Wood, 1972). Henry Dangar camped by the river in October 1825, eight kilometres downstream from the confluence with the Goulburn River. At this point the river dropped over a bedrock step around one metre high (Wood, 1972). Allan Cunningham (April 1825) described a river 50 metres wide with steep banks, 3 metres deep at a camp eight kilometres upstream from the junction of the Goulburn River (Wood, 1972). The following day after climbing Ogilvie's Hill, Cunningham descended again to the river some kilometres upstream. The river was a similar width, around 45m, and too deep to cross. Cunningham was required to skirt the bank for

around half a kilometre in order to locate an appropriate gravel bar to enable crossing (Wood, 1972). The surgeon Peter Cunningham made passing reference to the character of the river between Maitland and Muswellbrook in 1826. "From Wallis Plains upwards to Twickenham Meadows, the country gradually rises in elevation, but so imperceptibly, that you are only made aware of it by the numerous rapids you perceive in the river as you pass along"(Cunningham, 1826, 80).

The bights and false-shelves referred to in the Moriarty Report appear consistent with in-channel features such as benches and ledges. These are described as being no more than '30 or 40 rods' (150-200m) by John Brown and 'few and far between' around Singleton (Brown, in Moriarty, 1870, 56). It is uncertain whether the scrub or brush mantling these features were examples of successional communities and hence suggestive of recent disturbance or were relatively stable. However, from all reports, the thick brush at these locations predated European settlement. As well as bank attached in-channel geomorphic features such as benches and ledges, reference is made to islands or mid-channel bars. Similar to false-shelves or bights, islands are described as being well vegetated at the time of settlement.

3.1.7.3 Post-European change

In 1825 Allan Cunningham recorded a channel width of around 50 metres near Denman. At this location the channel is currently around 150 metres wide, a fourfold increase (Gardiner, 1991). The mass wasting of soil from river banks along the Hunter through the latter part of the 19th and early 20th Centuries is well documented. Concern about riparian degradation, particularly bank erosion generated considerable interest, precipitating a number of government reports including the Moriarty Report of 1870. Witness testimony from this report is compelling, providing consistent and graphic descriptions of the rapid acceleration of erosion from a restricted, localised occurrence in the 1830s to a defining feature of the river by the 1860s.

Early European accounts of erosion and in-stream sedimentation from those farming the river margins from the early 1830s described only relatively small, local events, possibly an artefact of the flood of 1832. However, that same flood also left 'great holes' in the landscape at Glenlyddon, sufficient to force the abandonment of the land at that location (Munro, in Moriarty, 1870, 58). Nevertheless, most accounts from the period of early settlement describe grassed or thickly vegetated banks of brush or *Casuarina* with little, if any, obvious erosion.

After the flood of 1832, there were several smaller freshes, one in 1840 and again in 1851 and then a series of catastrophic floods through the decade 1857-1867. Descriptions of the river began to change dramatically through this time. William Copeland Leslie, a Singleton resident from the early 1840s reported. "Opposite my own door half an acre of land has fallen in, and part of the bed of the river; near the opposite bank was a road where you could have driven horses and carts. There has been an immense increase in the size of the channel". In reference to the flood of 1867, Singleton resident, William Dangar described the changes to the river along his property; "I lost a great deal of lucerne that I had sown, and the washing away of fences of course is a great loss, as well as the landslips on the banks of the river. In some instances several acres gone. I know one place where seven or eight acres went"

Some of the earliest photos taken along the Hunter at Singleton around 45 years after first settlement (plate 1) provide an important visual record, adding dimension to the verbal accounts of William Copeland Leslie and William Dangar. Changes recorded in a further photo taken 5 years later (plate 2) from almost an identical location provide a clear indication of the pace of bank collapse and removal of sediment. A striking feature of these photographs is the lack of riparian vegetation.

Plate 1: Hunter River at Singleton 1861

Plate 1: Hunter River at Singleton 1866

Plate 1: Hunter River at Singleton 1963

In the five years between these photographs, bank erosion markedly increased, evidenced from a grassed ledge well below half a metre in height in the foreground (plate 1) to an active, eroding scarp of several metres (plate 2). Looking beyond the bridge (upstream), a large section of bank or a bench on the right bank (left bank in photo) clearly visible in 1861 has been removed by 1866. The channel at Singleton Railway Bridge has widened considerably since the 1860s (see plate 3 & figure 14). In 1958, in a paper published in the *Journal of the Institute of Engineers, Australia, A.F.* Reddock wrote “...another threat to a railway bridge is evident at Singleton where the river is actively eroding its right bank immediately upstream of that bridge, whilst the town water supply pumping station which is located in the immediate vicinity of this bridge has also been endangered by erosion of the river bank which became active during the large flood flow in February, 1955” (Reddock 1958, 243).

Accounts of eroding banks submitted as evidence for the Moriarty Report are only equalled or exceeded by the descriptions of vast amounts of sedimentation occurring along the banks, within the channel and across the floodplain. John Nowlan offers clear insight to the pace of sedimentation upon the alluvial lowlands around Maitland in the mid 19th century; “At this particular place within the last thirteen years two post and rail fences (two or three rail fences) have been buried, but it has not all been covered by rich alluvial deposit. A portion of the deposit was sand, and this last flood again has left a great deal of good deposit. In 1857 the floods left nearly all raw sand, but the grass crept over it. The 1857 floods covered one fence, and I thought that I would dig out the deposit, but I found that the labour was greater than the cost of splitting new stuff. We put up another fence above, level with the top of the post, and now that is covered” (Nowlan, in Moriarty, 1872, 72). The depth of sedimentation was later referred to as being over 2.5m.

Mr Alexander Wilkinson from the Maitland area described similar processes occurring as a result of the flood of 1864; “When we get the Goulburn River down in flood before the Upper Hunter comes,

we get nothing but sand. If you walk around Horseshoe Bend, you will see a deposit of 16 inches at least from the 1864 flood; and if you notice the bank of the river, you will see the layers of sand and mud which have been deposited from time to time, according to whether the flood came from the Upper Hunter or from the Goulburn River". Evidently, for the land owner, sediment deposition was something akin to a lottery, some sedimentation, typically by clean sand of little productive value, 'soured' the land, rendering it worthless, however, a handful of farmers reported deposits allowing for great increases in agricultural output.

3.1.8 Vegetation of the Hunter Valley

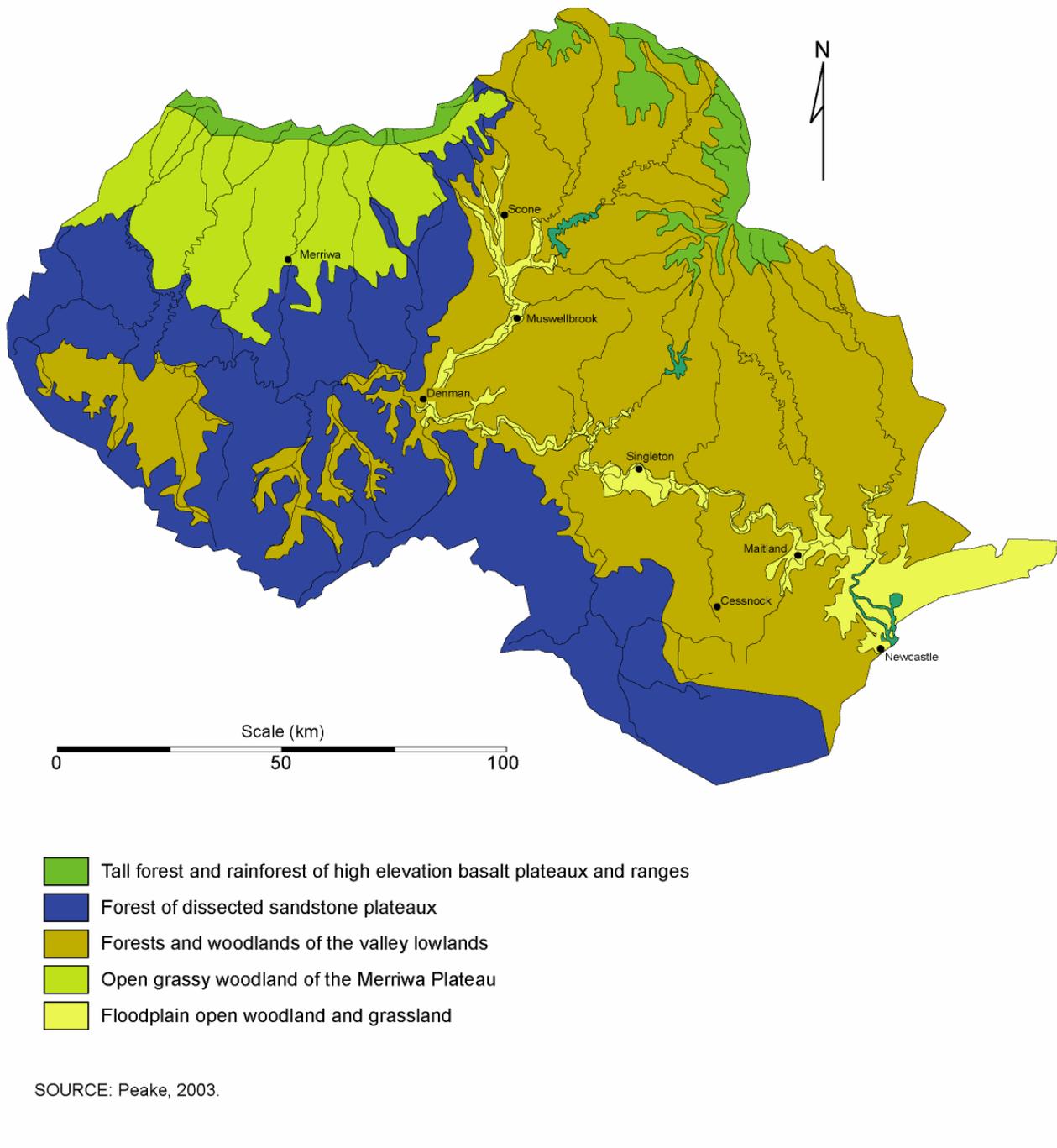
The Hunter Valley is floristically diverse. Due to the lack of a western escarpment and degree of penetration inland, the Hunter Valley marks both the most eastern and western extent of a significant number of plant species. Similarly, due to its unique geography, the Hunter also serves as a physical barrier between the floristic communities of the greater Sydney region and those of the north coast and adjacent ranges.

Vegetation communities mantling the rugged, dissected Triassic sandstone plateau in the south and west and high basalt capped ranges to the north and east have undergone substantially less post-European modification in comparison to changes wrought upon the valley floor. This is due, in a large part, to the physical inaccessibility of many of these landscapes, however, growing awareness of ecological value has seen around 430 000ha or 20% of the entire Hunter catchment formally protected for conservation purposes. There are 29 nature reserves and national parks within the catchment, two of the largest are the Wollomby/Yengo World Heritage Area in the south and Barrington Tops/Mt Royal National Park in the north. In contrast to the highlands around the catchment margin, only 0.7% (6200ha) of the valley lowlands and valley floor has been formally protected.

This is of particular importance given the extent of post-European change within these areas. Only around 20% of the original (pre-European) forest and woodland cover remains within the valley lowlands (Peake, 2003); there are few, if any, examples of remnant riparian forest.

The Hunter Valley can be broken into eight broad floristic groups, bearing a broad relationship to local geology and geomorphology. The five groups most significant to the Upper Hunter are outlined below (after Peake, 2003) and shown in figure 16.

FIGURE 16: VEGETATION OF THE HUNTER CATCHMENT



3.1.8.1 Forests and woodlands of the valley lowlands

There are a suite of different forest and woodland types mantling the rolling landscape of the valley lowlands. Open woodlands are often dominated by grey, white or slaty box (*Eucalyptus moluccana*, *E. albens*, *E. dawsonii*). *Corymbia maculata* (spotted gum) is common as both a forest remnant and thick regrowth, as too are the ironbarks, *Eucalyptus crebra* and *Eucalyptus fibrosa*. *Casuarina cunninghamiana* (river oak) is ubiquitous along creek-lines and water courses, replaced by

Casuarina glauca (swamp oak) in saline areas. Scattered pockets of dry rainforest are found on more fertile, sheltered sites with easterly or southerly aspects.

3.1.8.2 Floodplain open woodlands and grasslands

In the middle and upper Hunter, floodplain forest is dominated by three Eucalypt species, *Eucalyptus camaldulensis* (river red-gum), *E. tereticornis* (forest red-gum) and *E. melliodora* (yellow box). *Eucalyptus amplifolia* ssp. *amplifolia* (cabbage gum) and *Angophora floribunda* (rough-barked apple) are more frequent in the lower Hunter. Riparian margins are typically lined with *Casuarina cunninghamiana* (river oak) with *C. glauca* (swamp oak) dominating upon saline sites. It is likely that pockets of *Toona ciliata* (red cedar) existed in sheltered riparian locations during pre-European time. Native grasses, *Themeda australis* (kangaroo grass) and *Danthonia* (wallaby grass) are restricted to areas with little agricultural modification.

3.1.8.3 Tall forests and rainforest of high elevation basalt plateau and ranges.

These areas primarily comprise Tertiary basalt, however Barrington Tops Granodiorite is encountered over extensive areas of the high northern plateau. Better quality soils and rainfall over 1000mm favours the growth of tall open forest, subtropical rainforest and Antarctic beech forest (*Nothofagus morrei*). In areas of highest elevation *Eucalyptus pauciflora* (snow-gum) dominates. Tall open forest is typically dominated by *Eucalyptus dalrympleana* (white gum) *Eucalyptus laevopinea* (silver-top stringybark) and ribbon gums, *Eucalyptus viminalis* and *E. nobilis*.

3.1.8.4 Open grassy woodland of the Merriwa Plateau

The Merriwa plateau formed from the extensive outpouring of basaltic lava from vents along the Liverpool Range during the Tertiary. Vegetation mantling the plateau is characterised by open grassy woodland dominated by *Eucalyptus albens* (white box) and less frequently, *E. melliodora* (yellow box). Other notable tree species include *Eucalyptus blakelyi* (Blakely's red-gum), *Santalum lanceolatum* (northern sandalwood), *Brachychiton populneus* (kurrajong), and *Notelaea macrocarpa* (native olive). Grasses include *Austrostipa aristiglumis* (plains grass), however native grass cover has been greatly reduced due to cropping and grazing.

3.1.8.5 Forests of dissected sandstone plateau

The southern and south-western third of the catchment comprises an enormous diversity of vegetation types. *Eucalyptus punctata* (grey gum), *E. piperita* (Sydney peppermint), *E. gummifera* and *E. eximia* (red and yellow bloodwood), *Angophora costata* (smooth-barked apple), *E. crebra* (narrow-leaved ironbark) are a few of the tree species typically found along ridge crests and hillslopes in this region. Tree species commonly found on the lower slopes and valley floor include *Eucalyptus acmenoides* (white mahogany), *Angophora floribunda* (rough-barked apple), *E. amplifolia* (cabbage gum) and *E. deanei* (round-leaved blue-gum) in sheltered valley settings. A rich diversity of understorey species is found in association with most forest and woodland types, exposed sites comprise heath and eucalypts displaying mallee form.

3.1.9 The History of European Settlement in the Upper Hunter

The Upper Hunter provided the home for two aboriginal tribes, the Kamilaroi and the Wanaruah, prior to the arrival of Europeans. People are likely to have been living in the Hunter Valley for tens of thousands of years.

Henry Dangar has been credited as the first European to venture into the Upper Hunter Valley. Dangar, whilst surveying for John Howe around Singleton in the early 1820s, decided to explore the valley further upstream. His first journey was essentially an informal excursion, recorded only as a sketch map. Impressed by the “rich alluvial lands” (Dangar, 1828, p.43), a more substantial surveying expedition was undertaken later that year. Dangar named the lands he explored Twickenham Meadows and St Germain’s Meadows.

Land in the Hunter Valley was settled from the early 19th century. Until 1830, land grants were ostensibly free. Land was allocated on a proportional basis, corresponding to the number of convict labours and stock the selector was prepared to employ (Monteith, 1953). As a result, large tracts of fertile land were rapidly opened up for agriculture, predominantly on grassed hills and alluvial plains.

From 1831 all land was sold, with first preference offered to the pre-existing lessee. As most of the rich alluvial land had been appropriated, new settlers were left to farm the less-fertile hillslopes. The 1861 Robertson Land Acts and a general shift towards dairy farming saw larger farms divided up and smaller plots sold off. This had the effect of increasing the intensity of land-use. In the 1890’s gold was found in the Upper Hunter, generating a brief rush in Scone.

Major centres in the Upper Hunter include Muswellbrook, Scone and Murrurundi. Smaller towns include Aberdeen, Wingen, Blandford, Gundy and Parkville. Early Muswellbrook was primarily a travellers rest and centre for local governance. The site officially became a town in 1833 and by 1941 its population had slowly increased to 217. The arrival of the railway in 1969 catalysed growth, increasing population to around 1500.

In 1870, with a population of 1445, the Muswellbrook area was declared a municipality. In 1989, the Shire of Denman and the Municipality of Muswellbrook merged to form Muswellbrook Shire, comprising a population of close to 15 000. The 2001 census listed 14796 people living in the statistical local area (SLA) of Muswellbrook, a total area of 3405.6 sq. km.

Scone established itself as a service centre, largely controlled by the Dumaresq family. Scone municipality was established in 1888. It also experienced a population spike with the advent of the railway. The 2001 census listed 9459 people living in the 4041.1 sq. km. Scone SLA.

Aberdeen was built at the request of landowner Thomas Macqueen to complement his large property, Segenhoe, in 1838. Murrurundi established as transport centre, conveniently located between the Hunter Valley and Liverpool Plains. From its first survey in 1837, the town had grown to a population of 350 by 1867. The railway arrived in 1872, providing a boost for commercial activity. Murrurundi became a municipality in 1890, with its population peaking around 1914. In the 2001 census, 2017 people were recorded in the 2480.6 sq. km. Murrurundi SLA, which includes the town of Blandford.

3.1.10 Land-Use

3.1.10.1 Agriculture

The Hunter accounts for approximately 3% of the land given over to agriculture in NSW. The total value of production in 1998 was around \$430 million, or 6% of State agricultural output. Land holdings are slightly smaller in comparison to the average property size in NSW. Small, agriculturally profitable enterprises are generally confined to the valley floor with its rich soils and

ready access to water. However, a growing trend towards hobby farms and lifestyle blocks has seen the fragmentation of large off-river farms and diversification of land-use.

Sustained by irrigation and some of the most fertile soils in NSW, the dairy industry comprises a herd of more than 73 000 cattle. The introduction of the railway into the Upper Hunter (1869-72) catalysed the growth of dairying due to reduced transport time and costs. Dairy properties typically occupy both the alluvial flats and adjacent lower hillslopes. Irrigated pasture and on-farm production of lucerne provide the bulk of fodder for much of the year with hillslopes accessed during the cooler months. Dairying is concentrated in the Upper Hunter around Muswellbrook, Aberdeen and Scone.

Although agriculture in the Hunter is often defined by systems of intensive production along the valley floor such as dairying or horse studs, the off-river country supports populations of over 500 000 cattle and similar numbers of sheep. Beef production in 1998 was valued at more than \$69 million. Herds are generally naturally reproducing, comprising Herefords and other British breeds. Sheep are farmed for both wool and meat. Wool production is primarily supported by merinos with cross-breeds used for fat lamb production. Livestock carrying capacity within drier, unirrigated areas is around six dry sheep equivalents per hectare (Sinclair & Knight, 1981).

3.1.10.2 Mining

The first European explorers to make their way into the upper valley recorded the presence of coal, particularly along the river.

The earliest mines in the middle and upper valley were established to meet the energy needs of local industry from the 1850s. The Glendon Mine was opened at Singleton to provide coal for the boilers of a condensed milk factory at Lower Belford (Bridge, 1958). The first mine at Muswellbrook, the Kayuga Mine (1892), was established to provide energy for the local butter factory. Other small operations, at Scone (1870-72) and Mount Wingen (1873-79) were producing coal for local and domestic use. Difficult mining conditions, including limited access to water, led to their early closure.

Growing demand for coal from the Kayuga Mine in the early 20th Century was met by a dramatic acceleration in production. Kayuga was favoured due to its relative freedom from industrial disputes that often interrupted supply from mines in the lower valley. Nevertheless, the Kayuga operation closed in 1908, due in part to the accidental discovery of coal on Muswellbrook Common whilst sinking a well. Approval to mine the Common was granted almost immediately; the Mayor and several members of council were key members of the mining syndicate (Beckett *et al.* 1997). By 1923, the mining company had constructed a power station, supplying electricity to Muswellbrook, Scone, Denman and Aberdeen. Underground mining continued for 90 years until the closure of the Muswellbrook No.2 Mine in 1997.

From the late 1940s, direct government involvement by both the State and Federal Governments saw the opening of a number of open-cut mines in the Foybrook and Ravensworth areas, providing coal for gas production, the Railways Department and for export. In 1969, the Electricity Commission sought to build a major (3000 megawatt) power station at Liddell, securing the long-term future of these operations. Open cut mining was well established in the middle Hunter by the 1970s, often proving more profitable than underground mining. Most Hunter Valley coal is located fairly close to the surface, favouring large-scale multi-seam mining. Unable to compete with the growing number of open cut mines and a burgeoning coal industry in Queensland, underground mining around Cessnock began to falter from the 1950s, culminating in a dramatic series of pit closures. Since the 1970s, mining has moved progressively into the upper part of the valley with

recent operations such as Mt Arthur, Bengalla and Dartbrook all located within close proximity to Muswellbrook. In 2000 open cut mining produced around 84% of total coal output for the Hunter Valley.

Recoverable coal reserves in the Hunter account for around 67% of the State total of 7430 million tonnes. Nevertheless, it has been predicted that between eight and thirteen Hunter mines will close within the coming decade due to the depletion of local reserves. Coal production in the Hunter increased from 64 million tonnes in 1990 to almost 107 millions tonnes in 2000, 80% of the State's total. The rise in production has been a direct response to a growing export market. Only around 20% is used domestically for energy production with the remainder exported. Australia is the world's largest coal exporter with over 65 million tonnes exported through the Port of Newcastle in 2000.

Sand and gravel extraction occurs in the channel and on the floodplain of the Hunter River. Demand for these materials has risen due to population growth and development in the valley (Erskine *et al.*, 1983). Sediment extraction has been occurring at a faster rate than replenishment (Erskine *et al.*, 1983). In some cases, protective gravel is being removed from the bed of the river, resulting in instability.

3.1.10.3 Power Generation

Macquarie Generation owns and operates the Bayswater and Liddell Power Stations in the Upper Hunter, located around 15 km south of Muswellbrook. Together they are capable of generating over 40% of the States electricity or around 4,600 MW. Bayswater and Liddell generate electricity by producing steam from coal-fired boilers which is then directed under high pressure to drive turbo-generators. Liddell was constructed from 1971-73 and was the first major NSW power station to obtain its cooling water from sources other than the ocean; a result of the construction of Lake Liddell, capable of holding 152,000 ML of water. Around 100 ML/day is lost as evaporation through the cooling process. Water for cooling is provided both from the Lake Liddell catchment and from the Hunter River. The larger Bayswater Power Station was constructed in the mid 1980s, in close proximity to Liddell in order to access pre-existing infrastructure.

Plate 1: Hunter River At Singleton 1861

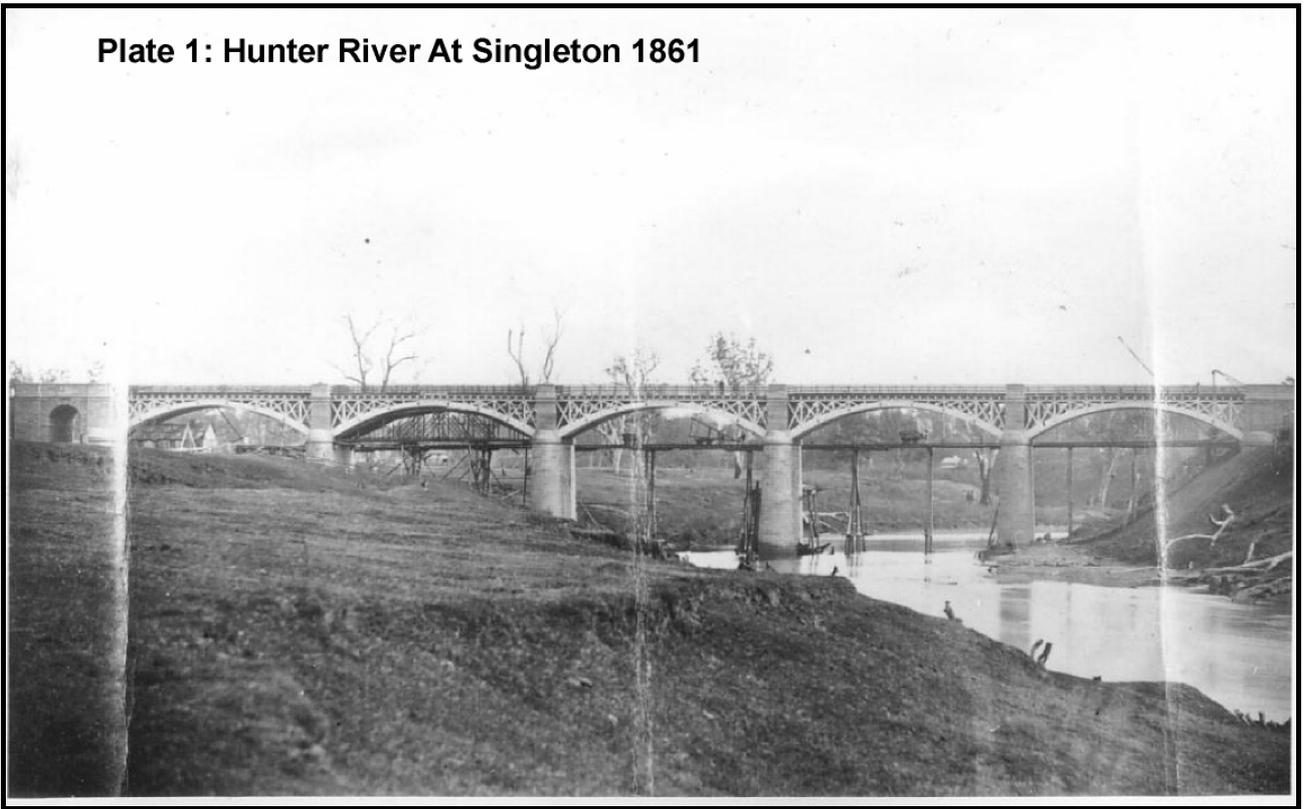


Plate 2: Hunter River at Singleton 1866.

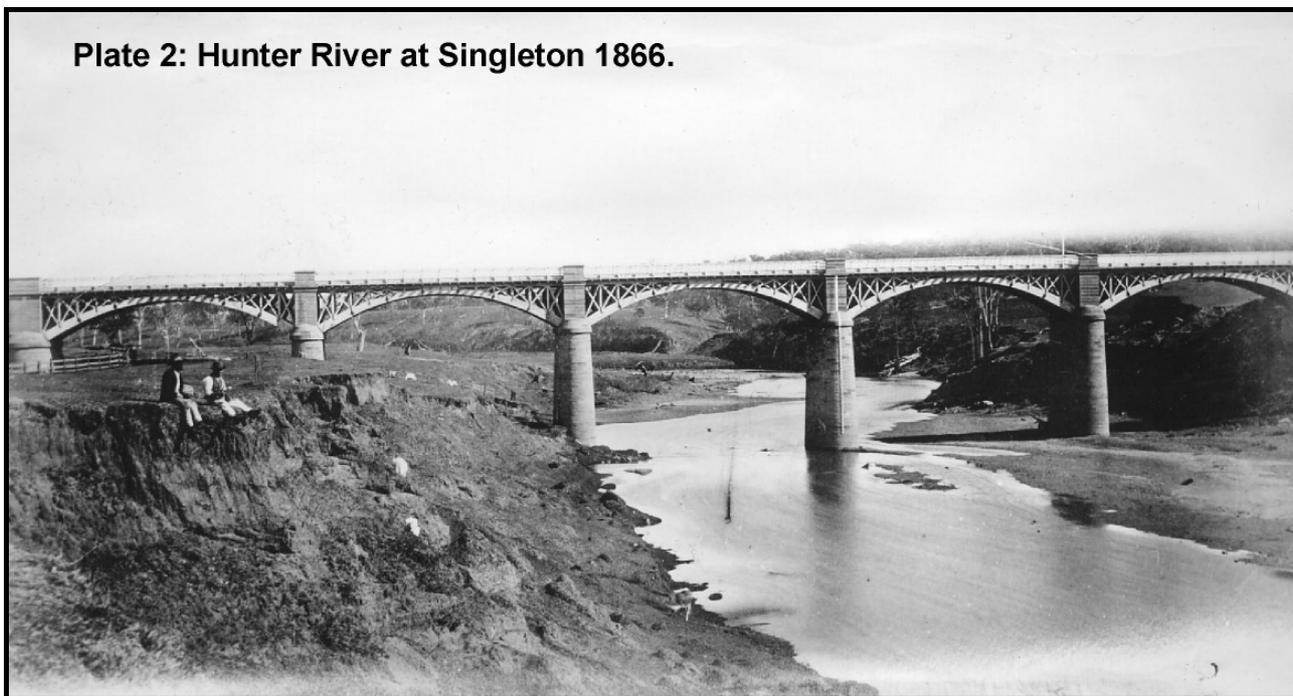
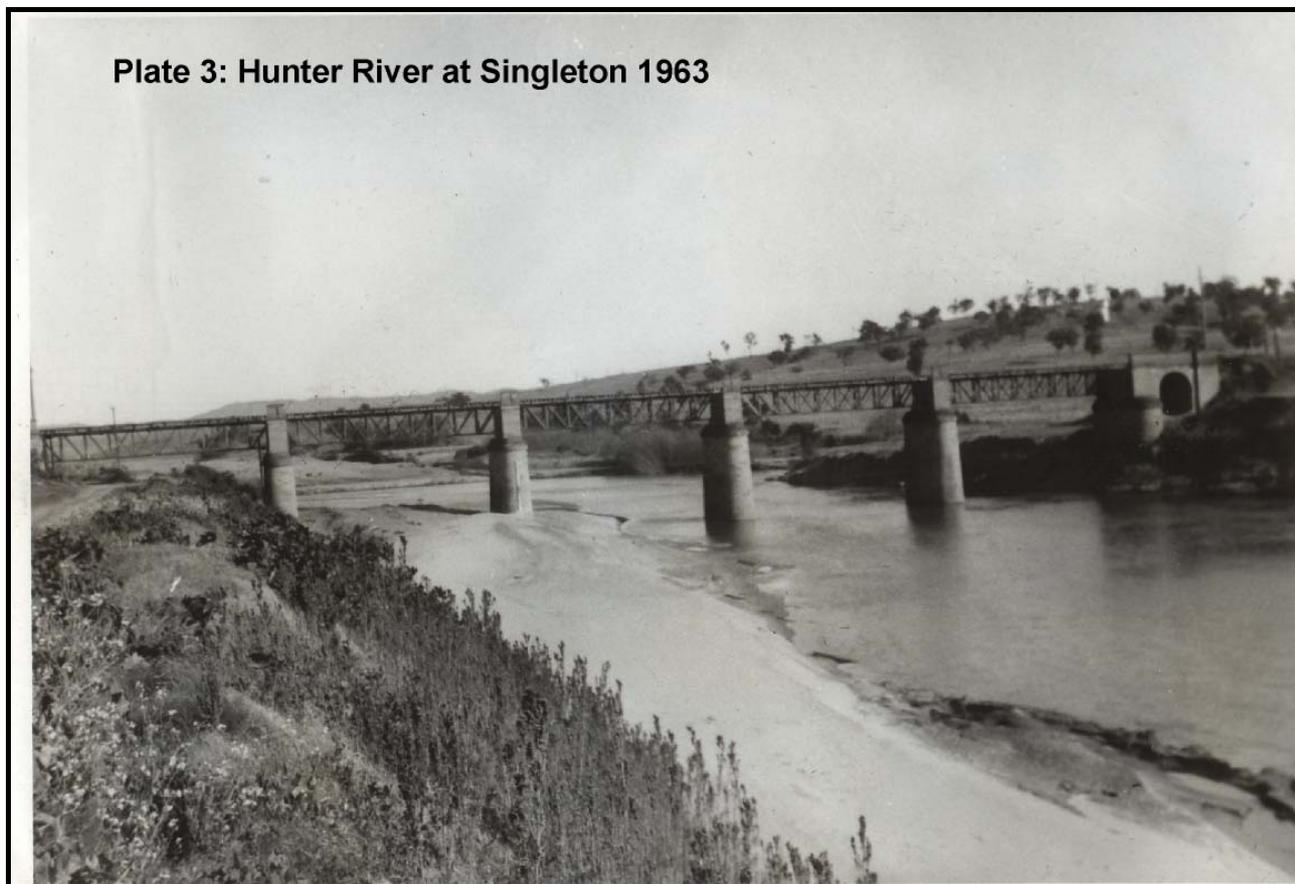


Plate 3: Hunter River at Singleton 1963



3.2 STAGE ONE, STEP TWO: THE CHARACTER AND BEHAVIOUR OF RIVER STYLES IN THE UPPER HUNTER CATCHMENT

Ten River Styles were identified in the Upper Hunter catchment. Eight of these exist on other coastal catchments of New South Wales (Brierley et al. 2002). Two new laterally unconfined River Styles were observed and named; “Meandering entrenched gravel bed” and “Low sinuosity entrenched gravel bed”. Proformas for all River Styles are presented in the following pages. These proformas are summaries of the character, behaviour and controls for each River Style across the range of reaches in the catchment. The cross-sections, aerial photographs, photographs, and diagrams included in the proformas are for the best available representative example from different subcatchments. The key distinguishing attributes of each River Style are noted in Table 6. The catchment specific Upper Hunter River Styles tree is presented in Figure 17 and Figure 18 notes the distribution of River Styles across the catchment.

Table 6: Distinguishing attributes of River Styles in the Upper Hunter catchment

River Style	Valley setting	River character			River behaviour
		Channel planform	Geomorphic units	Bed material texture	
Steep headwater	Confined	Single channel, low sinuosity, highly stable.	Waterfall, cascades, rapids, pool/riffle/run sequences, occasional floodplain pocket.	Bedrock-boulder-gravel	Steep, bedrock channel with a heterogenous assemblage of geomorphic units. Acts to flush sediments through a confined valley with localised deposition in less steep areas. Limited capacity for lateral adjustment.
Gorge	Confined	Single channel, low sinuosity, highly stable.	Steps, rapids, pools, islands, bars.	Bedrock-boulder-gravel	Bedrock-controlled river where the assemblage of geomorphic units is dictated by the outcropping of bedrock and local slope. All sediments are flushed, however there is some short term storage. Channel cannot adjust within the confined valley setting.
Confined valley with occasional floodplain pockets	Confined	Single channel, low sinuosity, highly stable.	Steps, pools, riffles/glides/runs, bars, benches/ledges.	Bedrock-boulder-gravel-sand	Bedrock induced geomorphic units found in a narrow valley with limited capacity for adjustment. Floodplains are formed from suspended load deposition in areas of localised valley widening.
Partly-confined valley with bedrock-controlled discontinuous floodplain	Partly-confined	Single channel, sinuous valley alignment, moderately stable.	Island, pool, riffle, run, bars, chute, ramp, ledges, benches, secondary channel, flood runners, palaeo-channels, terraces.	Bedrock-gravel-sand	Found in sinuous valleys, these rivers progressively transfer sediment from point bar to point bar. Sediment accumulation and floodplain formation is confined largely to the insides of bends. Sediment removal occurs along concave banks. Over time sediment inputs and outputs are balanced in these reaches. Floodplains are formed from suspended load deposition behind bedrock spurs and may be reworked via floodplain stripping.
Partly-confined valley with low sinuosity planform-controlled discontinuous floodplain	Partly-confined	Single channel, straight or irregular valley with a low-sinuosity channel, moderately stable.	Steps, pools, riffles, runs, bars, benches, ledges, flood runners, palaeo-channels, terraces.	Bedrock-gravel-sand	Found in straight valleys, channel alignment is influenced by terraces and fans. The sediment load is mixed, with material being transported downstream from bar to bar. The channel has moderate stability because of bedrock impingements, but is otherwise prone to adjust across the floodplain via floodrunners, chutes and channel expansion laterally and vertically.

Table 6 (cont.): Distinguishing attributes of River Styles in the Upper Hunter catchment

Partly-confined valley with meandering planform-controlled discontinuous floodplain	Partly-confined	Single channel, straight or irregular valley with a meandering channel, moderately stable.	Pools, riffles, runs, bars, gravel sheets, ledges, benches, chutes, flood runners, palaeo-channels, terraces.	Bedrock-gravel-sand	Terraces commonly confine the channel, as well as alluvial fans and piedmont features. Where there is adequate stream power to rework the channel; pools, riffles and bars exist as mixed load dominates. The channel adjusts over the vertically accreted floodplain via channel expansion, migration and avulsion with moderate stability.
Low-moderate sinuosity gravel bed	Laterally unconfined	Single, low-sinuosity macrochannel, low - moderate stability.	Pools, riffles, runs, bars, benches, chute, secondary channel, flood runners, palaeo-channels, terraces.	Gravel-sand	Sediment is transported both as bed load and mixed load creating bars and sheets. The floodplain is vertically accreted. Most channel instability and adjustment occurs within the macro channel, which adjusts through expansion and contraction.
Meandering gravel bed	Laterally unconfined	Single, meandering channel, low - moderate stability.	Gravel sheets, ledges, bars, pools, flood runners, palaeo-channels, levees.	Gravel-sand	Sediment is transported both as bed load and mixed load creating bars and sheets. Gravels accumulate in point bars while material is scoured from the outside bend. Most channel instability and adjustment occurs within the macro channel, which adjusts through expansion and contraction. The extensive, continuous floodplain is vertically accreted and palaeochannels are evident suggesting avulsion and reworked by overbank flows.
Low sinuosity entrenched gravel bed	Laterally unconfined	Single, low-sinuosity channel, low - moderate stability.	Ledges, lateral bars, pools, gravel sheets, flood runners	Gravel-sand-clay	Suspended load transport leaving a slightly undulating bed. Frequent overbank flows deposit the vertically accreted floodplain. Adjusts through avulsion of the channel.
Meandering entrenched gravel bed	Laterally unconfined	Single, meandering channel, low - moderate stability.	Ledges, point bars, pools, gravel sheets, flood runners	Gravel-sand- clay	Suspended load transport leaving a slightly undulating bed. Frequent overbank flows deposit the vertically accreted floodplain. Adjusts through avulsion of the channel.

Figure 17: River Styles® tree for the Upper Hunter catchment

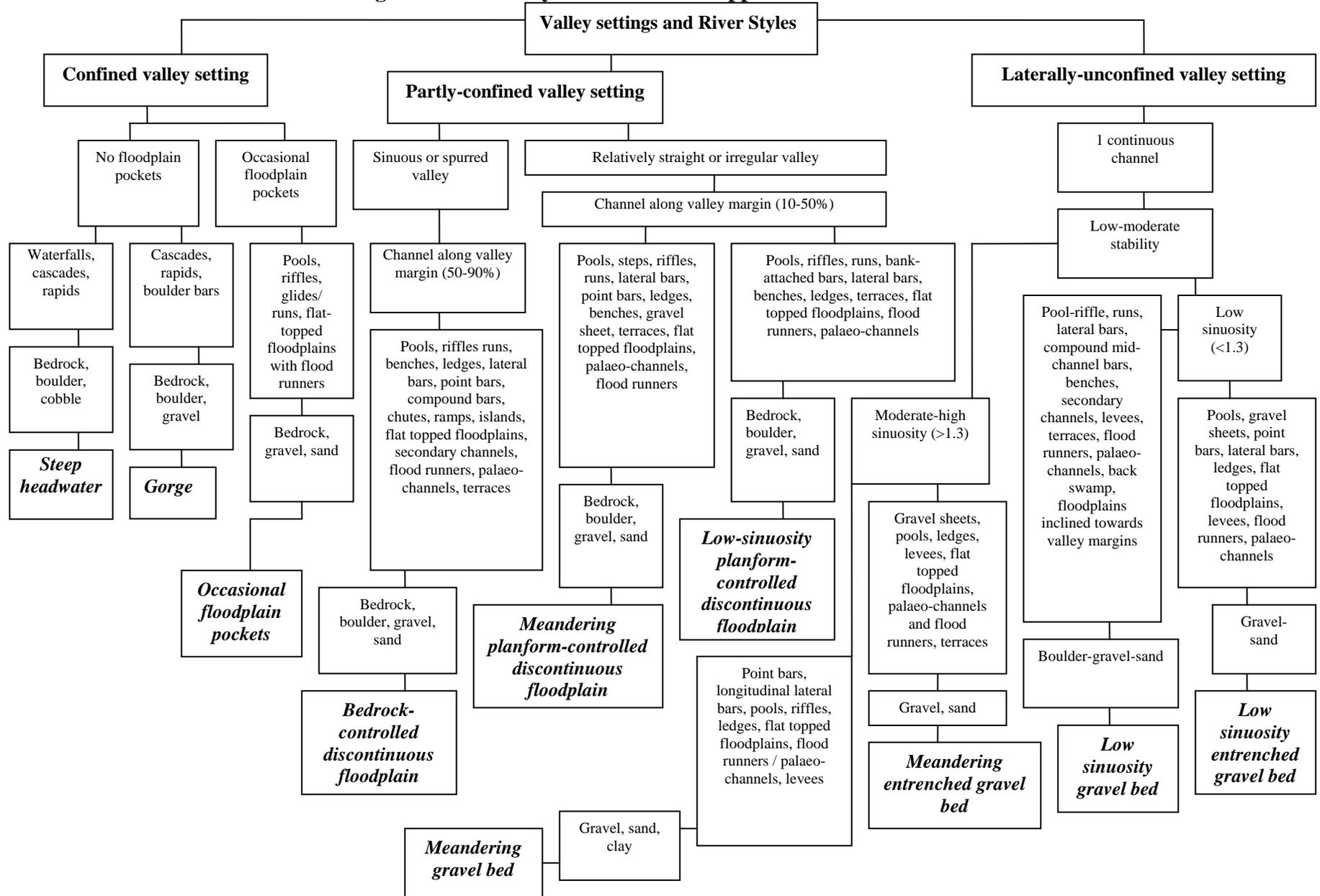
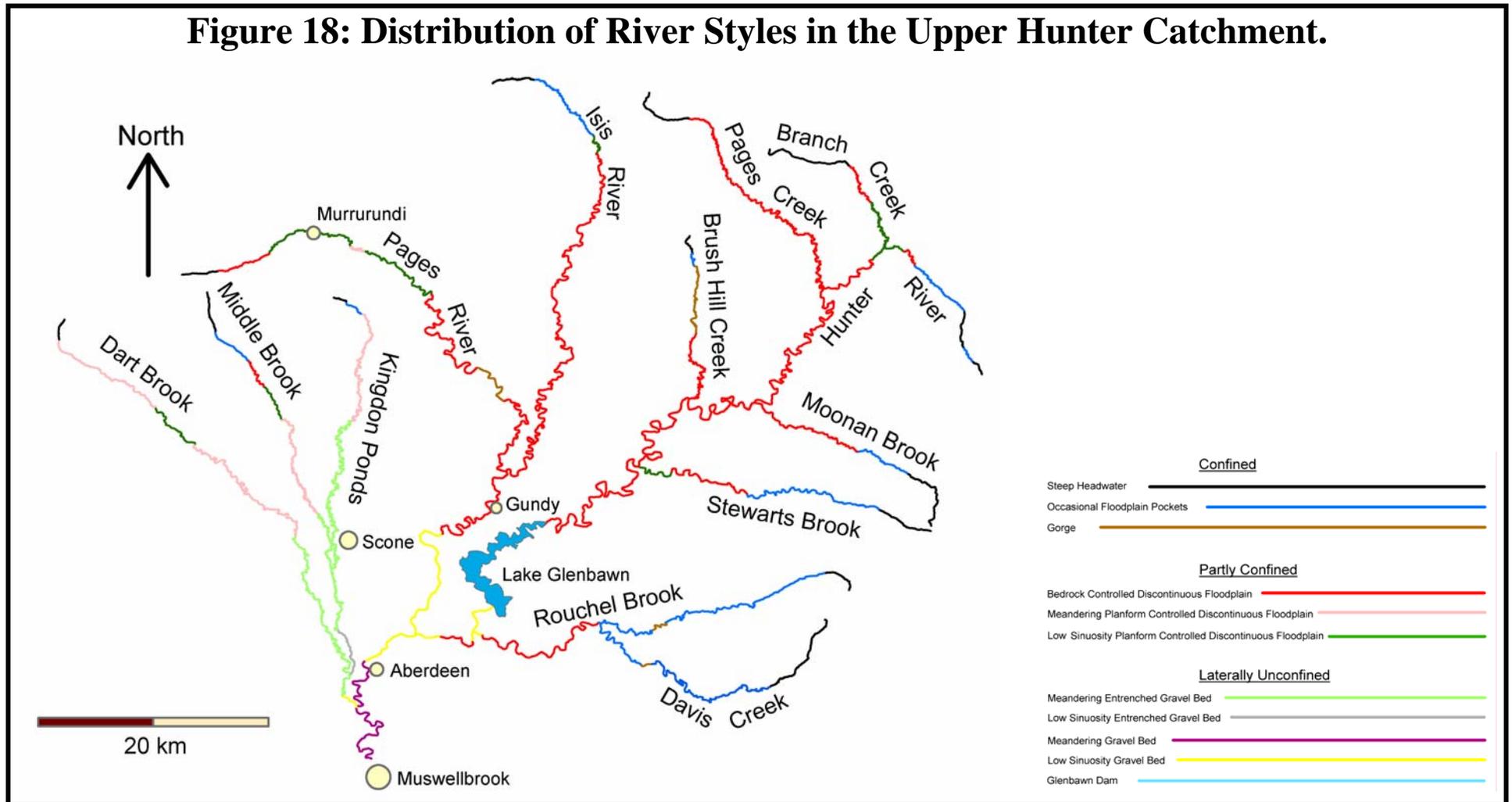


Figure 18: Distribution of River Styles in the Upper Hunter Catchment.



Three River Styles were identified in the confined valley-setting (Gorge, Steep Headwater, and Occasional Floodplain Pockets), **three in the partly-confined valley-setting** (Bedrock-Controlled Discontinuous Floodplain, Low Sinuosity Planform Controlled Discontinuous Floodplain, and Meandering Planform Controlled Discontinuous Floodplain) and **four in the laterally-unconfined valley-setting** (Low Sinuosity Gravel Bed, Meandering Entrenched Gravel Bed, Low Sinuosity Entrenched Gravel Bed and Meandering Gravel Bed). The boundaries between River Styles were either sharp or gradual.

3.2.1 River Styles found in the Confined valley setting

The three River Styles found in confined valley-setting occur in different landscape units. The **Steep Headwater** River Style is found in the Remnant Plateau and Plateau Slopes landscape units and has a wide range of instream geomorphic units including bedrock and boulder pools, riffles, mid-channel and lateral sand bars. A confined, laterally stable channel is set within valleys that have eroded into the remnant plateau or plateau slopes. These valleys tend to be approximately straight.

The **Confined Valley with Occasional Floodplain Pockets** River Style is found in the Plateau Slopes and Rugged and Hilly landscape unit. It occurs along most river courses in the catchment and is often transitional between the Plateau Slopes and Rugged and Hilly landscape unit. This River Style is bedrock-confined, with the channel often occupying the entire valley floor. The channel is stable, and acts as a conveyor of sediment. The extent of bed aggradation and degradation indicates the volume of material moving through the system and the efficiency of flushing. Bedrock-induced pools, glides and runs characterise the channel bed. Shallow, narrow floodplain pockets occur along the valley margins either protected behind bedrock spurs or in locally wider sections of valley (e.g. at tributary confluences).

The **Gorge** River Style is found within the Plateau Slopes and Rugged and Hilly landscape unit and is set within a deeply incised v-shaped valley. A bedrock channel occupies the entire valley floor (i.e. there is no floodplain), with a series of bedrock-induced bed forms.

3.2.2 River Styles found in the Partly confined valley setting

The three River Styles found in the partially confined valley-setting occur in different landscape units. The **Partly Confined Valley with Bedrock Controlled Discontinuous Floodplain** River Style occurs within the Remnant Plateau and Rugged and Hilly landscape unit. This River Style has an imposed sinuous channel within a meandering valley and is characterised by point bar and point bench deposition on the inside of bends and by erosion of near-vertical concave banks. The floodplains occur along the convex banks of bends and are often characterised by floodrunners or floodplain stripping. In some of the Bedrock Controlled Discontinuous Floodplain reaches of the upper Hunter catchment, particularly those on the eastern side of the catchment, the valley margins are bedrock terraces (strath terraces).

The **Partly Confined Valley with Low Sinuosity Planform Controlled Discontinuous Floodplain** River Style occurs entirely within the Rugged and Hilly landscape unit. This River Style has a free forming low sinuosity channel within a valley that is irregularly shaped or straight. The channel is characterised by bank-attached lateral bars and benches along straighter sections of channel, and point bar and point bench deposition on the inside of bends. The position of the channel as seen in planform divides the floodplain into discontinuous sections. The position of the floodplains is dependent on the lateral movement of the channel. The floodplains are built up by the process of vertical accretion of finer sediment and often characterised by floodrunners and

palaeochannels. The low sinuosity planform controlled discontinuous floodplain section of the Isis River has a meandering appearance in plan view. Sinuosity is the ratio of channel length to valley length, therefore, if the valley margin is meandering and running parallel to the channel the sinuosity is low. In the case of the low sinuosity planform controlled discontinuous floodplain reach on the Isis River the valley margin meanders. This margin is the eroded edge of an alluvial fan spreading out from a lateral gully.

The **Partly Confined Valley with Meandering Planform Controlled Discontinuous Floodplain River Style** occurs within the Rugged and Hilly and Undulating Plain landscape unit and is often transitional between the Rugged and Hilly and Undulating Plain landscape unit. This River Style has an free forming sinuous channel within a moderately sinuous to straight valley. The position of the channel as seen in planform divides the floodplain into discontinuous sections. The position of the floodplains is dependent on the lateral movement of the channel. Movement of the channel within the floodplain occurs by the process of lateral or longitudinal meander progression and meander cut off. The floodplains are built up by the process of vertical accretion of fine sediment and are often characterised by floodrunners and palaeochannels.

3.2.3 River Styles found in the Laterally-unconfined valley setting

Four laterally unconfined River Styles were identified in the Upper Hunter catchment. Given their alluvial setting, these River Styles have been the most sensitive to change in the period of post-European settlement.

The **Low sinuosity Entrenched Gravel Bed River Style** only occurs on the lower 4 or 5 km of Kingdon Ponds. This reach is within a wide valley in the undulating plain landscape unit. The channel is single, continuous, and relatively stable. It is characterised by pools – riffles, ledges, lateral bars, and mid channel bars. The floodplain is continuous often with levees, floodrunners, and palaeochannels. This River Style has an free forming channel with a low sinuosity channel. The floodplains are extensive, vertically accreted, fine grained, and are characterised by levees, floodrunners, and palaeochannels. The fine grained material that makes up the floodplains is very cohesive and inhibits channel adjustment.

The **Meandering Entrenched Gravel Bed River Style** occurs within the undulating plains landscape unit. This River Style has a free forming sinuous channel within a wide valley. The channel is single, continuous, and relatively stable. The channel is characterised by pools and riffles, ledges, and lateral bars. The channel bed is dominantly sand and gravel. The source of the gravel appears to be a gravel layer that, most likely, extends laterally below the current floodplain. The channel appears to often be dry and the gravels of the bed are often covered by a thin drape of silty material. The floodplains are continuous, extensive, vertically accreted, fine grained, and are characterised by levees, floodrunners, and palaeochannels. The fine grained material that makes up the floodplains is very cohesive and inhibits channel adjustment. The important distinction between Meandering Entrenched Gravel Bed and Meandering Gravel Bed River Styles is that the Meandering Entrenched River Style has a low width/depth ratio and the channel has a greater degree of stability.

The **Low Sinuosity Gravel Bed River Style** occurs on the Pages and Hunter Rivers as they enter the wider valleys of the undulating plain landscape unit. The channel is single, continuous, and relatively unstable. It is characterised by pools – riffles, runs, benches, lateral bars, and mid channel bars. The floodplain is continuous often with levees, floodrunners, and palaeochannels. This River Style has an free forming channel that is low to moderately sinuous. The floodplains are extensive, vertically accreted, fine grained, and are characterised by levees, floodrunners, and palaeochannels.

The **Meandering Gravel Bed** River Style occurs within the Undulating Plain landscape unit. This River Style has a free forming sinuous channel within a wide valley. It is single, continuous, and relatively unstable. It is characterised by point bars, islands, lateral bars, and pools and riffles. The floodplain is continuous often with levees, floodrunners, and palaeochannels. The floodplains are continuous, extensive, multi-surfaced, vertically accreted, fine grained, and are characterised by levees, floodrunners, backswamps, terraces, and palaeochannels.

3.2.4 River Styles Proformas

3.2.4.1 Steep Headwater River Style

Defining attributes of River Style (from River Styles tree): This reach is set within a very steep, confined valley, which restricts the formation of a floodplain. The typical geomorphic units found within this environment are waterfalls, cascades and rapids, which are composed of bedrock, boulders and gravels.

Subcatchments in which River Style is observed: Pages River, Dart Brook, Kingdon Ponds, Middle Brook, Isis River, Rouchel Brook, Davis Creek, Pages Creek, Branch Creek, Brush Hill Creek, Moonan Brook, Stewarts Brook, Hunter River.

Note: Limited analyses were undertaken in the Steep Headwater River Style due to accessibility. Hence, this analysis is based largely on air photograph and topographic map interpretation.

DETAILS OF ANALYSIS	
<i>Representative sites:</i> Middle Brook	
<i>Map sheet(s) air photographs used:</i>	
<i>Analysts:</i> Deanne Bird, Kirsty Hughes, Elizabeth Lamaro, Deirdre Wilcock	
<i>Date:</i> 29/03/03	

RIVER CHARACTER	
Valley-setting	Confined
River planform <ul style="list-style-type: none"> • Sinuosity • Number of channels • Lateral stability 	The straight valley shape imposes the low sinuosity single channel morphology. Lateral stability is high given the fully confined nature of the valley.
Bed material texture	Bed material consists of gravel, boulders and bedrock. Bedrock is a significant control on the location of features such as pools, riffles, runs and steps. Material size can be up to boulder size and averages 800 mm B_{max} .
Channel geometry (size and shape)	Channel geometry is highly irregular given that the channel margins are dominated by bedrock. Channel size is dictated by the width of the valley.

<p>Geomorphic units (geometry, sedimentology)</p>	<p>Instream Instream geomorphic units are high energy, predominantly, bedrock features that form on high slopes. The local slope along these reaches dictates the assemblage of waterfalls, cascades, rapids, pools and riffles. Where localised sediment accumulation occurs gravel bars may be formed. These features may have a forced morphology imposed by woody debris or bedrock outcrops along the reach.</p> <p>Waterfall – a channel wide step formed from bedrock, coarse boulders and/or large woody debris. May include a transverse waterfall which is >1m in height and separates a backwater pool from a plunge pool downstream. At 820 m a.s.l. Pages River has a large waterfall named High Valley Fall. There is another smaller fall below this.</p> <p>Cascades – very stable, coarse-grained or bedrock feature. Characterised by longitudinally and laterally disorganised bed material typically consisting of cobbles and boulders. Flow cascades over large boulders in a series of short steps about one clast diameter high, separated by areas of more tranquil flow of less than one channel width in extent.</p> <p>Rapids – Very stable, steep, stair-like sequences formed by arrangements of boulders</p> <p>Pool and riffle sequences – bedrock-controlled formations with accumulations of gravel forming undulations in the channel bed.</p> <p>Lateral and mid-channel bars – tend to accumulate behind bedrock outcrops or woody debris. Have a low relief and limited extent. Size according to the channel width, and may extend up to 2 - 3 times channel width.</p>
<p>Vegetation associations</p>	<p>Instream geomorphic units (and on hillslope margins) Because of their inaccessibility, this River Style often contains native vegetation, e.g. river red gum, casuarinas. Woody debris may be present in the channel zone.</p> <p>Floodplain geomorphic units n/a</p>
<p>Floodplains Due to the confined valley setting there are no floodplain units found along this River Style.</p>	

<p>RIVER BEHAVIOUR</p>	
<p>Bankfull stage and overbank stage are not relevant for this River Style, as it contains no floodplain and the channel is defined by the valley morphology. Hence, the analysis of river behaviour is simply divided into low flow stage and high flow stage analyses.</p> <p>Low flow stage At low flow stage a standing or subcritical flow is maintained in the pool and riffle sequences allowing temporary sediment accumulation to occur. Water tumbles over waterfalls and cascades makes up of bedrock and coarse substrate. Very little in the way of geomorphic work is done at this flow stage.</p> <p>High flow stage As flow increases areas of sediment accumulation (e.g. lateral and mid-channel bars) may be reworked or flushed from the reach and scouring will take place. Riffles can be mobilised during high flow stages but will reform as the flow decreases. During high flow stage flow becomes super critical, but it usually does not have the capacity to modify the bed load. Extremely high flows can cause scour in bedrock and shift boulders from within these geomorphic units. During high flow events the flow energy is dissipated in the backwater pool and plunge pool associated with a waterfall.</p> <p>Overall this steep, fast flowing River Style is within a highly stable channel setting with a limited capacity to adjust. The channel margins are constrained by the bedrock valley margins restricting sediment accumulation and therefore the reach acts as a sediment throughput zone. High slope-channel connectivity due to the lack of floodplain also makes this reach a source of colluvial materials.</p>	

CONTROLS	
Upstream catchment area	This River Style drains small catchment areas in the headwaters of many river courses. Average catchment area = 6.7 km ² .
Landscape unit and within-Catchment position	Typically found in the headwater regions of the catchment in the Remnant Plateau and Plateau Slopes landscape units. This River Style is always the upper most River Style in the catchment, formed downstream of the drainage divide.
Process zone	Sediment throughput zone with all but the largest materials being flushed. Hillslope sediment source zone due to high slope-channel connectivity.
Valley morphology (size and shape)	Valley morphology is a regular V-shape. The level of 'ruggedness' is highly dependant on elevation, e.g. the headwaters flowing down the flanks of Barrington Plateau have a greater relief than those flowing from the Liverpool Range.
Slope	Channel slope average is 0.139.
Stream power	Gross Stream Power 90648.3 W/m

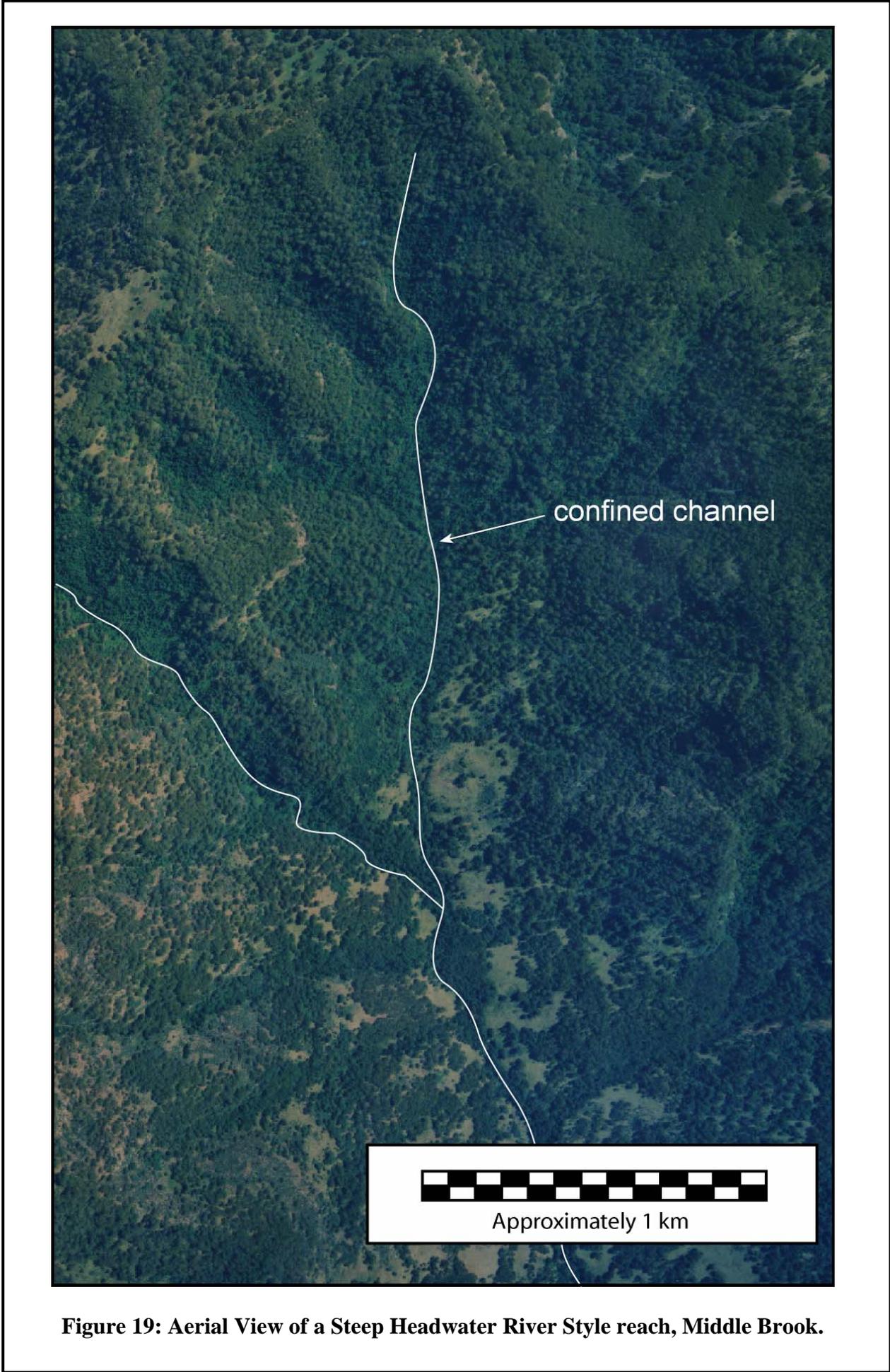


Figure 19: Aerial View of a Steep Headwater River Style reach, Middle Brook.

3.2.4.2 Confined Valley with Occasional Floodplain Pockets River Style

Defining attributes of River Style (from River Styles tree):

Found in a confined valley setting, this River Style is distinguished by occasional floodplain pockets. Despite these pockets of sediment deposition, the channel abuts the valley margin along 90% of its course. Common geomorphic units include pools, riffles and glides/runs. Bed material ranges from bedrock, and boulders to sands.

Subcatchments in which River Style is observed: Davis Creek, Hunter River, Isis River, Middle Brook, Pages River, Rouchel Brook.

RIVER CHARACTER	
Valley-setting	Confined
River planform <ul style="list-style-type: none"> • Sinuosity • Number of channels • Lateral stability 	The channel is single and occupies the whole valley floor except where floodplain pockets occur. These floodplain pockets occur within localised accommodation space often protected by bedrock spurs. Sinuosity is low, channel configuration being dictated by valley alignment, making the channel laterally stable.
Bed material texture	Channel bed texture is predominately gravel to small boulders with bedrock outcrop. Along the Isis River, the average B_{max} is 239 mm (selection of 20 largest clasts) with one large erratic of 850 mm. Along Rouchel Brook, the surface layer on the bed is comprised of a wide range of clasts, ranging from gravels (40mm B_{max}) to boulders up to 500 mm B_{max} .
Channel geometry (size and shape)	Channel geometry is highly irregular, controlled by valley width and morphology. At the surveyed cross section on the Isis River the channel is approximately 22 m wide and 2.5 m deep (where floodplain pocket occur). Along Rouchel Brook channel width is generally 40-50 metres.
Geomorphic units (Geometry, sedimentology)	<p>Instream</p> <p>This River Style is dominated by bedrock and sculpted geomorphic units. The instream zone tends to be dominated by elongate, bedrock or gravel based pools and runs with occasional riffles and bedrock steps. Any alluvial bars that are present tend to be mid-channel features which can be vegetated, forming islands. Localised lateral bars may occur along straighter sections of this river type. Along the channel margins, localised benches and ledges may occur adjacent to occasional floodplain pockets.</p> <p>Pool – tend to be elongate and bedrock or gravel based. Sometimes contain sands. Size varies from up to 50 m wide and 100 m long to relatively shallow, localised bedrock-controlled features up to 3 m wide, 4 – 5 m long and less than 0.5 m deep.</p> <p>Run – Planar features that separate pools. Runs are comprised of gravels or bedrock. These features can be relatively long, but shallow. Extend up to 30 m wide and 60 m long along Rouchel Brook.</p> <p>Bedrock steps – comprised of exposed bedrock and produce a near vertical step in the channel bed over which water flows. Can range in size from tens centimetres up to several metres.</p> <p>Riffle – Tend to occur between pools on steep slopes (steeper than runs). Comprised of gravels up to 30 cm (B_{max}). Range is size up to 3 - 15.5 m long and 4 - 30 m wide.</p> <p>Mid-channel bar – comprised of gravel and may be vegetated to form an island. Range in size up to 5 m wide and 15 m long.</p> <p>Lateral bar - comprised of gravel and may be a compound feature with scour holes and chute channels. Range is size up to 8 m long and 3m wide at the apex.</p> <p>Ledges and benches – erosional and deposition features, respectively. They are located adjacent to occasional floodplain pockets and have a stepped morphology. Can be up to 8 m wide and 25 m long.</p>

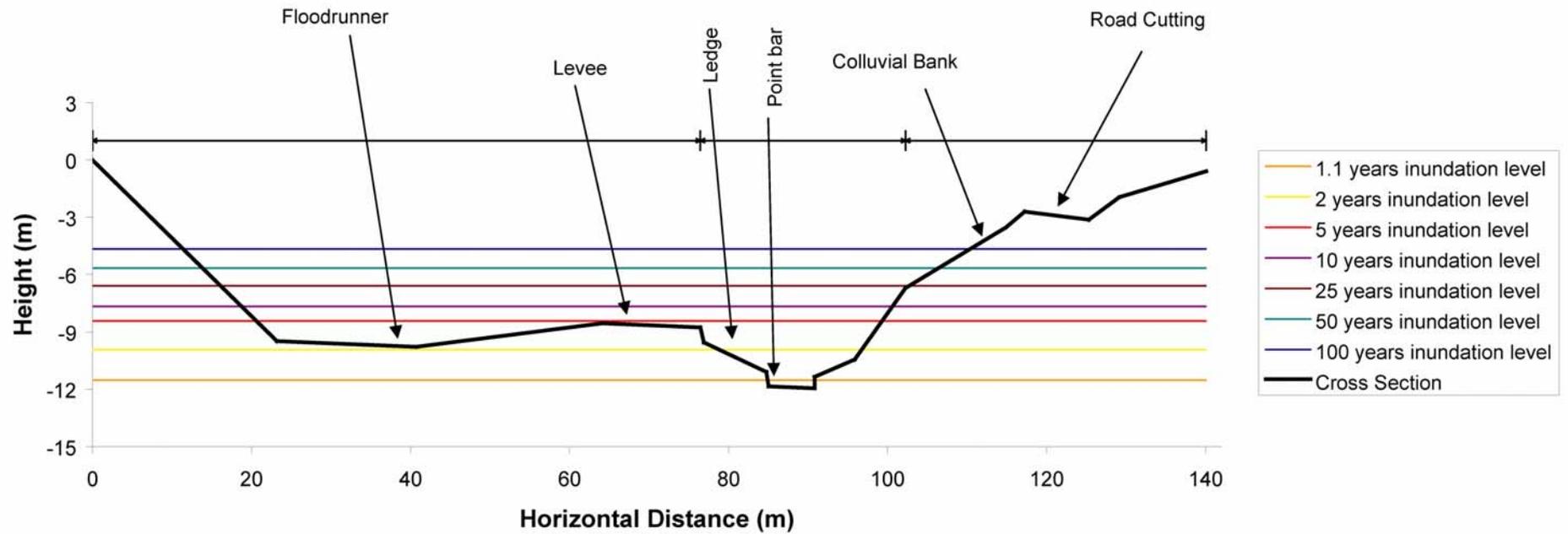
	<p>Floodplains</p> <p>The occasional floodplain pockets found along this River Style tend to be relatively shallow and narrow and are comprised of coarse textured gravels with fine matrix (sands or silts) (e.g. along Rouchel Brook). Sedimentology along Dart Brook consisted of 50cm boulders sitting on the floodplain, a 10-20cm top layer of fine, dark sediment and a gravel/cobble base. Typical pockets would be 1 – 20 m wide and 5 – 80 m long. Where floodplains are protected behind bedrock spurs, fine grained floodplain pockets may occur (e.g. along Isis River). The floodplain surface may be scoured and small floodrunners evident. These floodrunners tend to occur adjacent to the valley margin. Along the Isis River the floodplain pockets are slightly leveed (up to 1 m above the floodplain). Low-relief terraces <2m above the active floodplain, can occur adjacent to the valley margin.</p>
Vegetation associations	<p>Instream geomorphic units</p> <p>Vegetation distribution on instream geomorphic units varies considerably across the catchment, depending on the condition of the river and landuse. Along a representative reach of the Isis River and Rouchel Brook, bars surfaces comprise several weed species dominate including Cirsium, Scottish Thistle, Crofton weed, daisy weed (unidentified), sedge and introduced pasture (Kikuyu grass). Woody debris is present where tree fall occurs.</p>
	<p>Floodplain geomorphic units</p> <p>Improved pasture, tussock grass and a wide variety of exotic weeds cover all floodplain units. In many cases there is a thin riparian strip dominated by Casuarinas, acacias and woody eucalypts.</p>

RIVER BEHAVIOUR	
Low flow stage	<p>The channel is relatively stable at low flow stage, that is, pool and riffle sequences are maintained by bedrock, large gravel and small boulders. Little geomorphic work is being done. Small amounts of sand and silt could be transported as bed load and suspended load, respectively, but would probably be trapped in pools.</p>
Bankfull stage	<p>There is limited scope for river adjustment given the confined nature of the valley. Most geomorphic features found in the channel are formed under high energy conditions, with geomorphic unit configuration and assemblages dictated largely by the occurrence of bedrock, colluvium, and boulder/gravel accumulations. However, higher stream powers can reworking bed material, scour ledges and banks, and transport large boulders. At the surveyed cross section bankfull flow stage has a calculated reoccurrence interval between 1 in 2 and 1 in 5 years.</p>
Overbank stage	<p>Vertical accretion processes form the floodplains, with sediments deposited from suspension in the waning stages of over bank flows. Adjacent to the floodplain pockets the channel may widen under high energy conditions. Under these high energy conditions the floodplain is often reworked by scour processes, flood channel formation or stripping, as the entire valley floor acts as a channel. Overbank flow stage has a calculated reoccurrence interval of 1 in 25 year At the surveyed cross section bankfull flow stage has a calculated reoccurrence interval between 1 in 5 and 1 in 10 years.</p>

CONTROLS	
Upstream catchment area	Average catchment area = 47.583 km ²
Landscape unit and within-Catchment position	This River Style is found within the Plateau slope and Rugged and Hilly landscape units. This River Style tends to form in upper to middle reaches of the catchment. Within the Plateau slope landscape unit it occurs downstream of steep headwater reaches. Within the Rugged and Hilly landscape unit it occurs in narrow gorge like valley sections. This River Style only forms where localised valley widening occurs and shallow, narrow occasional floodplain pockets are able to form.
Process zone	As this River Style is confined there is limited area for sediment storage, thus it is dominantly a bedload transfer zone. However, sediment may be locally sourced from adjacent colluvial hillslopes. Only localised sediment storage occurs in small, occasional floodplain pockets.
Valley morphology (size and shape)	These confined valleys tend to have high relief, be deeply incised and narrow (only up to 200 m along Rouchel Brook). The valley can be irregularly shaped or moderately sinuous, valley crest to crest is approximately 1.75km.

Valley slope	Slope tends to be relatively steep, with an average of 0.02																																																																															
Stream power	<table border="1"> <thead> <tr> <th colspan="8">Occasional Floodplain Pockets (Isis River - 152989 Ellerston 9134)</th> </tr> <tr> <th colspan="8">(Geomorphic Assessor output using Log Pearson discharge – catchment relationship)</th> </tr> <tr> <th></th> <th>1.1 yrs</th> <th>2 yrs</th> <th>5 yrs</th> <th>10 yrs</th> <th>25 yrs</th> <th>50 yrs</th> <th>100 yrs</th> </tr> </thead> <tbody> <tr> <td>Stream Power (N/s/m or Watts/m)</td> <td>366.9</td> <td>8204.7</td> <td>28564.4</td> <td>54783.6</td> <td>108731.5</td> <td>168221.6</td> <td>247762.8</td> </tr> <tr> <td>Energy Slope</td> <td>0.0119083</td> <td>0.0119083</td> <td>0.0119083</td> <td>0.0119083</td> <td>0.0119083</td> <td>0.0119083</td> <td>0.0119083</td> </tr> <tr> <td>Critical Flow (m³/s)</td> <td>3.140303</td> <td>70.23357</td> <td>244.5162</td> <td>468.95761</td> <td>930.76064</td> <td>1440.0069</td> <td>2120.8936</td> </tr> <tr> <td>Water Levels (m)</td> <td>-11.41</td> <td>-9.81</td> <td>-8.32</td> <td>-7.58</td> <td>-6.51</td> <td>-5.6</td> <td>-4.6</td> </tr> <tr> <td>Critical Surface Width (m)</td> <td>5.9</td> <td>17.8</td> <td>78.7</td> <td>81.8</td> <td>86.6</td> <td>92.5</td> <td>99</td> </tr> <tr> <td>Unit Stream Power (Watts/m² or N/m²/s)</td> <td>62.2</td> <td>460.9</td> <td>363</td> <td>669.7</td> <td>1255.6</td> <td>1818.6</td> <td>2502.7</td> </tr> </tbody> </table>								Occasional Floodplain Pockets (Isis River - 152989 Ellerston 9134)								(Geomorphic Assessor output using Log Pearson discharge – catchment relationship)									1.1 yrs	2 yrs	5 yrs	10 yrs	25 yrs	50 yrs	100 yrs	Stream Power (N/s/m or Watts/m)	366.9	8204.7	28564.4	54783.6	108731.5	168221.6	247762.8	Energy Slope	0.0119083	0.0119083	0.0119083	0.0119083	0.0119083	0.0119083	0.0119083	Critical Flow (m³/s)	3.140303	70.23357	244.5162	468.95761	930.76064	1440.0069	2120.8936	Water Levels (m)	-11.41	-9.81	-8.32	-7.58	-6.51	-5.6	-4.6	Critical Surface Width (m)	5.9	17.8	78.7	81.8	86.6	92.5	99	Unit Stream Power (Watts/m² or N/m²/s)	62.2	460.9	363	669.7	1255.6	1818.6	2502.7
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**Figure 20: Schematic cross section, Occasional Floodplain Pockets River Style
(Isis River - 152989 Ellerston 9134)**



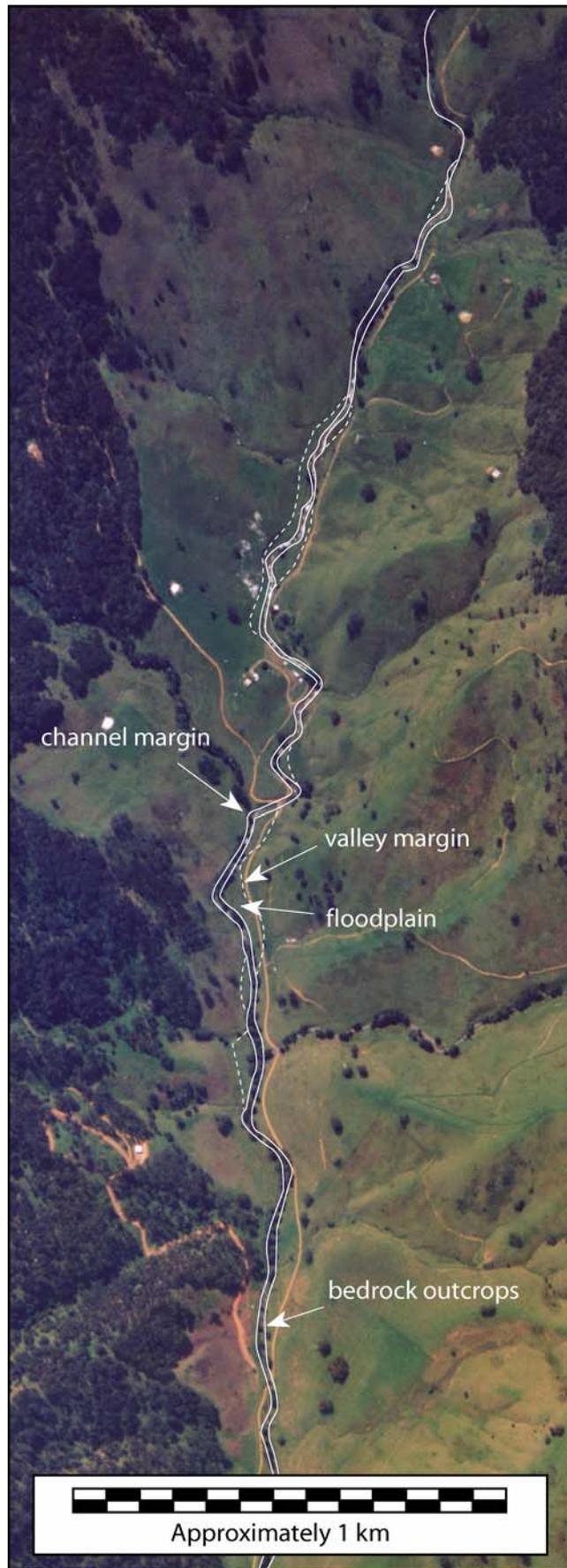


Figure 21: Aerial View of an Occasional Floodplain Pockets River Style reach, Rouchel Brook



Figure 22: Occasional Floodplain Pockets River Style on Stewarts Brook, looking upstream