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 **<u>integrate</u>** 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 *valley-setting* in which a river is formed.
Valley-setting	The ***confined valley-setting*** has no floodplain or isolated pockets of floodplain. Over 90% of the channel margin abuts the valley margin. The ***partly-confined valley-setting*** contains discrete but discontinuous floodplain pockets that can alternate in a downstream direction. Between 10-90% of the channel abuts the valley margin. The ***laterally-unconfined valley-setting*** is characterised by rivers with continuous floodplains along both channel banks. Less then 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	*Imposed boundary conditions* 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	F*lux boundary conditions* 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 <u>and</u> 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 been 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 km^2 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

Stage One, Step One: Assessment of regional and catchment setting controls

(1) Review background information and available literature.

⇓

(2) Derive catchment-framed maps including streamlines, geology, rainfall distribution, land use etc., using GIS where available.

⇓

(3) Designate landscape units

⇓

(4) Produce longitudinal profiles with contributing area plots.

⇓

(5) Analyse subcatchment morphometric parameters.

⇓

(6) Analyse discharge data and hydrological regimes.

(7) Present regional setting information.

Stage One, Step Two: Definition and mapping of River Styles

(1) Analyse the catchment-wide distribution of River Styles.

(2) Designate River Styles using air photographs and produce of a River Styles.

⇓

(3) Select representative reaches of each River Style and draft proformas and planform maps using air photograph interpretation.

⇓

(4) Ratify River Styles boundaries in the field.

⇓

(5) Complete field analyses to finalise proformas and amend planform maps at each representative field.

⇓

(6) Characterise and explain river behaviour for each River Style through interpretation of reach-scale assemblages of geomorphic units.

Stage One, Step Three: Interpretation of controls on the character, behaviour and downstream patterns of River Styles

(1) Determine downstream patterns of River Styles. Group the tributaries and trunk stream according to their patterns.

⇓

(2) Determine the imposed boundary condition controls on river character and behaviour along longitudinal profiles.

⇓

(3) Determine the flux boundary condition controls on river character and behaviour along longitudinal profiles.

⇓

(4) For representative examples of each downstream pattern of River Styles, produce a summary longitudinal profile that synthesises the relationship between patterns of River Styles and relevant controlling parameters.

⇓

(5) Produce a summary table that synthesises catchment-wide understanding of controls on 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.

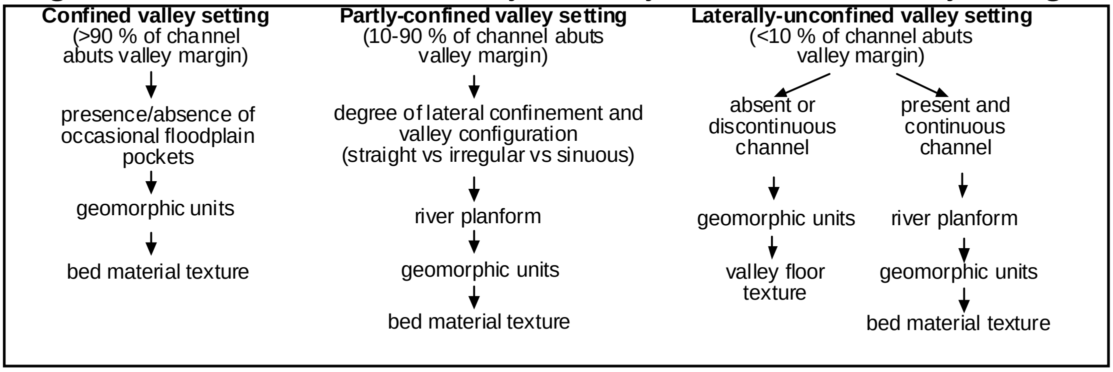
For the Upper Hunter catchment, regional setting analyses involved compilation of significant historical and archival information (sourced from the Mitchell Library in Sydney, that State Archives in Sydney, the Muswellbrook Office of the NSW Department of Infrastructure, Planning and Natural Resources (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.

Figure 3 Procedures used to identify River Styles® in different 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 km^2), 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 4^{th} 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 overlayed 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 km^2 of which the Upper Hunter Catchment covers about 20%. The Upper Hunter Catchment covers an area of around 4,480 km^2 from its confluence with the Goulburn River at Denman. In this report 13 river courses were assessed ranging in catchment area from 4481 km^2 (Hunter River) to 71 km^2 (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.

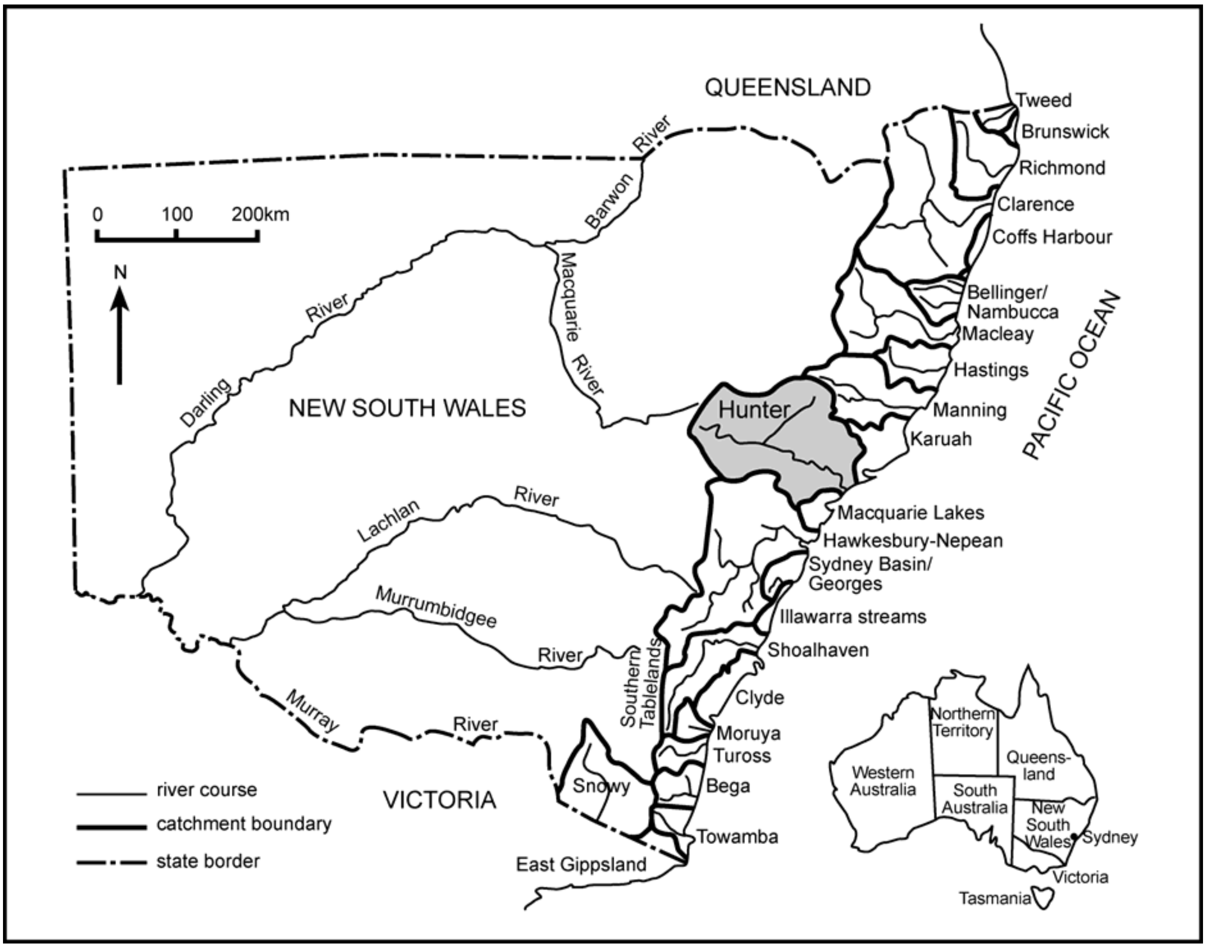


Figure 4: The location of the Hunter Catchment within Australian and NSW.

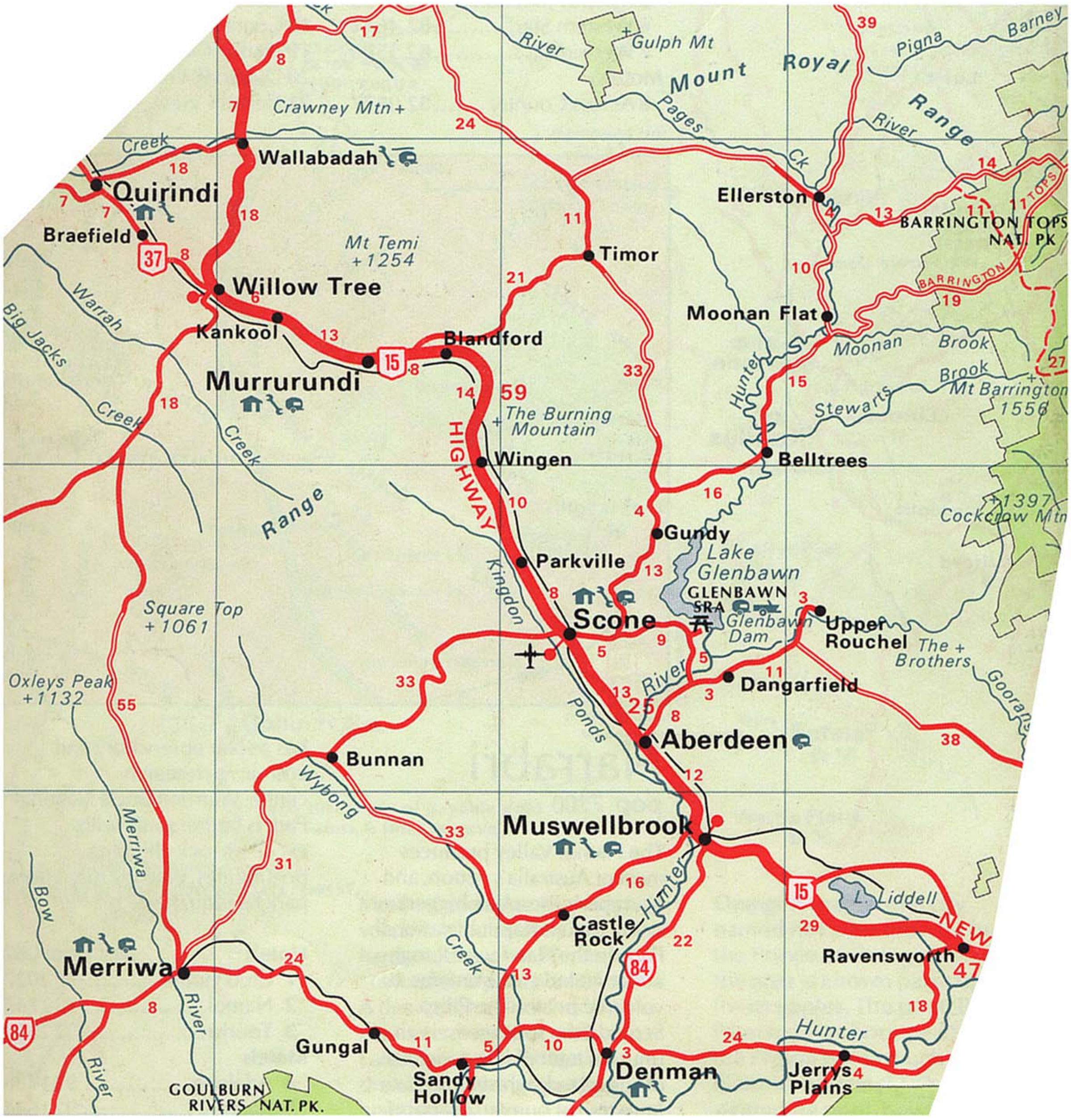


Figure 5: General road map of the Upper Hunter area with many of the place names referred to in this report.

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, were 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, where as, 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.

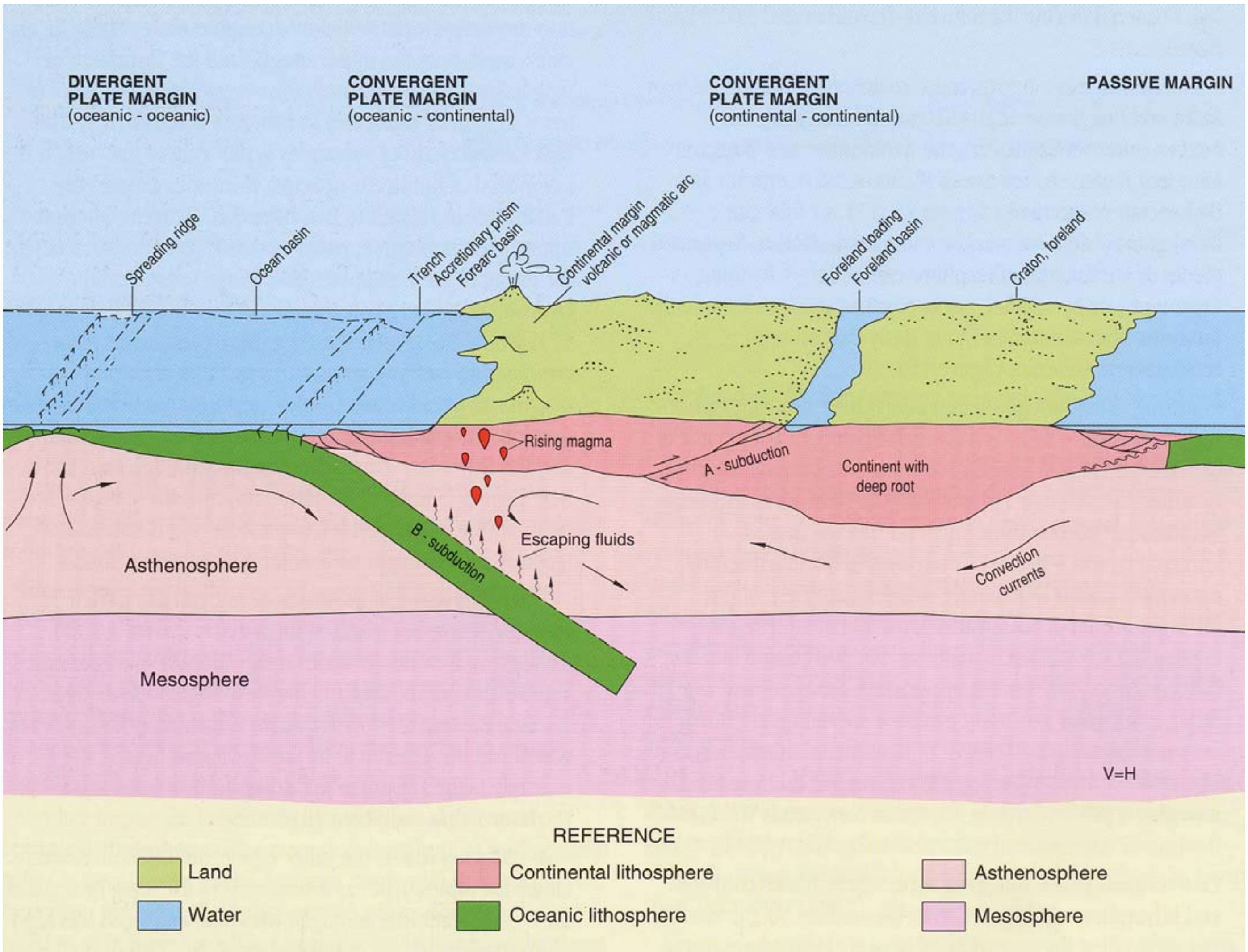


Figure 6: Subduction Model. In the context of the subduction along the east coast of Australia this diagram is drawn looking southward.
(Source: Anon 1999, pp12)

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 overthrusted 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.

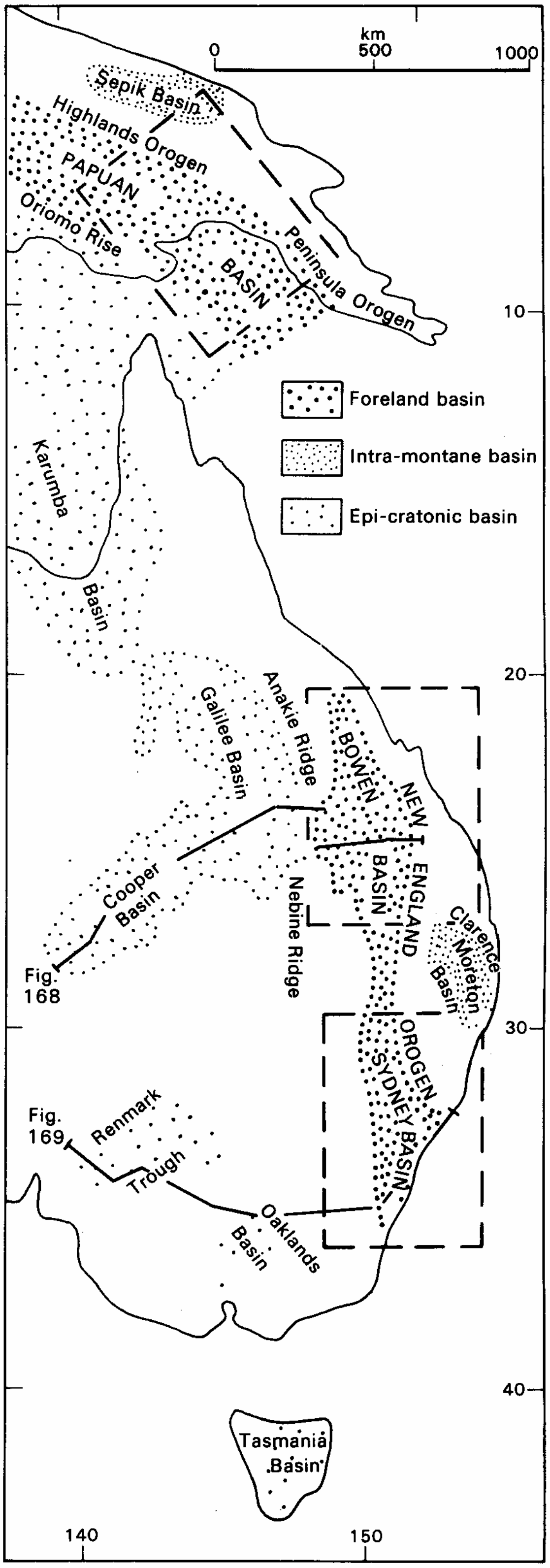


Figure 7: Australia – Papua New Guinea Analogue.
(Source: Jones et al. 1984, pp258)

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.

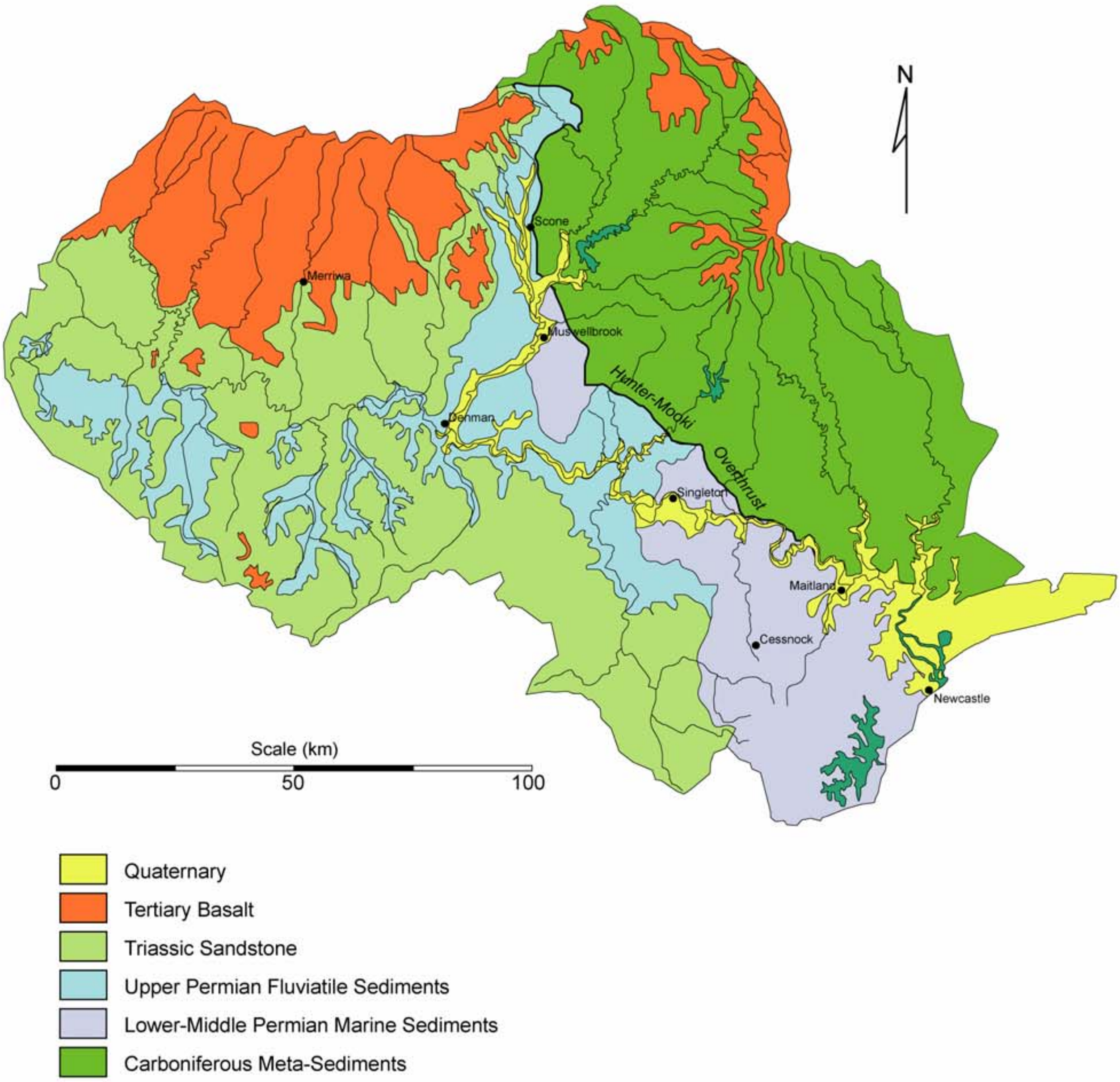
Since the Permian/Triassic Periods the New England Fold Belt has been eroded and worn until the volcanoes, mountains, and valleys of the highlands disappeared.

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.

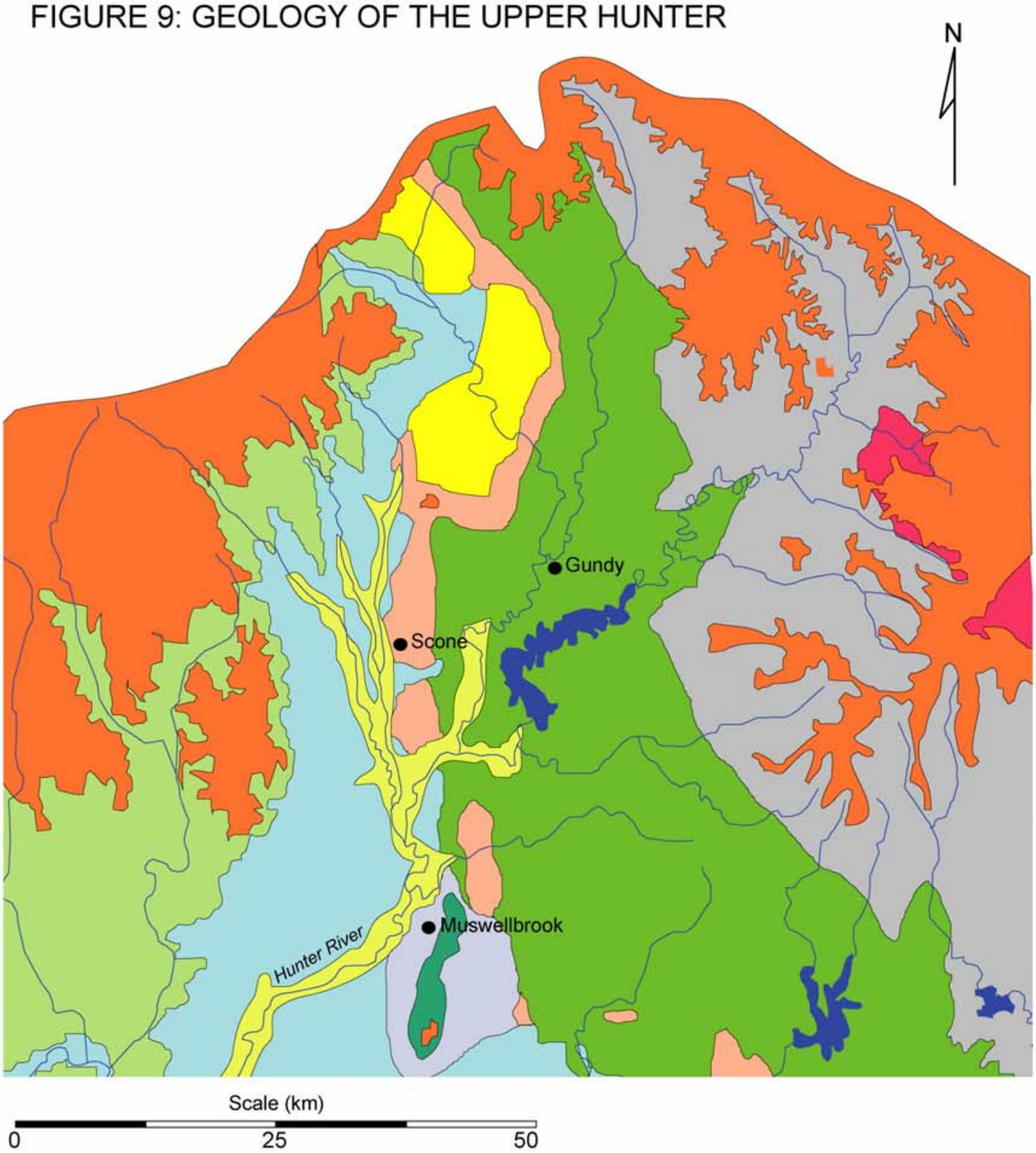
Figure 8 is a geological map of the Hunter Catchment and figure 9 is an excerpt of the upper Hunter. The geological map (fig 8) shows Permian sediments abutting the Hunter – Mooki Fault. These consist of coal measures, claystone, siltstones, sandstones, and conglomerates. Stratagraphically above the 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 diminish 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.

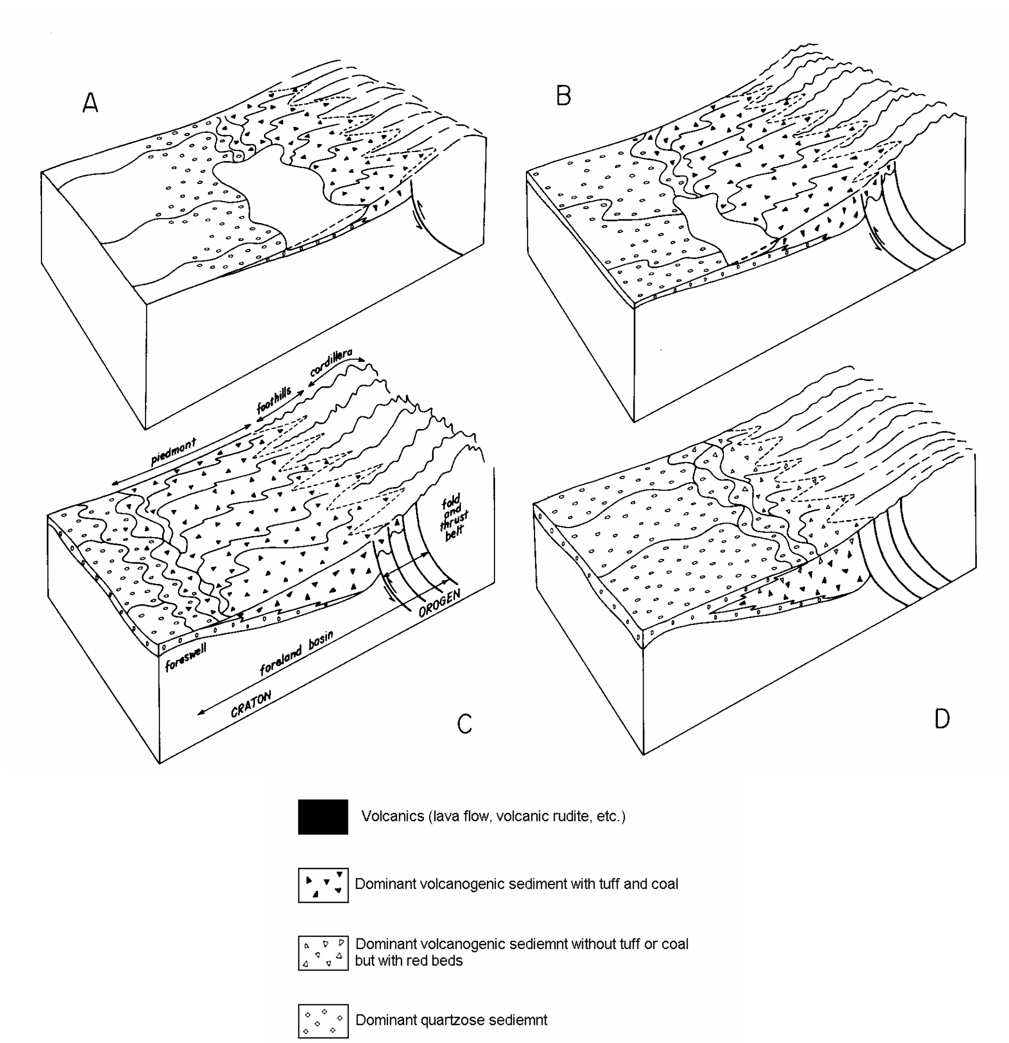


Figure 10: Model of Sedimentation
(Source: Jones et al. 1984, pp258)

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

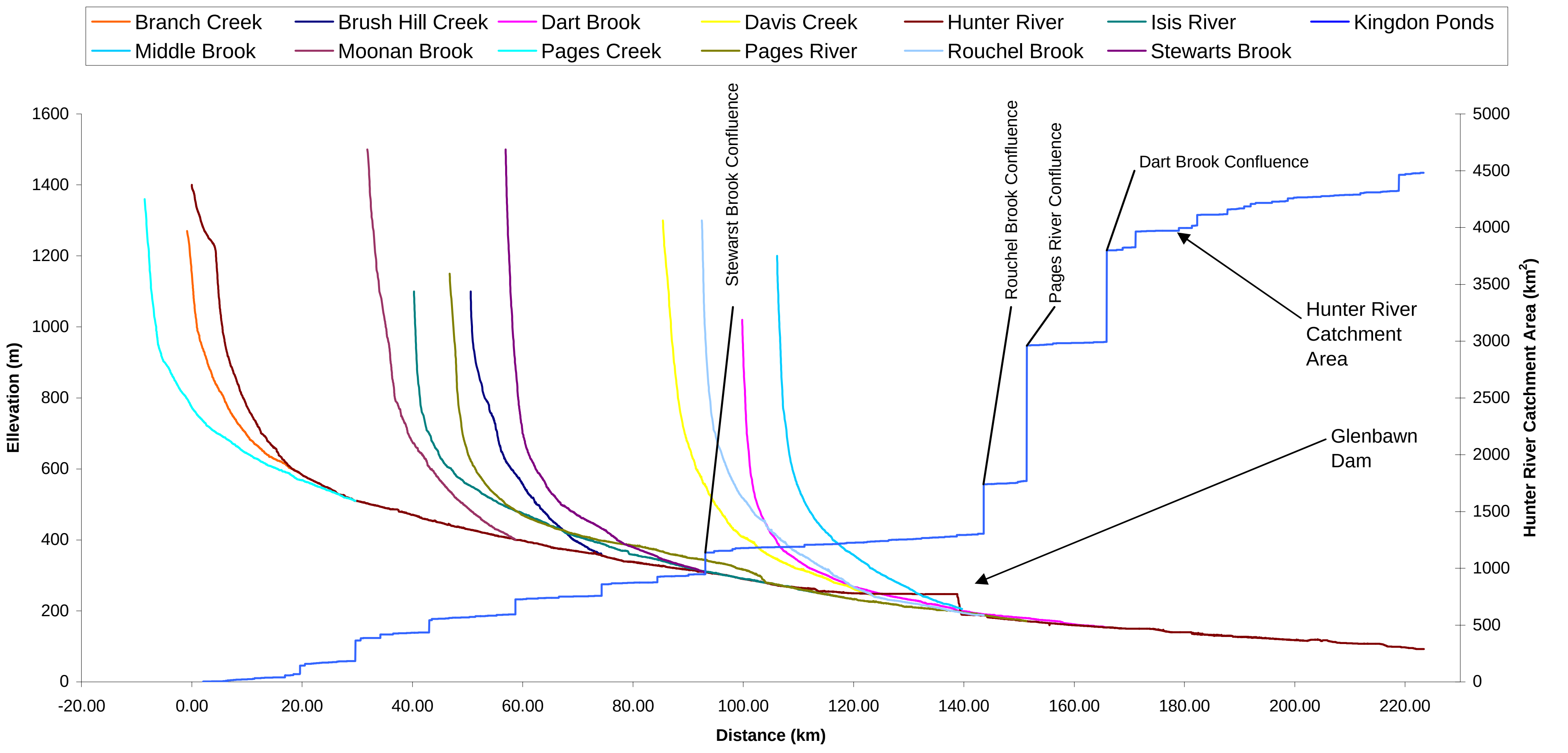


Figure 13-1: Longitudinal Profile Branch Creek

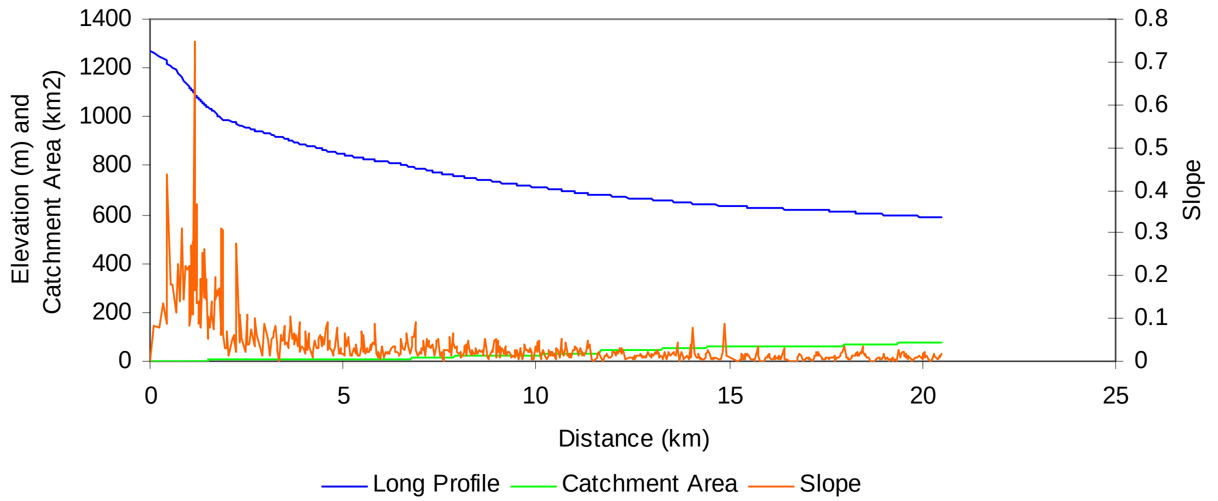


Figure 13-2: Longitudinal Profile Brush Hill Creek

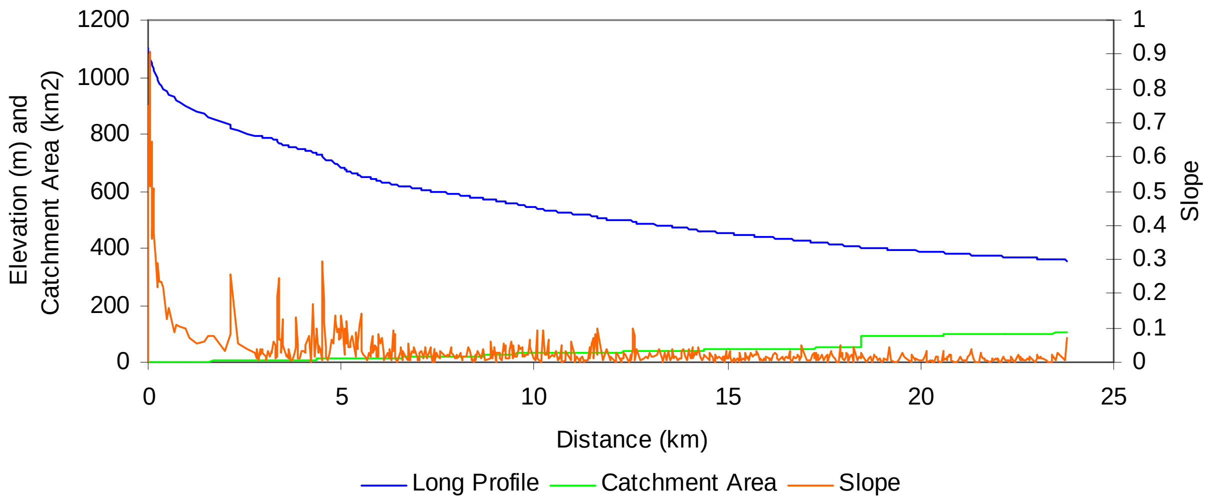


Figure 13-3: Longitudinal Profile Dart Brook

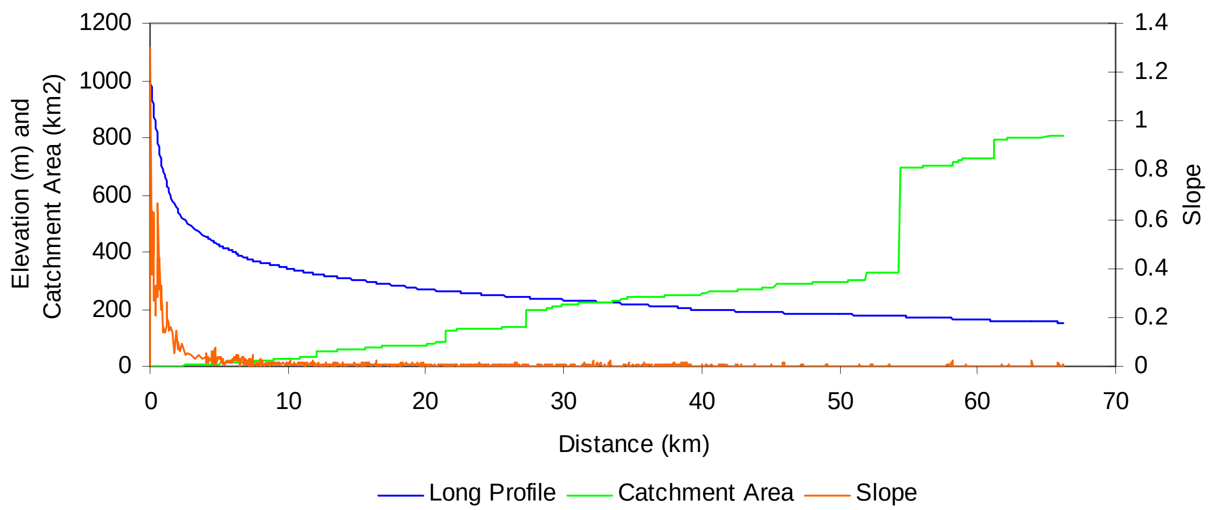


Figure 13-4: Longitudinal Profile Davis Creek

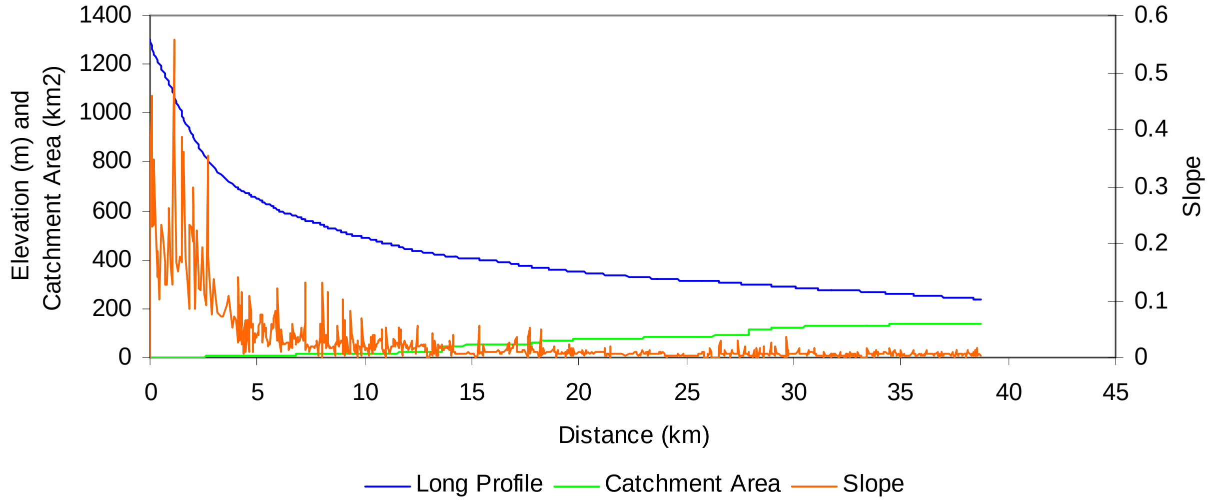


Figure 13-5: Longitudinal Profile Hunter River

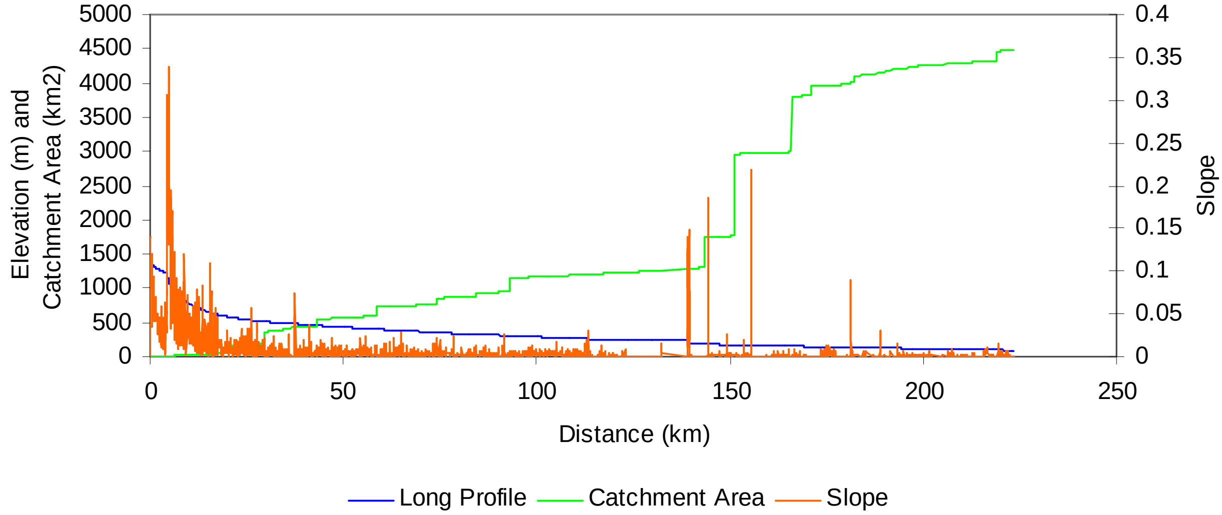


Figure 13-6: Longitudinal Profile Isis River

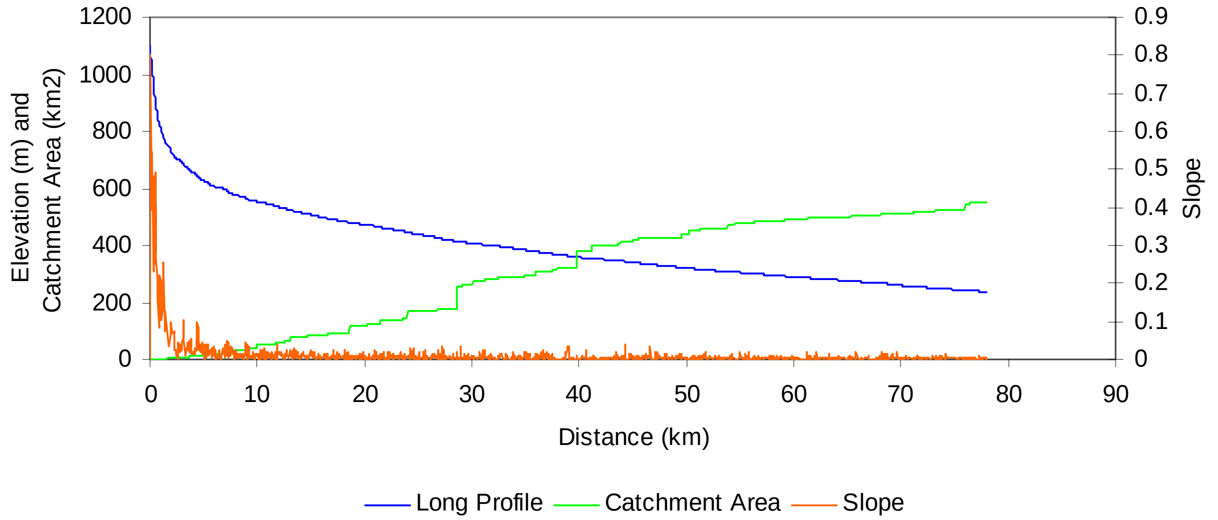


Figure 13-7: Longitudinal Profile Kingdon Ponds

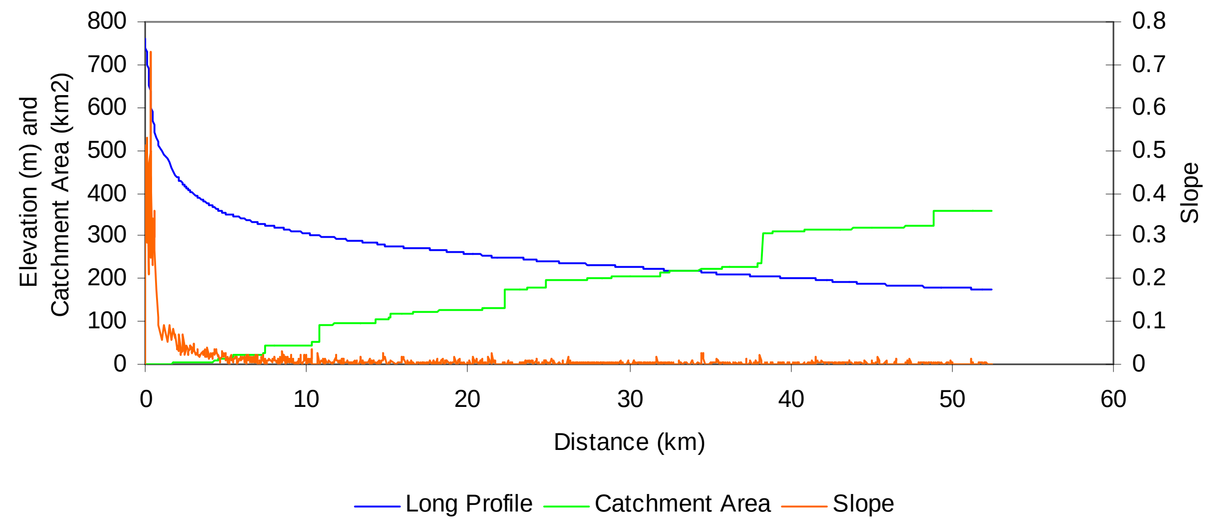


Figure 13-8: Longitudinal Profile Middle Brook

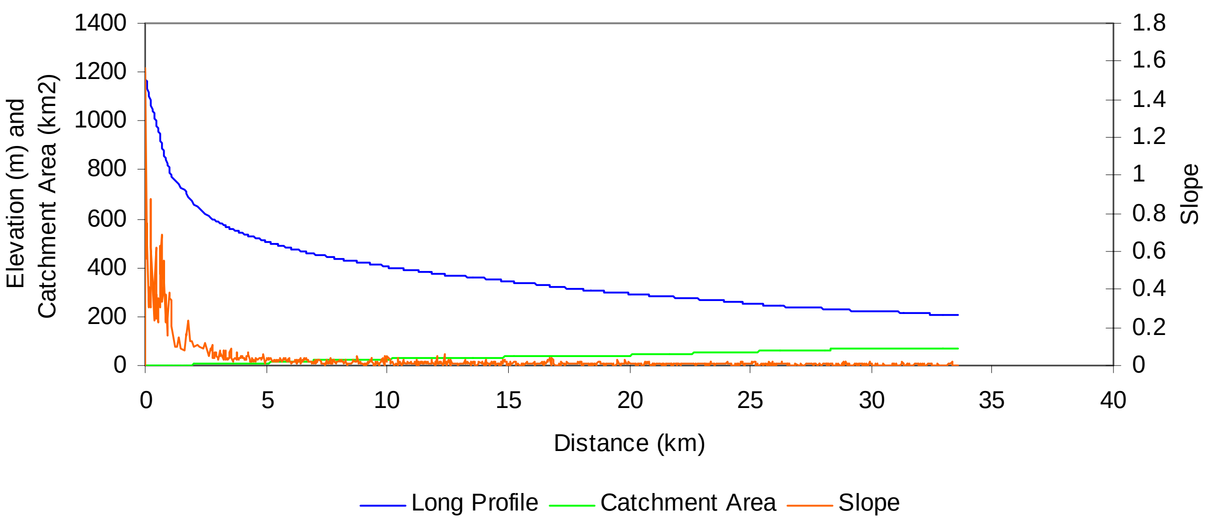


Figure 13-9: Longitudinal Profile Moonan Brook

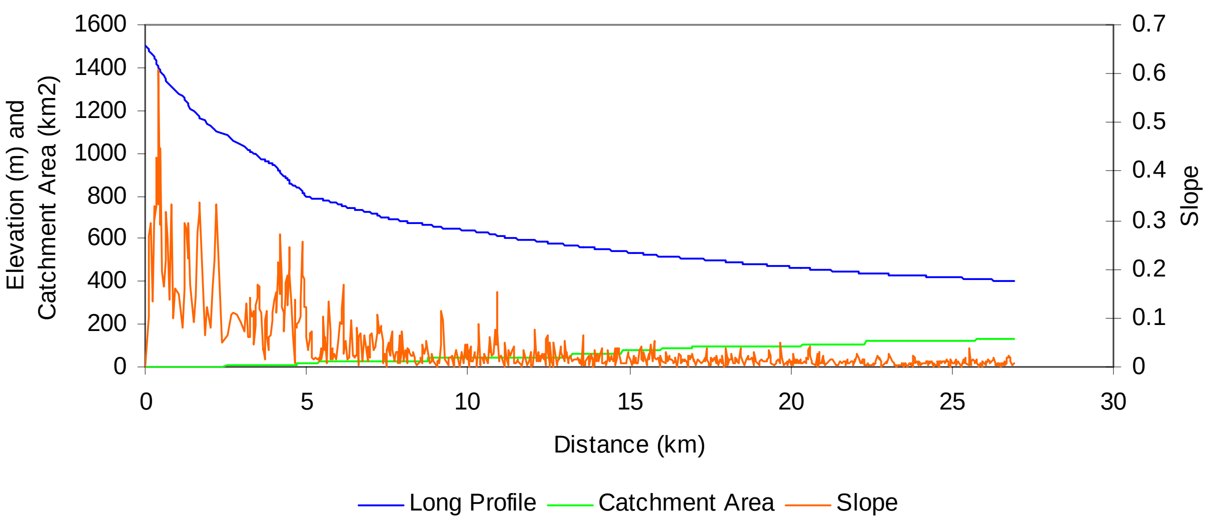


Figure 13-10: Longitudinal Profile Pages Creek

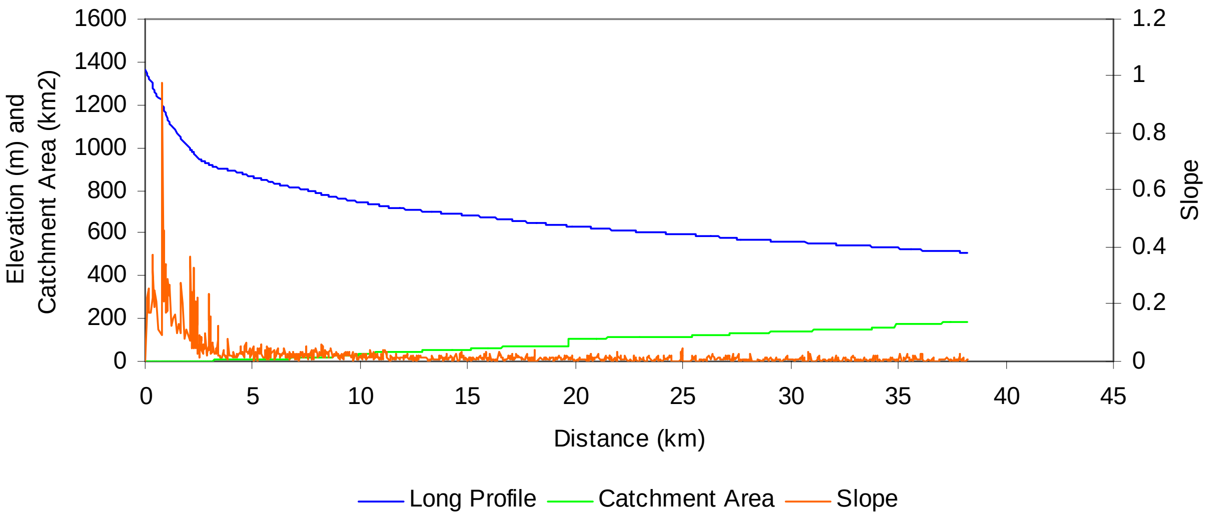


Figure 13-11: Longitudinal Profile Pages River

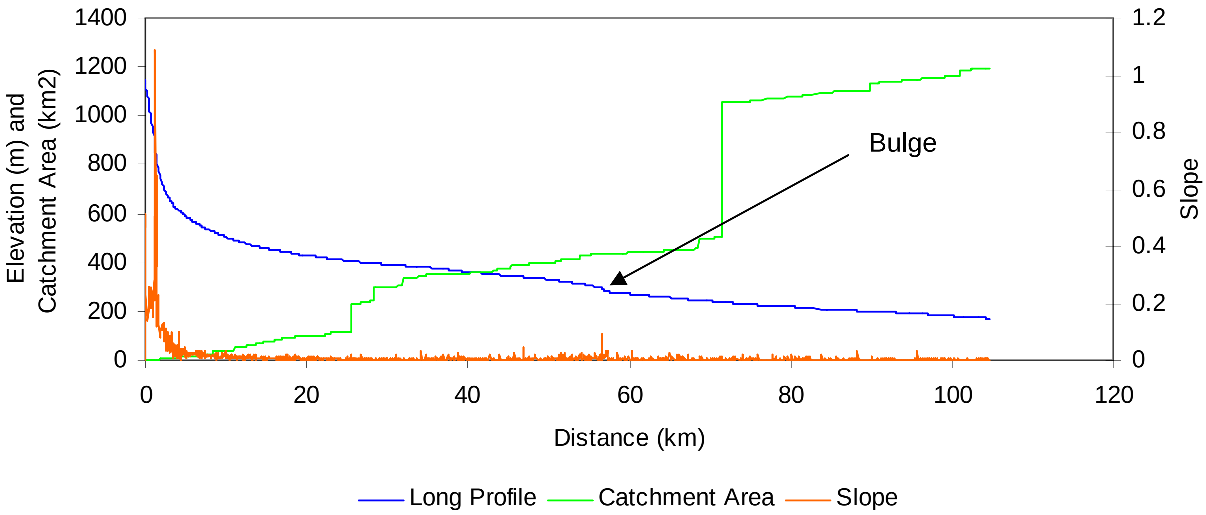
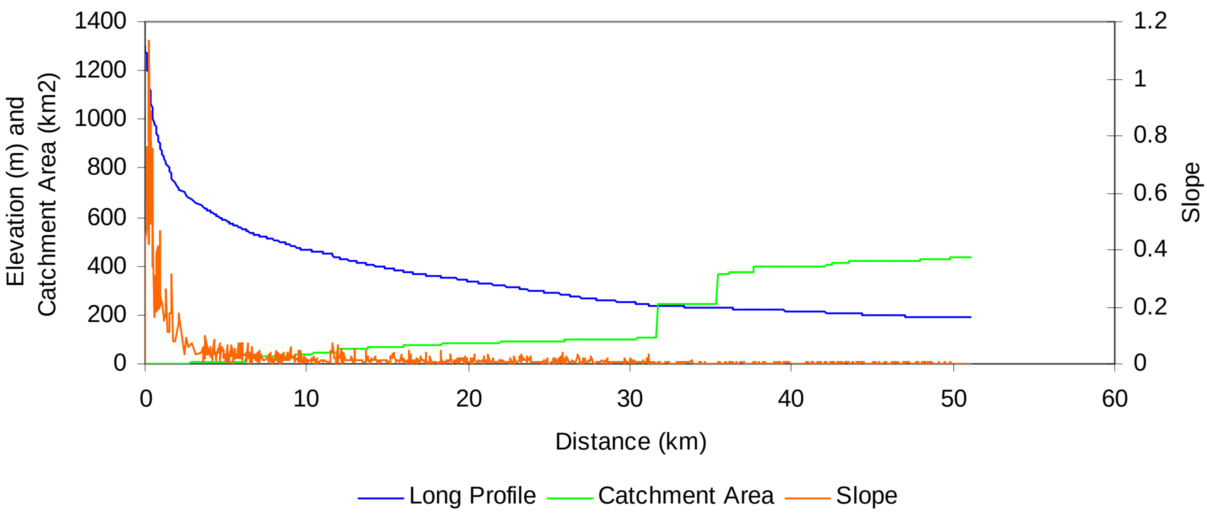
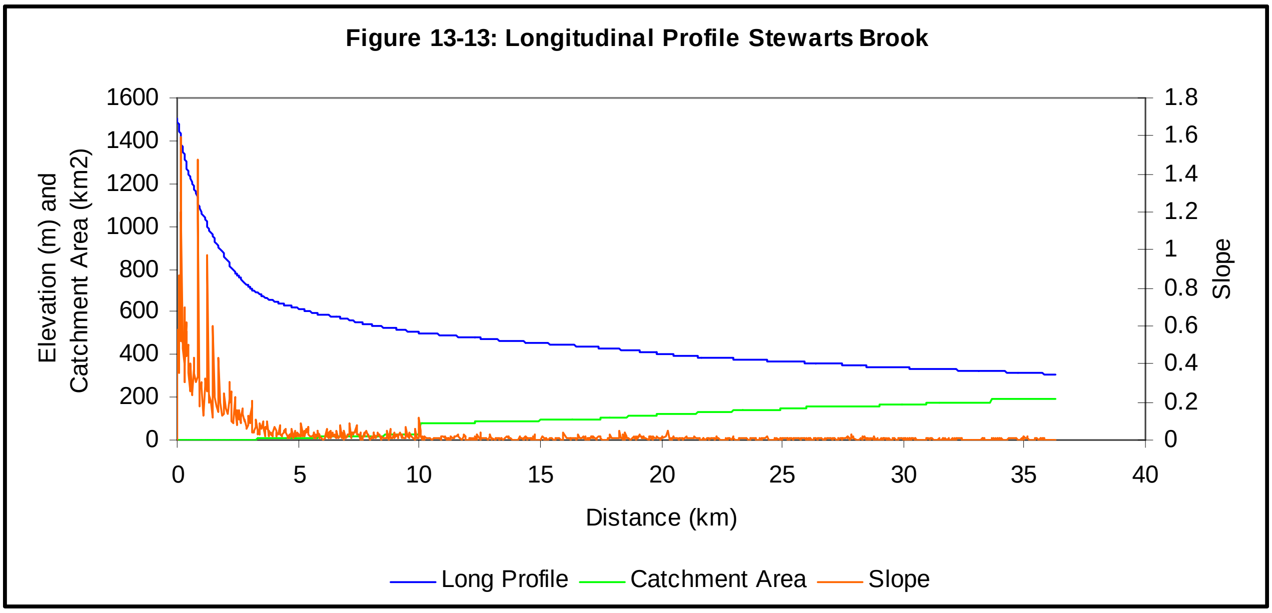


Figure 13-12: Longitudinal Profile Rouchel Brook





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 40ºC 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 7ºC. 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.

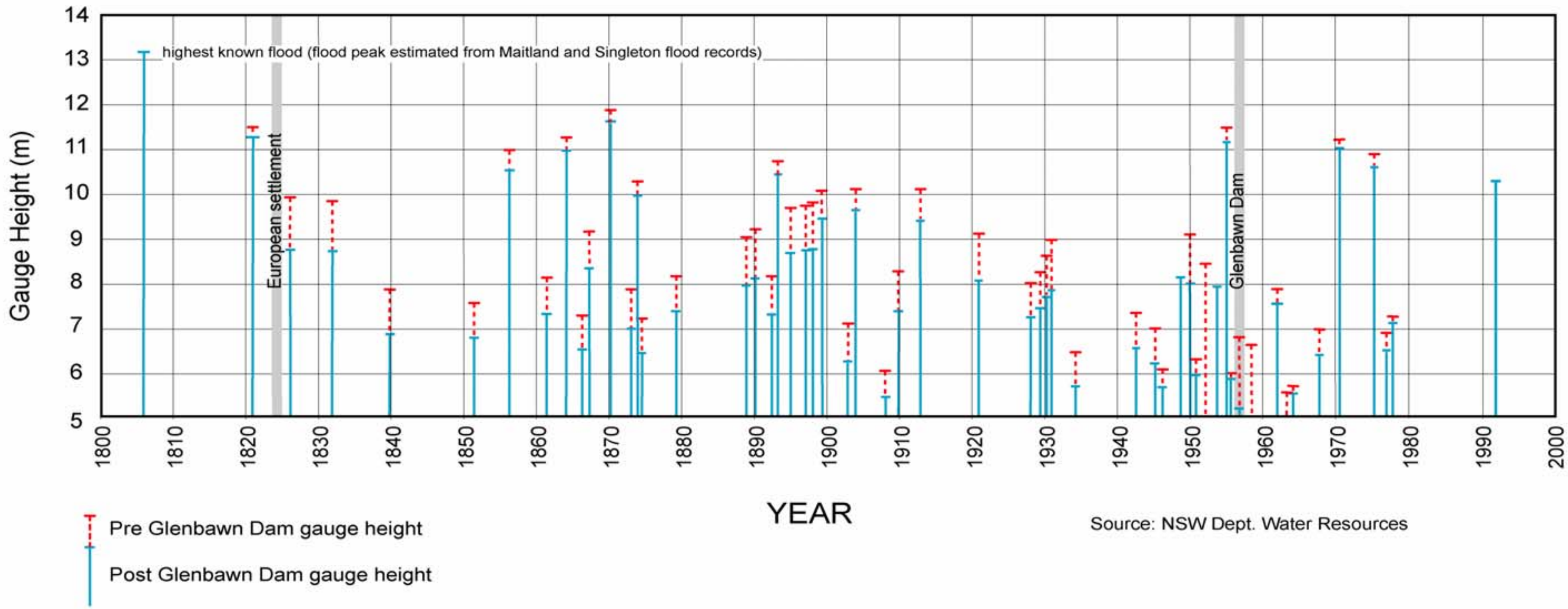
The second form of weather pattern responsible for flooding in the Hunter Valley involves the penetration of moist equatorial air inland to higher latitudes. Lifting of this air mass due to its interception with cooler, dense coastal inflow produces intense regional precipitation. This phenomenon tends 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.

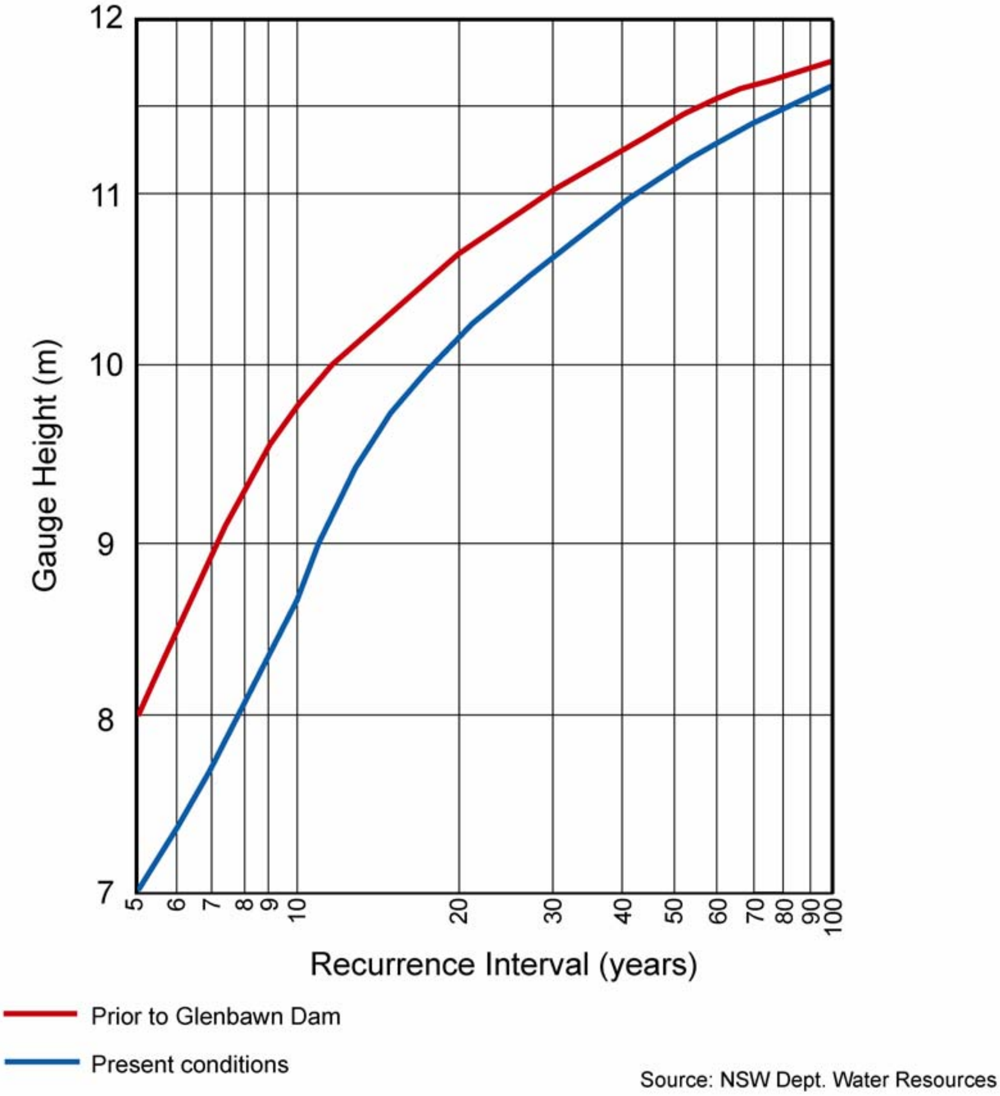


Source: NSW Dept. Water Resources

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.

Figure 15: Flood frequency curve for the Hunter River at Muswellbrook



Source: NSW Dept. Water Resources

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 km^2, 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 cilliata*) 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 foliaged 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 early19th 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 19^{th} and early 20^{th} 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.

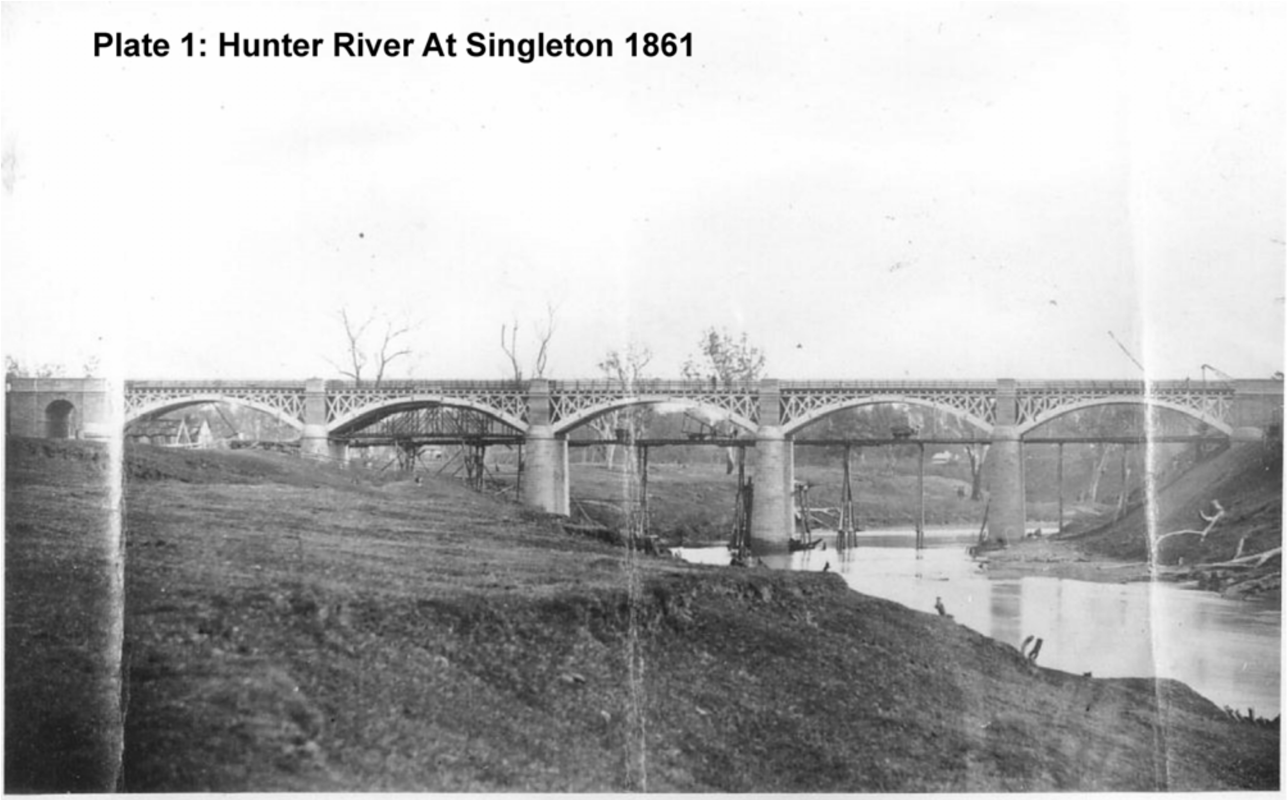


Plate 1: Hunter River At Singleton 1861

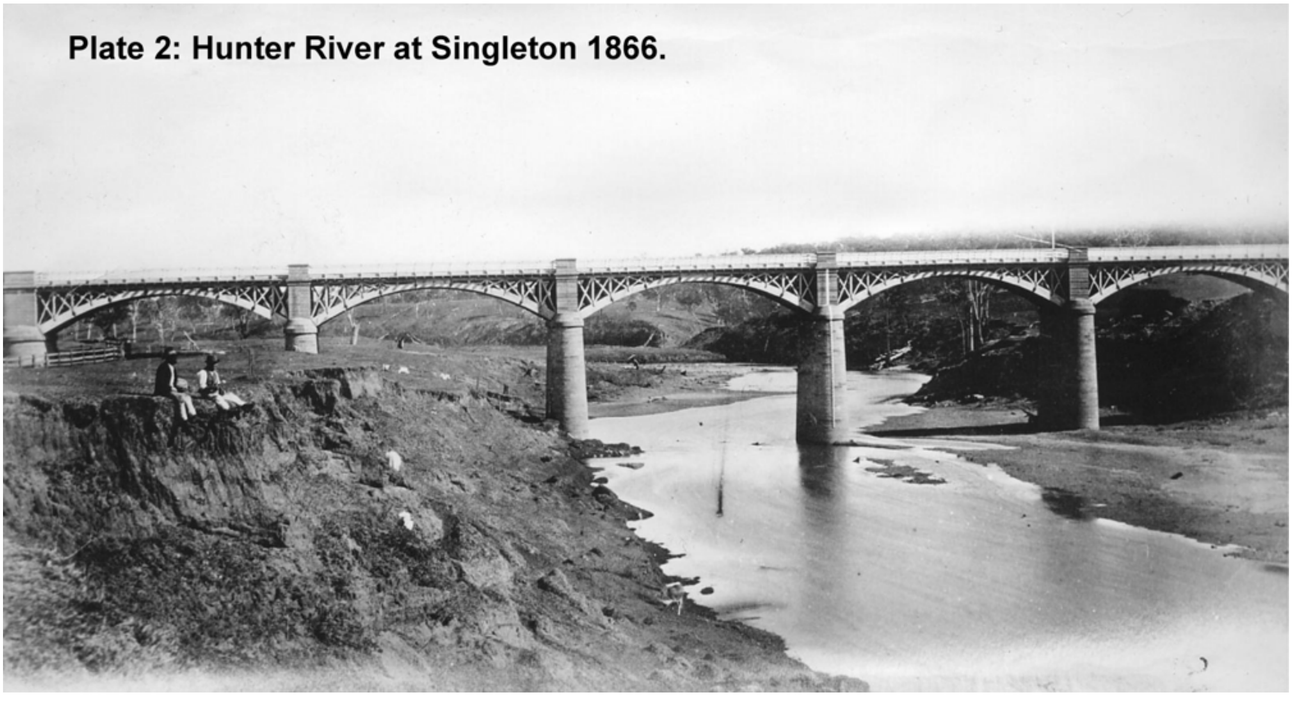
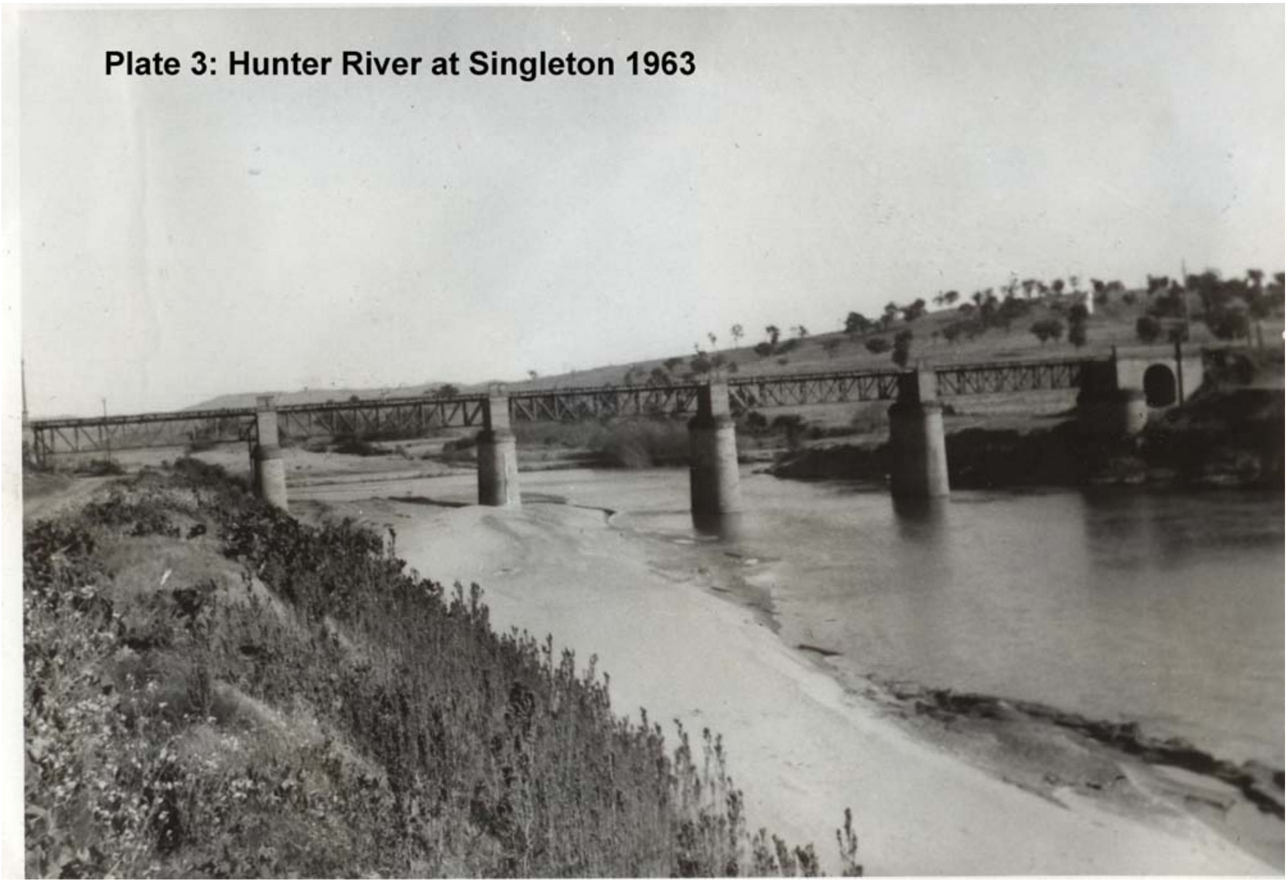


Plate 2: Hunter River at Singleton 1866.



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

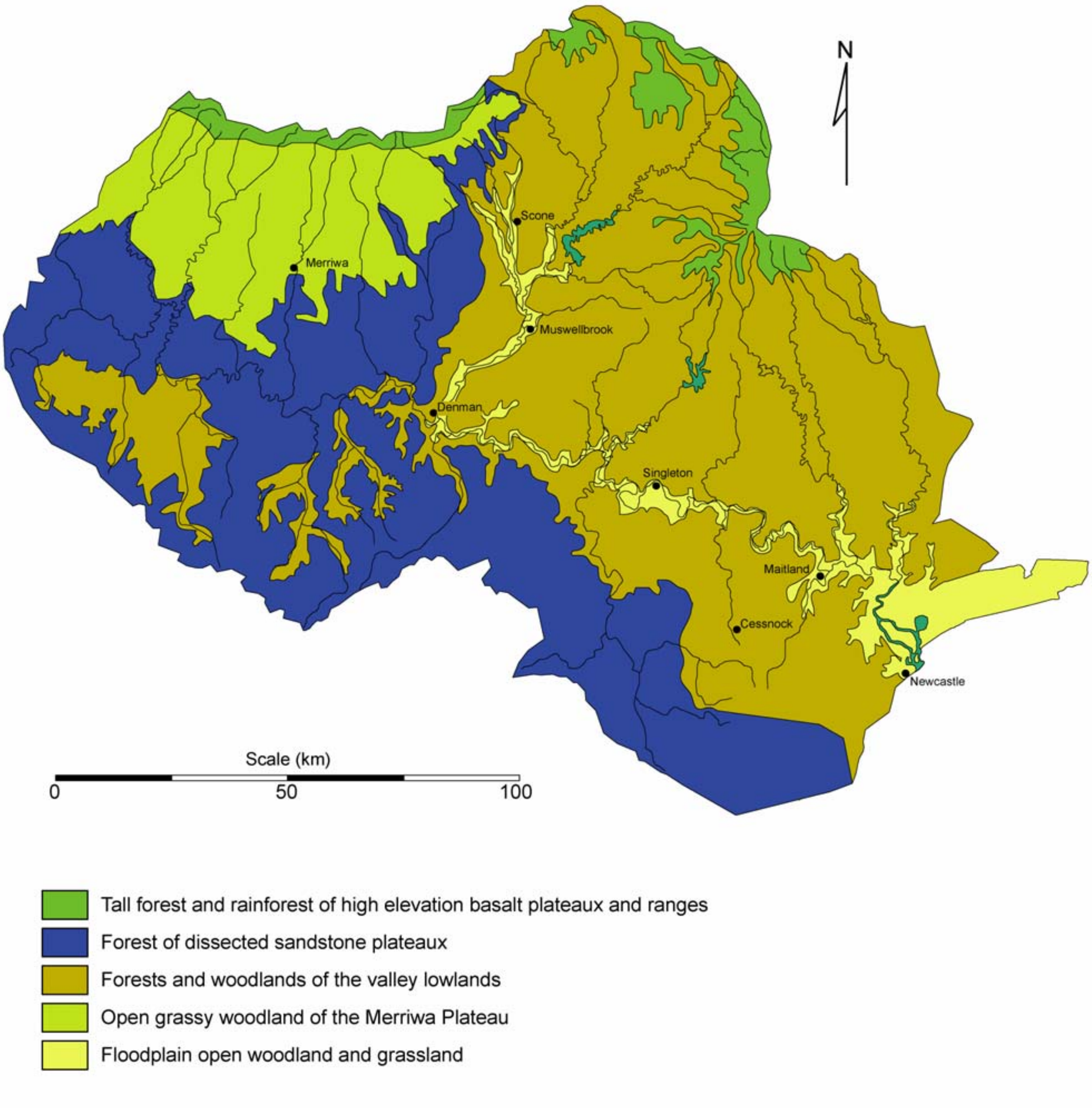
The Hunter Valley is floristically diverse. Due to the lack of a western escarpment and degree of penetration inland, the Hunter Valley marks both the most eastern and western extent of a significant number of plant species. Similarly, due to its unique geography, the Hunter also serves as a physical 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 Wollomi/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



SOURCE: Peake, 2003.

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 cilliata* (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 trees 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.

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

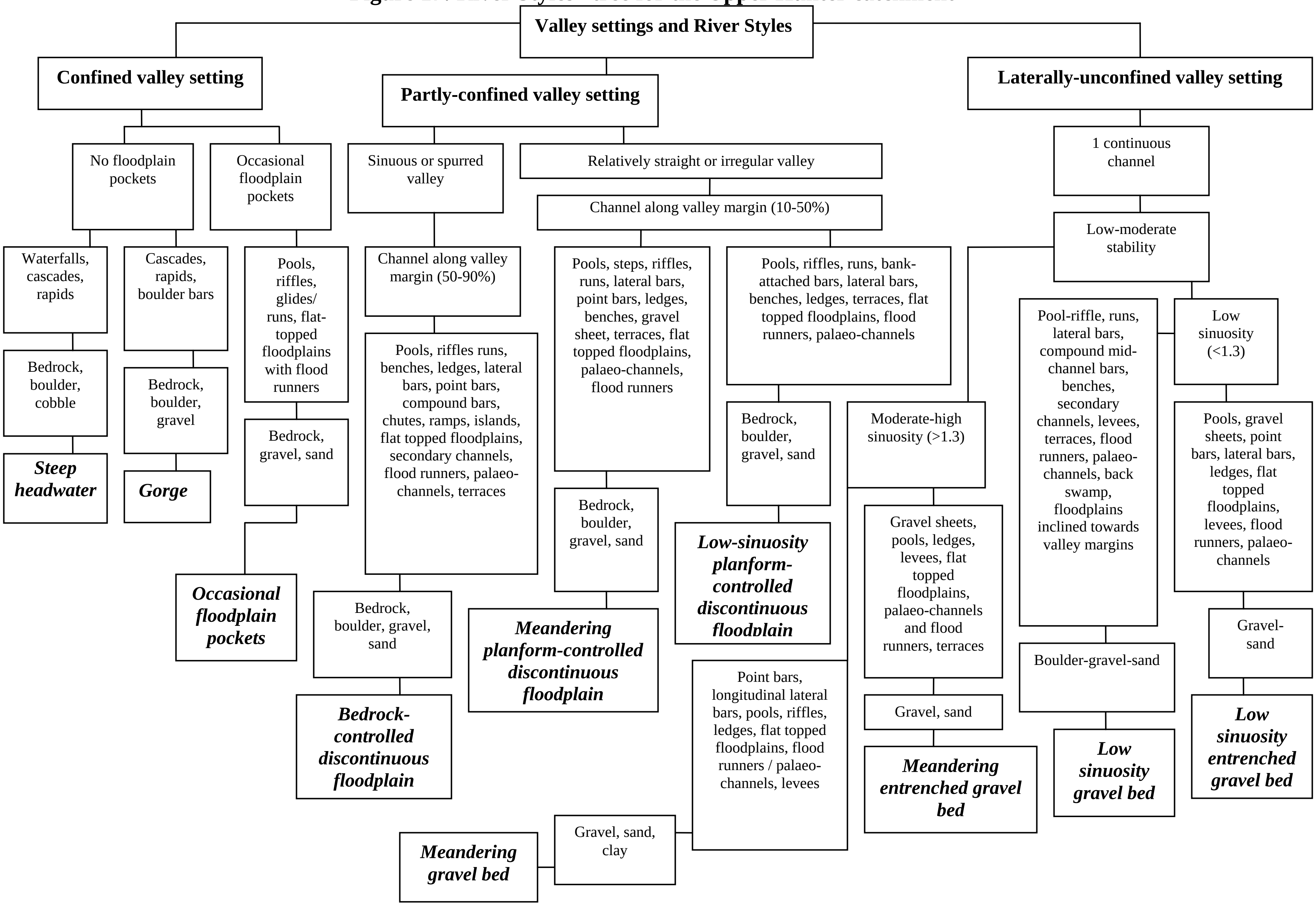
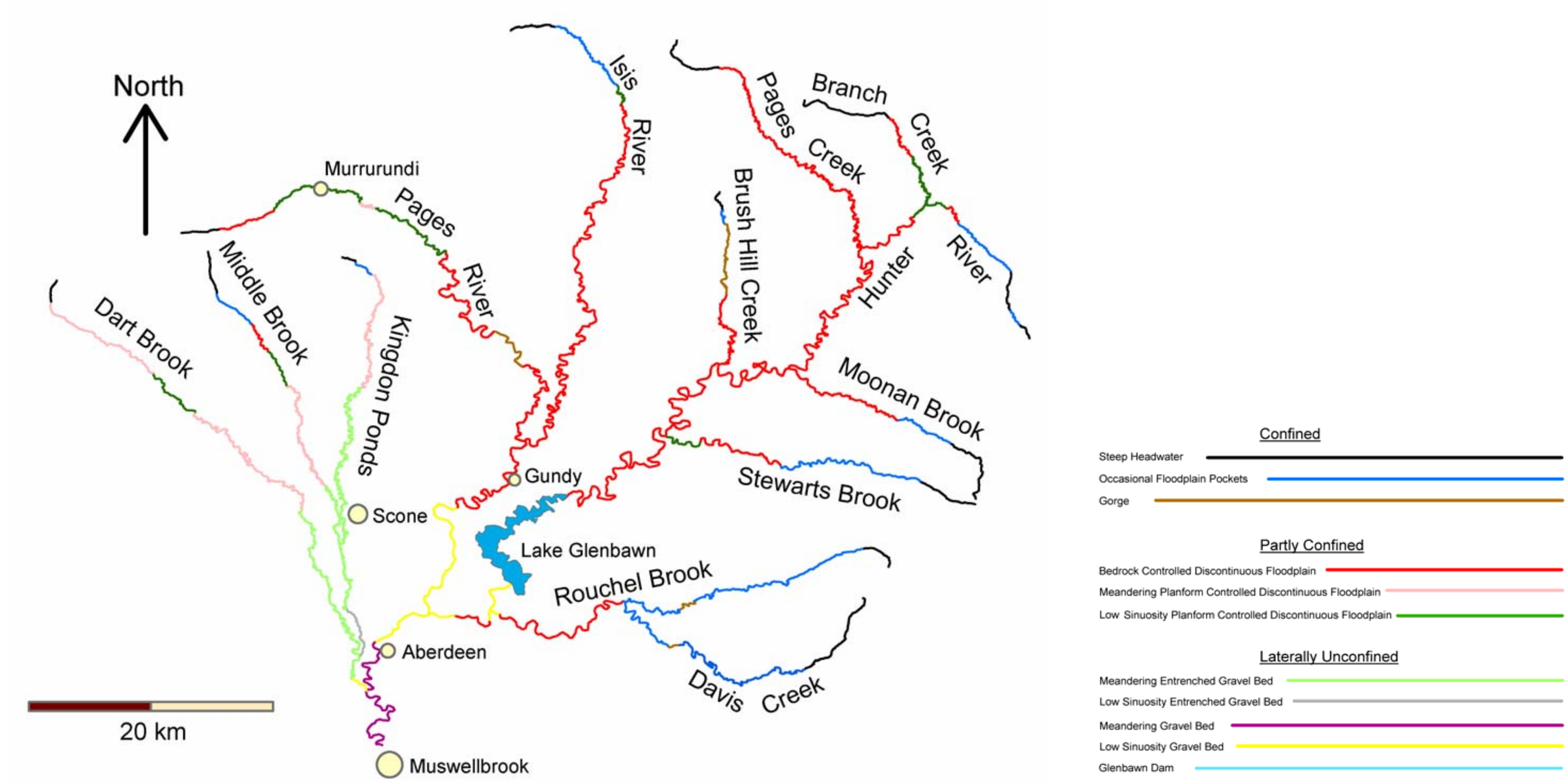


Figure 18: Distribution of River Styles in the Upper Hunter Catchment.



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
Representative sites**:* Middle Brook ***Map sheet(s) air photographs used: ***Analysts**:* Deanne Bird, Kirsty Hughes, Elizabeth Lamaro, Deirdre Wilcock ***Date**:* 29/03/03

RIVER CHARACTER	
Valley-setting	Confined
River planform • 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.

Geomorphic units (geometry, sedimentology)	**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. **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. **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. **Rapids –** Very stable, steep, stair-like sequences formed by arrangements of boulders **Pool and riffle sequences –** bedrock-controlled formations with accumulations of gravel forming undulations in the channel bed. **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.
	Floodplains Due to the confined valley setting there are no floodplain units found along this River Style.
Vegetation associations	**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.
	Floodplain geomorphic units n/a

RIVER BEHAVIOUR

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.

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.

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.

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.

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

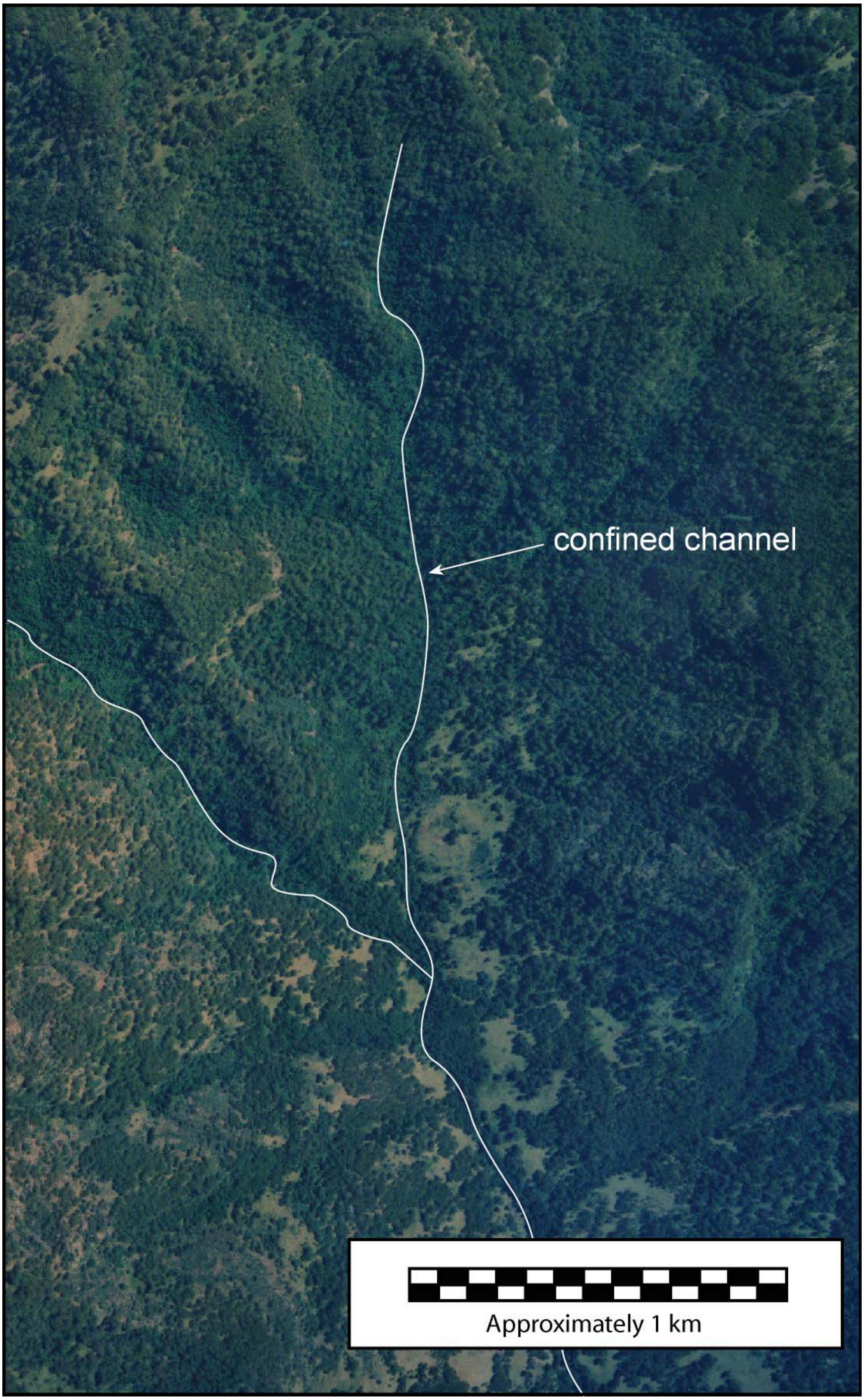


Figure 19: Aerial View of a Steep Headwater River Style reach, Middle Brook.

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 • 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)	**Instream** 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. **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. **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. **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. **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. **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. **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. **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.

	Floodplains 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.
Vegetation associations	**Instream geomorphic units** 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.
	Floodplain geomorphic units 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.

RIVER BEHAVIOUR

Low flow stage
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.

Bankfull stage
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.

Overbank stage
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.

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	see table below

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 (m^3/s)	3.140303	70.23357	244.5162	468.95761	930.76064	1440.0069	2120.8936
Water Level is (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/m^2 or N/m^2/s)	62.2	460.9	363	669.7	1255.6	1818.6	2502.7

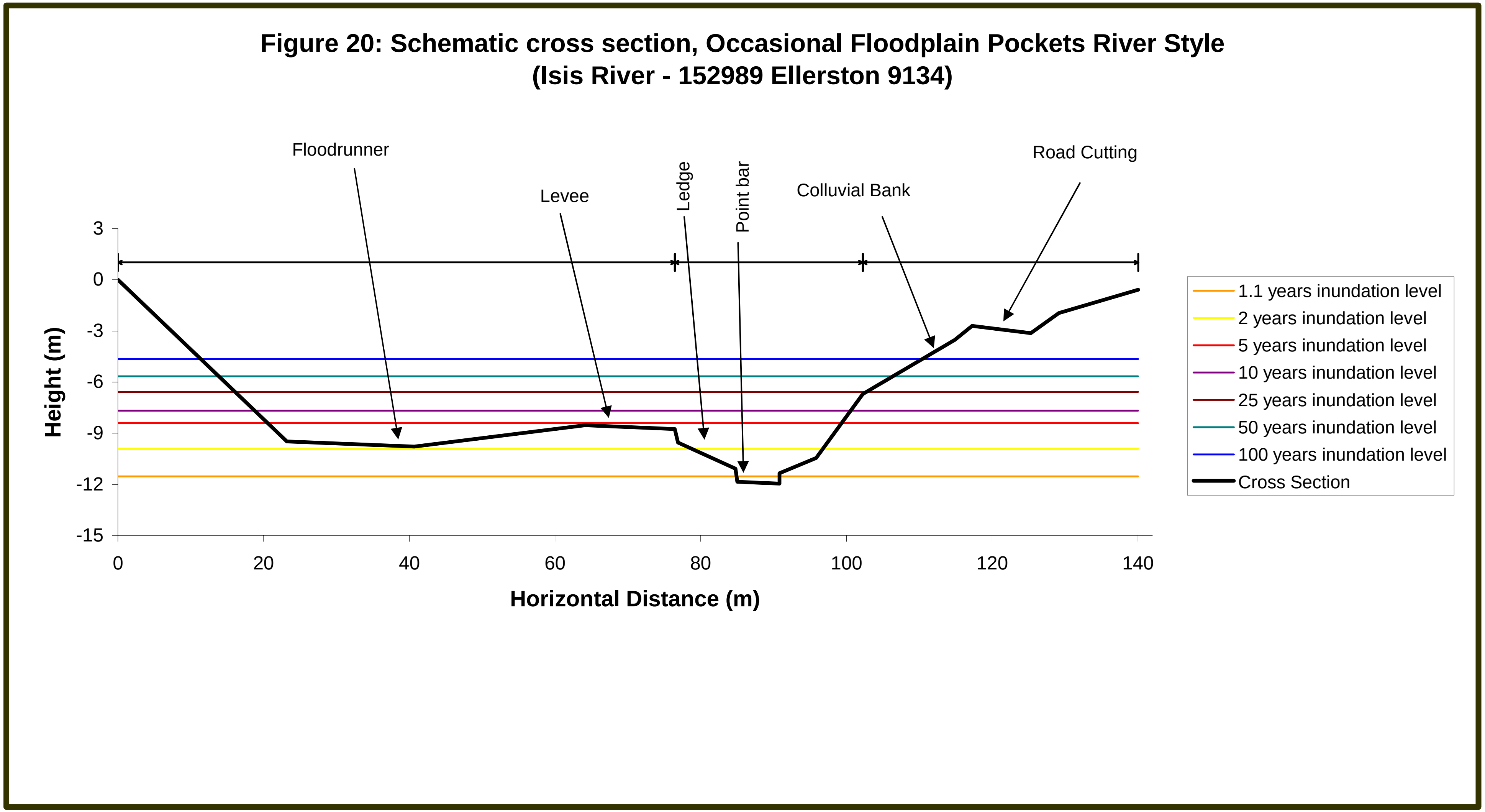


Figure 20: Schematic cross section, Occasional Floodplain Pockets River Style
(Isis River - 152989 Ellerston 9134)
Floodrunner
Levee
Ledge
Point bar
Colluvial Bank
Road Cutting
Height (m)
3
0
-3
-6
-9
-12
-15
0
20
40
60
80
100
120
140
Horizontal Distance (m)
1.1 years inundation level
2 years inundation level
5 years inundation level
10 years inundation level
25 years inundation level
50 years inundation level
100 years inundation level
Cross Section

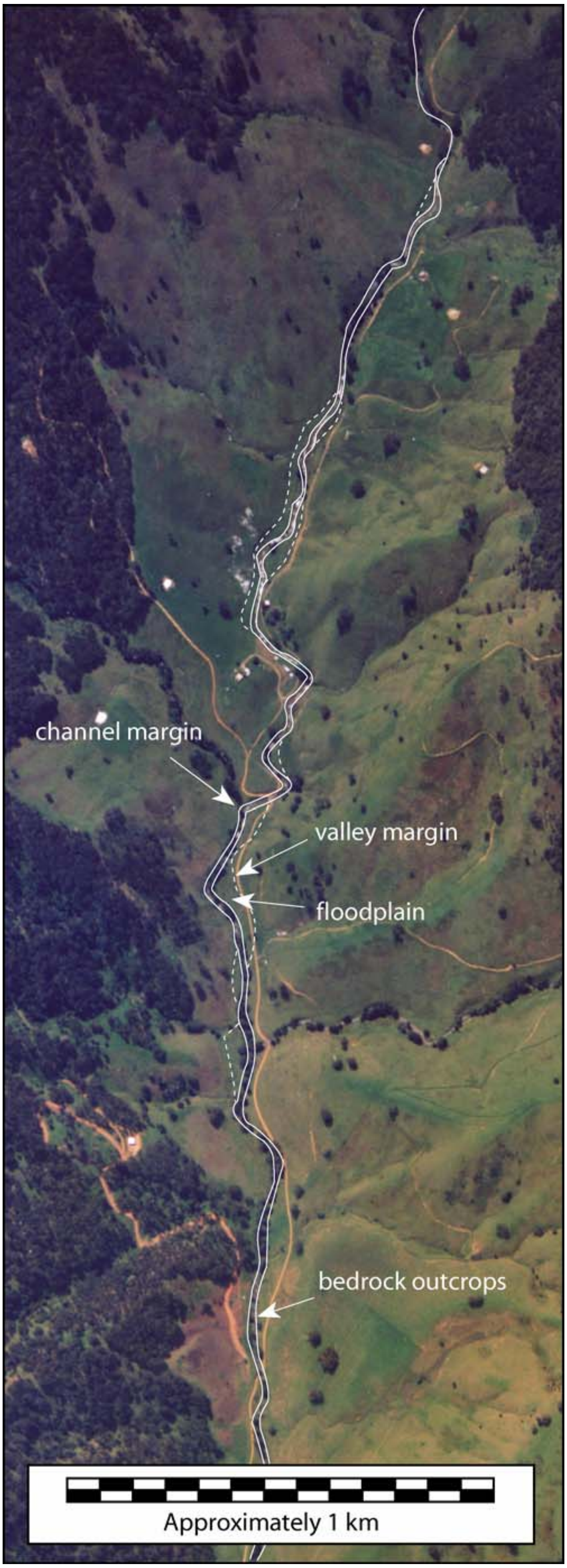


Figure 21: Aerial View of an Occasional Floodplain Pockets River Style reach, Rouchel Brook

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

3.2.4.3 Gorge River Style

Defining attributes of River Style (from River Styles tree):
Found in a confined valley setting, this River Style has no floodplain pockets. Geomorphic units that can be found include cascades, rapids and boulder bars that consist of bedrock, boulders and gravel.

Subcatchments in which River Style is observed: Pages River, Rouchel Brook, Davis Creek, Brush Hill Creek.

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

DETAILS OF ANALYSIS
Representative reaches: Pages River, Davis Creek ***Map sheet(s) air photographs used:*** Pages: Waverley 9134-III-S and Rouchel Brook 9133-IV-S ***Analysts***: Deanne Bird, Elizabeth Lamaro, Deirdre Wilcock ***Date***: 29-30/03/03

RIVER CHARACTER	
Valley-setting	Confined
River planform • 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.
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.
Geomorphic units (geometry, sedimentology)	**Instream** Instream geomorphic units are high energy, predominantly, bedrock features that form on moderately high slopes. The local slope along these reaches dictates the assemblage of cascades, rapids, runs, 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.
	Floodplains Due to the confined valley setting there are no floodplain units found along this River Style.
Vegetation associations	**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.
	Floodplain geomorphic units n/a

RIVER BEHAVIOUR
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. **Low flow stage** The channel is very stable at low flow stage, 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. **High flow stage** At slightly higher flows sediment stores will be reworked, with size and shape of these transient stores being dictated by the more permanent bedrock and boulder features. In high flows the sediment is flushed and the channel will be stripped, making this a throughput zone. The magnitude of the flow (and the input from upstream reaches) will determine the absolute amount of material that is transferred through the reach. In high magnitude events the river will experience 100% confinement, effectively concentrating energy to create high stream powers and erosive flow. Many of the geomorphic units are bedrock defined. These features are highly stable. Only extremely high flows are capable of eroding and transporting sediment and sculpting bedrock geomorphic units. Flow events of high magnitude can move boulders, the collision of boulders produces sediment. The produce of sediment increase the capacity for geomorphological change. The ultimate bed forms will be dictated by valley slope, with the observed range of pool and riffle and runs being found on lower slopes, up to bedrock steps on higher slopes.

CONTROLS	
Upstream catchment area	Given their mid-catchment position, the gorge River Style drains significant catchment areas. Up stream catchment area ranges from around 91 km^2 along Rouchel Brook to 407 km^2 along the Pages River. Average catchment area = 144.442 km^2
Landscape unit and within-Catchment position	Nearly all the gorge reaches in the Hunter catchment are found within the **Rugged and Hilly** country in the middle parts of the subcatchment. Their locations are controlled by resistant rock and inherited drainage patterns. The gorge section on the Pages River is named Cameron's Gorge.
Process zone	This River Style efficiently transfers sediment (transfer zone). Sediment is transported through the reach during high magnitude events. Transient sediment stores occur during intervening low flow periods. There is limited capacity for long term storage of sediments within the reach. It is likely that the high slope-channel coupling will allow sediment from the slope to reach the channel, however, the rate will be very slow as it depends on rate of weathering. Woody debris may be input from the slopes.
Valley morphology (size and shape)	Very steep, confined bedrock valley of regular shape. Valley width tend to range between 20 to 60 m wide and 70 m deep with steep bedrock valley margins.
Valley slope	Given their mid-catchment position, many of the gorges are formed on relatively low slopes. Slopes range from 0.0351 along Brush Hill Creek to 0.067 along Davis Creek. Average slope = 0.015

Stream power	

Gorge (Davis Creek Camberwell 9133) (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)	236.8	5303.4	18.350.7	35087.8	69446.8	107276.2	157805.8
Energy Slope	0.0073974	0.0073974	0.0073974	0.0073974	0.0073974	0.0073974	0.0073974
Critical Flow (m^3/s)	3.2632363	73.081523	252.87567	483.51495	956.9864	1478.2802	2174.5847
Water Level is (m)	-1.72	-7.07	-5.69	-4.5	-2.7	-1.18	0.52
Critical Surface Width (m)	41.4	30.2	33.8	36.5	40.3	42.1	44
Unit Stream Power (Watts/m^2 or $N/m^2/s$)	5.7	175.6	542.9	961.3	1723.2	2548.1	3586.5

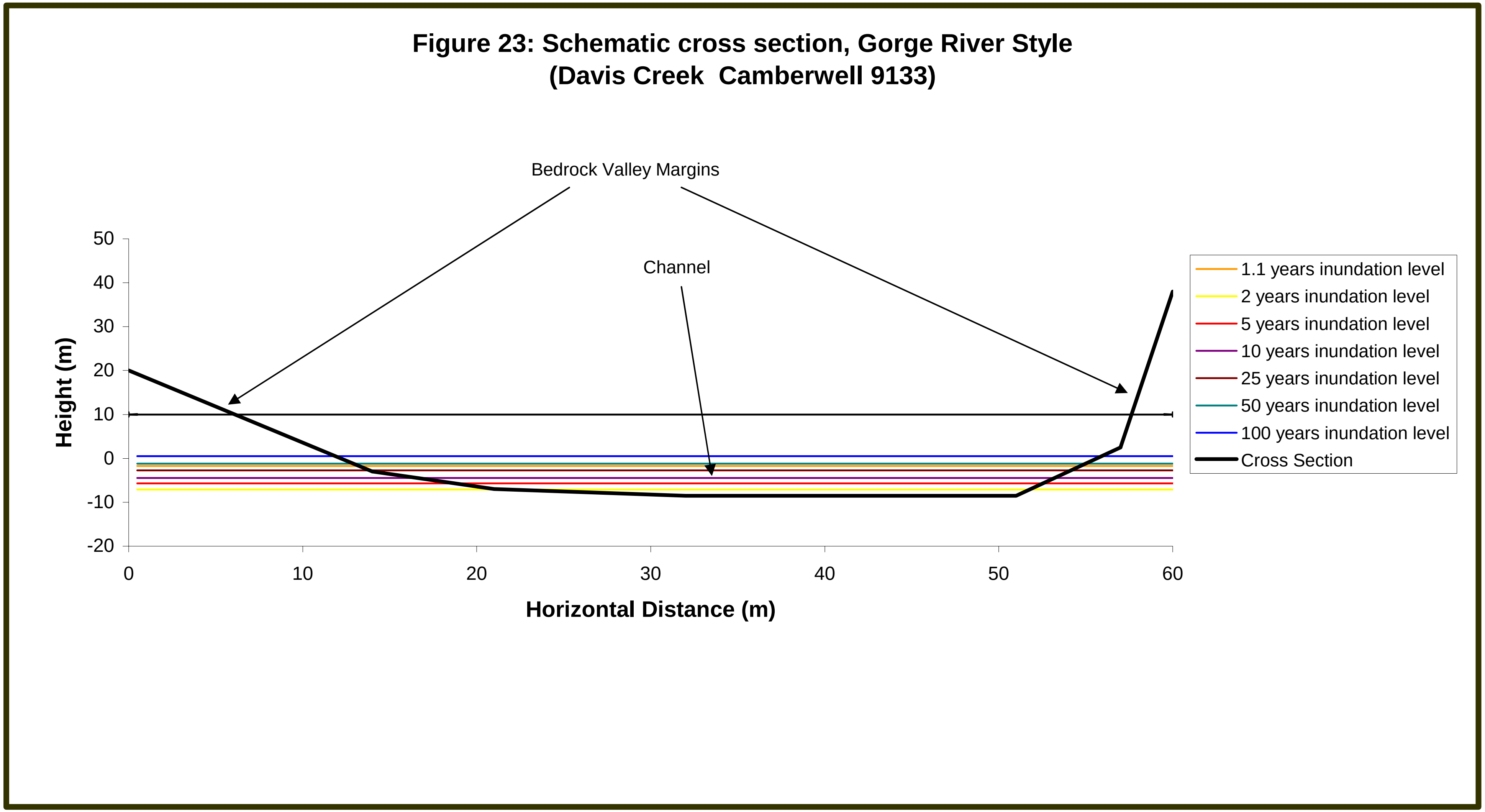


Figure 23: Schematic cross section, Gorge River Style
(Davis Creek Camberwell 9133)
Bedrock Valley Margins
Channel
Height (m)
50
40
30
20
10
0
-10
-20
0
10
20
30
40
50
60
Horizontal Distance (m)
1.1 years inundation level
2 years inundation level
5 years inundation level
10 years inundation level
25 years inundation level
50 years inundation level
100 years inundation level
Cross Section

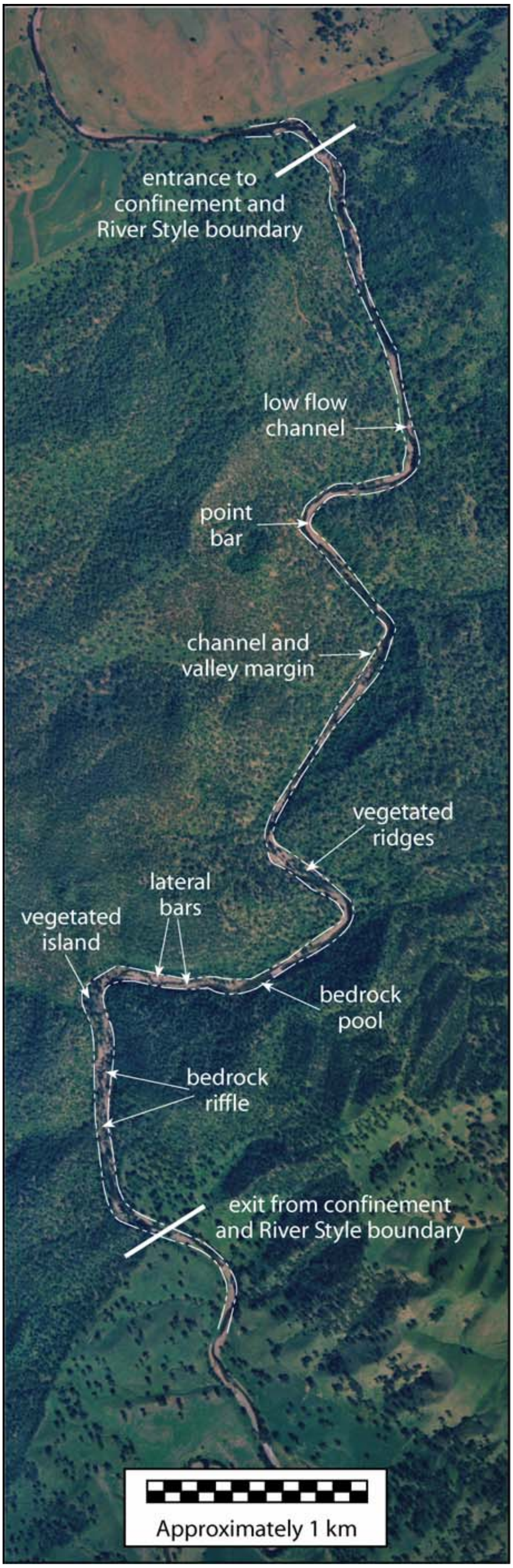


Figure 24: Aerial View of a Gorge River Style reach, Pages River

3.2.4.4 Partly Confined Valley with Bedrock Controlled Discontinuous Floodplain River Style

Defining attributes of River Style (from River Styles tree):
The low sinuosity, single channel abuts the irregular or spurred valley margin or confining terraces 50-90% of the time and is therefore partly controlled by the valley's morphology. Floodplain pockets occur where the valley has localised widening behind bedrock spurs or at tributary confluences. Bedrock outcrops dictate location and formation of geomorphic features such as pool and riffle sequences. The channel is prone to adjustments over the floodplain pockets but is stable where constricted by bedrock. Bed sediments range in size from boulders to sand. Strath or alluvial terraces may occur along the valley margins and act as confining features. For ease of communication in this report, the terrace margin variation has been included in this River Style.

Sub-catchments in which River Style is observed: Branch Creek, Brush Hill Creek, Hunter River, Isis River, Middle Brook, Moonan Brook, Pages Creek, Pages River, Stewarts Brook

DETAILS OF ANALYSIS
Representative Reaches: Pages River Hunter River; Pages Creek; Brush Hill Creek; Isis River; Davis Creek ***Map sheet(s) air photographs used:*** Murrurundi 1:25000 9034-11-N, Isis River 9134-IV-S 1:25,000, Timor 9134-III-N 1:25,000 ***Analysts**:* Deanne Bird, Elizabeth Lamaro, John Spencer, Deirdre Wilcock ***Date**:* 29-30/03/2003

RIVER CHARACTER	
Valley-setting	Partly confined. The valley morphology of this River Style tends to be relatively broad, and can range from hundreds of metres to several kilometers wide. Along many of the Upper Hunter river courses older floodplain surface occur along the valley margins and are elevated over 10 m above the channel. These terraces can be of two varieties, a strath terrace (a core of bedrock with a drape of fluvial sediments), or alluvial terraces (with a core of old cemented gravel material). Some of these surfaces are isolated islands of remnant floodplain stranded high above the current floodplain. They act as an additional confining feature along many of these partly-confined valleys. Hence, along many river courses, this River Style can be split according to the nature of the confining elements (i.e. either bedrock-controlled or terrace-controlled).
River planform • Sinuosity • Number of channels • Lateral stability	A low sinuosity (along Isis River the sinuosity of the channel is 1.1), single channel through an irregular or spurred valley. The channel is generally stable as it commonly abuts the valley margin. The channel has local capacity to adjust where floodplain pockets occur.
Bed material texture	**Bed material** along this River Style is predominantly coarse gravel, boulders and exposed bedrock. Coarse sand and fine gravel occurs along some reaches. Along the Pages River the average B_{max} of bed material is 423 mm and 399 mm (selection of 10 largest clasts). Along the Isis River, the B_{max} average of gravel bed material is 194 mm (selection of 40 largest). The channel bed sand fraction ranges from 0.5 - >2.0 phi. On bars the bar B_{max} average is 155 mm (selection of 20 largest clasts). Along the Hunter River, gravel fractions range from a B_{max} average of 100 - 150 mm on the channel bed, to 200 mm on point bars. **Bank material** along this River Style is typically sands and gravels or bedrock.

Channel geometry (shape and size)	**Channel shape** varies considerably along this River Style. Where floodplains and point bars occur along the convex banks of bends, channels tend to be asymmetrical. Along the confined sections, where no floodplains occur and bedrock dominates, channels tend to be irregular. Along reaches where channel expansion and/or contraction have occurred, an inset channel often occurs within a larger macrochannel. A compound channel shape results. This is common along section of this River Style where floodplain pockets occur and the channel is locally able to adjust its shape. **Channel size** varies significantly across the catchment and is dependent on the position of the reach within the subcatchment, the degree of valley confinement, and the condition of the reach. Along the Pages River, the macrochannel is 40m wide and 3.5m deep, and inset channel is 1.5 m wide and 0.6 m deep. Where this River Style occurs further downstream, both the macrochannel and inset channel are wider and deeper (60 m wide and 7 m deep, and 6m wide and 0.8 m deep respectively). Along the Isis River, channel width and depth are highly variable depending on the distribution of confined and floodplain sections. Widths ranging between 18 – 44 m, and depths from 1.1 – 4.4 m with no downstream pattern. Along the Hunter River, channel width varies between 30 and 70 m.

Geomorphic units (geometry, sedimentology)	**Instream** A highly variable assemblage of geomorphic units is found in the instream zone of this River Style. The most common features are bedrock-controlled pool-riffle-run sequences and a range of bank-attached point and lateral bars. Many of these bars are compound features, comprising a range of geomorphic units including ramps, chute channels, and ridges (vegetated and unvegetated). Where these features are dissected, secondary channels form. Where a local oversupply of sediment occurs, mid-channel diagonal bars may occur. If these mid-channel bars are vegetated they are islands and if they occur around large woody debris they are forced bars. Bedrock outcrops are a common feature along the beds of these rivers. Along the channel margins, ledges (erosional features with a stepped morphology) and benches (depositional features with a stepped morphology) are common. These features occur most commonly along the convex banks of bends behind point bars and adjacent to floodplain pockets. The variation of size of the instream geomorphic units depending on the position of the reach within the subcatchment, the degree of bedrock control, and the underlying substrate. Below is a summary of the geometry and composition of these geomorphic units across a range of representative sites where this River Style occurs. **Pool** – largely bedrock based, located on the apex of bedrock bends. Can have coarse sand or gravel lining the floor. Are depressions along the channel bed. Vary in size from deep and narrow to shallow and elongate. Geometry ranges from 1 – 5 m wide, 5 – 20 m long and 0.3 – 2 m deep. **Riffle** – comprised largely of accumulated gravels, but may be bedrock-induced. Are located at the entrance and exit of pools at the heads of point bars. Are elevated parts of the channel bed. Geometry ranges from 0.5 - 4 m wide, 0.5 – 20 m long and 0.2 – 0.5 m deep. **Run** – comprised of a mix of sands and gravels. Are flat planar features found along the inflection points of bends, often at the entrance to riffles. Geometry tends to be shallow, but long (up to 100 m) and relatively narrow (i.e. 3 - 4 m wide). **Point bar –** comprised largely of gravels and some coarse sand and are attached to the insides of bends. Point bars have an arcuate shape that dips towards the channel. Dimensions range from 3 – 15 m wide and 10 – 75 m long. Most tend to be larger compound features (up to 50 m wide and 100 m long), comprising a range of geomorphic units of varying sizes. Chute channels are elongate features that are scoured from the bar surface (40 m long, 3 m wide, 1 m deep), ramps are gravel deposits that plug the downstream end of chute channels or occur at the head of a point bar. Ridges are elongate, raised gravel deposits that commonly occur around vegetation (0.8 m high, 30 m long, 2 m wide). Secondary channels result from bar dissection (1 m deep, 2.5 m wide, 50 m long). **Lateral bar –** are bank-attached features comprised of gravels and boulders that occur along straighter sections of the reach (e.g. between bends). They are a relatively shallow feature ranging in size from 3 – 5 m wide and 12 – 50 m long. **Diagonal bar** – are mid-channel features comprising sands and fine gravels and may have a bedrock core. Are relatively small features between 0.5 – 3 m wide and 2 – 10 m long. **Island –** A vegetated mid-channel bar comprising a coarse gravel or boulder core and sand drapes, up to 70 m long and 30 m wide. Often a compound feature with dissection features and chute channels up to 30 m long, 1.5 m wide, 1 m deep. **Bench –** bank-attached depositional feature comprising gravels. Can form a step that is elevated up to 5 m above the channel bed. Commonly found behind point bars where they are termed point benches. **Ledge** - bank-attached erosional feature comprising materials the same as the floodplain. They are a step that can range in size from 1.5 – 15 m wide, 5 – 50 m long and sit 2 m above the channel bed. **Bedrock outcrops –** common along the bed between bends or on the outsides of bends where scour occurs.

	Floodplain Discontinuous floodplains have formed where the valley is locally wider. Floodplain pockets occur behind bedrock spurs and on the insides of bends. These floodplain pockets tend to be flat-topped and can be multi-leveled. Along the Pages and Isis Rivers, these pockets range from tens to hundreds of metres long (80 - 500 m), 20 – 120 m wide and consist largely of vertically accreted sands and fine gravels. The floodplain pockets may comprise a range of geomorphic units. Floodrunners are shallow depressions on the floodplain surface. Along the Pages river floodrunners are 0.5 m deep, 6 m wide, 100 m long. Floodchannels are deeper depressions that short circuit the floodplain. Some floodplain pockets may preserve palaeochannels reflecting a former channel position. In many partly-confined valleys of the upper Hunter, terraces line the valley margins. It is against these terraces that the contemporary floodplain is inset. The terraces can be relatively localised and only several metres wide, however, they can be elevated over 10 m above the contemporary channel bed. Along the Pages River, clasts found on higher terrace have been colonised by lichens indicating no reworking of these sediments for 50-100 years.
Vegetation associations	**Instream geomorphic units** Vegetation distribution on instream geomorphic units varies considerably across the catchment, depending on the condition of the river and landuse. Along one representative reach of the Pages River, vegetated islands have around 95% cover of casuarinas, river red gum, thistles, grasses and blackberries. Pools contain some native aquatic air plants with ~30% cover. Bars tend to have a relatively sparse (35 %) cover of grasses, thistles, weeds. Woody debris does occur around boulders and within channel vegetation causing log jams.
	Floodplain geomorphic units Improved pasture, tussock grass and a wide variety of exotic weeds cover all floodplains. In many cases there is a thin riparian strip dominated by Casuarinas, acacias and woody eucalypts.

RIVER BEHAVIOUR

Low flow stage
Tranquil flow is maintained through most pool/riffle and run sequences, although subsurface flow sustains some pools. Where sediment supply is locally high there is deposition of sediments to form diagonal bars. The low flow channel is restricted to the inset channels. Low flow occurs around coarse substrate, with limited reworking of sediments on the larger point bars.

Bankfull stage
At the surveyed cross section bankfull stage occurs between the 1 in 50 and 1 in 100 year flood events. At this flow stage, pools are scoured and fine sediment is transported as suspended load. Activation of secondary channels takes place. There is erosion creating ledges through expansion and stripping of the channel zone. Bars are often reworked to create a compound structure. Chute channels experience scour and fill sequences as sediment is reworked through this zone. Bedrock occurs at many outside bends, limiting potential for lateral movement of the river, while the positioning of spurs, which dictate the location of floodplains, limit downstream translation of the channel. In some areas, terraces perform the role of bedrock, confining the channel as these old alluvial deposits are not as readily re-workable as more recent sediment deposits. If the channel is experiencing expansion, ledges will be eroded during bankfull events. If the channel is over-large, and deposition occurs adjacent to the bank, benches form.

Overbank stage
Overbank flow occurs infrequently where the macro channel is large, at the surveyed cross section overbank flows occur around the 1 in 100 year flood events. Where the valley is wider and stream power is lower, discontinuous floodplains are vertically accreted. Sediment is deposited during the waning stages of flood events. Areas where floodplain pockets occur are also susceptible to channel adjustment. During high magnitude events the flood water flows over floodplain pockets and floodrunners and floodchannels are created. In extreme events, floodplain stripping may occur down to a basal gravel lag. The whole valley acts as the channel in these events, reworking its bed and the adjacent floodplain pockets.

Even though high stream power can be generated in this river style, it has reasonable lateral stability due to the confinement imposed by the bedrock valley margin,. Areas where the valley widens and larger floodplain pockets exist, are susceptible to channel degradation and widening in response to the removal of riparian vegetation or land use changes. Rehabilitation works are common along this River Style, aiming to secure bank erosion on bends. These have had varying degrees of success throughout the catchment.

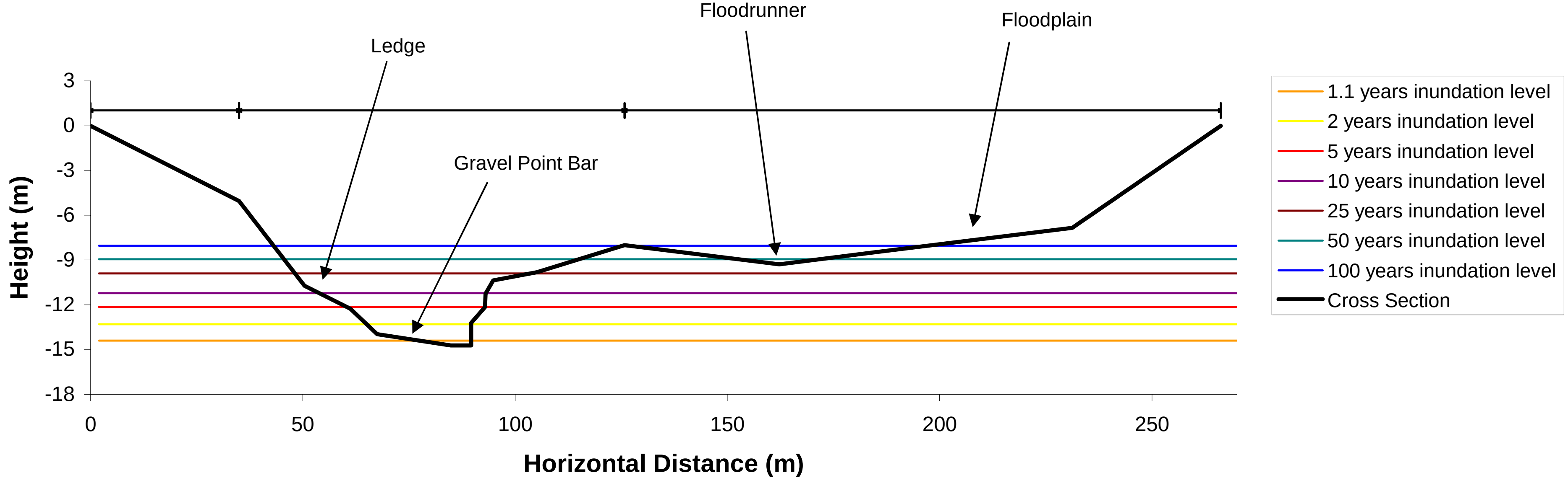
CONTROLS	
Upstream catchment area (km^2)	Ranges across the catchment from 6 km^2 along the upper Pages River to 1,741 km^2 along the Hunter River. Average catchment area = 422.736 km^2
Landscape unit and within-Catchment position	This River Style is largely found in the **Rugged and Hilly** landscape unit that dominates the majority of the catchment. Some occurrences extend into the **Plateau slope** landscape unit as rivers flow from the plateau country. This River Style tends to form in middle reaches of the catchment where the valleys are locally wider. This occurs along the Pages, Hunter and Isis Rivers. This River Styles can also be found in areas immediately downstream of steep headwaters and gorges (e.g. along the Pages River).
Process zone	This River Styles acts as a sediment transfer zone which over time attains a rough balance between sediment input and output. Sediment is transferred along the channel bed as bedload, and localised storage occurs in floodplain pockets.
Valley morphology (size and shape)	This River Style tends to occur in sinuous or spurred shaped valleys. Valley widths can vary from several hundreds of metres to several kilometres wide.
Channel/Valley slope	Slope varies between 0.002 to 0.007 across much of the catchment, with the upper Pages River having a locally higher slope at 0.018 just downstream of the steep headwaters. Average slope = 0.007
Unit stream power	

Bedrock Controlled Discontinuous Floodplain (Isis River, Whissonett Bridge 180826 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)	410.3	9206.1	31583.3	60130.1	118541	182706.4	268291.2
Energy Slope	0.0121191	0.0121191	0.0121191	0.0121191	0.0121191	0.0121191	0.0121191
Critical Flow (m^3/s)	3.5	77.4	265.7	505.8	997.1	1536.8	2256.7
Water Level is (m)	-14.24	-13.16	-12.01	-11.09	-9.8	-8.84	-7.95
Critical Surface Width (m)	12.3	24.6	32.5	39.3	55.2	126.4	154.5
Unit Stream Power (Watts/m^2 or N/m^2/s)	33.4	374.2	971.8	1530	2147.5	1445.5	1736.5

Figure 25: Schematic valley cross section, Bedrock Controlled Discontinuous Floodplain River Style (Isis River, Whissonett Bridge 180826 Ellerston 9134)



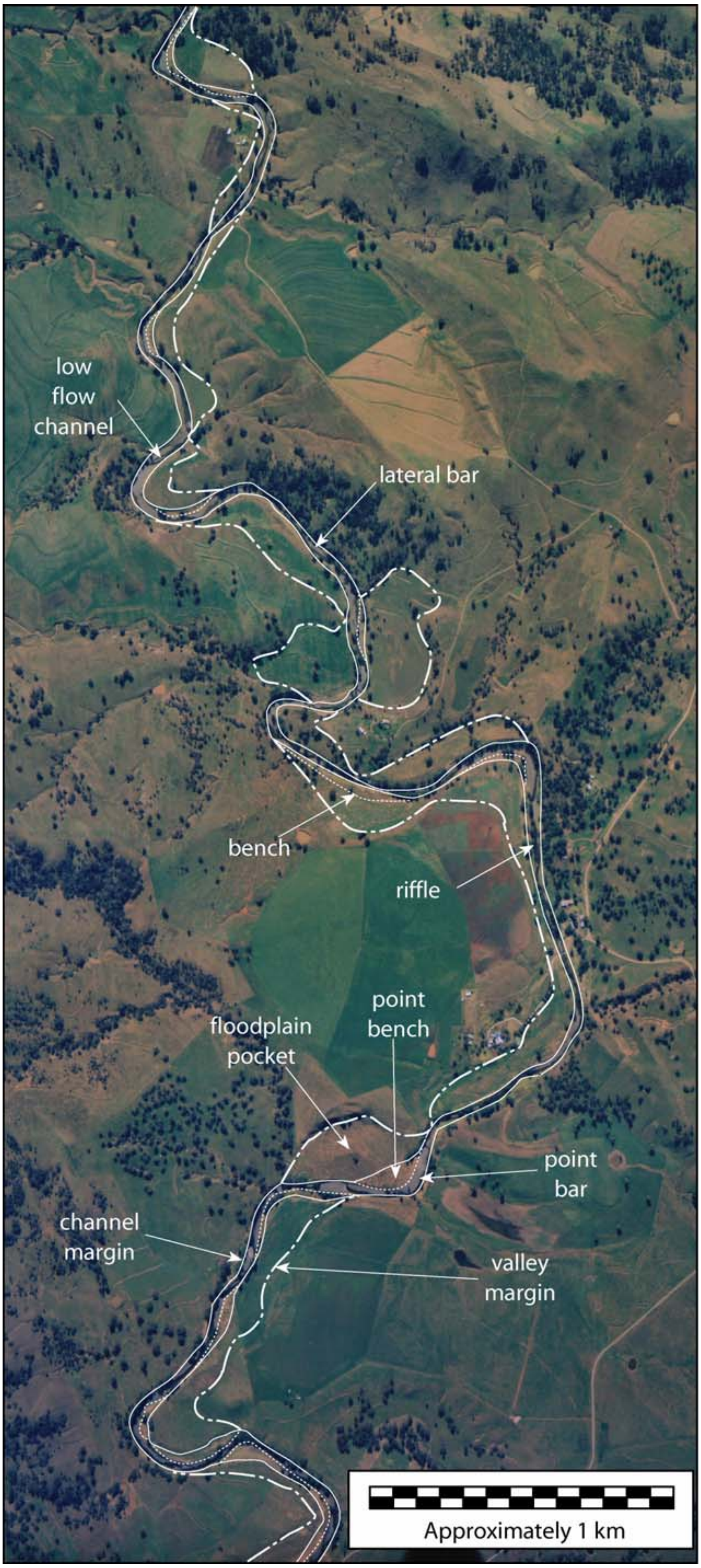


Figure 26: Aerial View of a Bedrock Controlled Discontinuous Floodplain River Style reach, Isis River

Figure 27: Bedrock Controlled Discontinuous Floodplain River Style on Pages River, looking upstream at Gundy

3.2.4.5 Partly Confined Valley with Meandering Planform-Controlled Discontinuous Floodplain River Style

Defining attributes of River Style (from River Styles tree): This River Style is set within a relatively straight valley with the channel contacting the valley margin along 10 - 50% of its length (~30%). It has a sinuosity of greater than 1.3, making it meandering. The channel has moderate capacity to adjust its planform over the valley floor, but continues to switch from one valley margin to the other, resulting in discontinuous floodplains along the valley. The valley is moderately wide allowing the channel to adjust its planform and its position producing palaeochannels and flood runners on the floodplain. Characteristic instream geomorphic units include pools, riffles, runs, point bars, lateral bars, benches and ledges. However, many of the reaches lack instream geomorphic units, and have homogenous flat beds. Floodplain geomorphic units include terraces, flood runners and palaeochannels. Bed sediments range in size from gravels to cobbles.

Subcatchments in which River Style is observed: Dart Brook, Kingdon Ponds, Middle Brook, Pages River.

DETAILS OF ANALYSIS
Representative sites**:* Pages River, Kingdon Ponds, ***Map sheet(s) air photographs used: Scone 9033-I-N, Parkville 9033-II-S, Kars Springs 9034-III-S, Murrurundi 9034-II-N; ***Analysts**:* Deanne Bird, Kirsty Hughes

RIVER CHARACTER	
Valley-setting	Partly confined
River planform • Sinuosity • Number of channels • Lateral stability	This River Style has a single, moderately sinuous (< 1.3) channel that switches from one valley margin to the other. As a result discontinuous pockets of floodplain are formed. Sinuosity ranges from around 1.3 to 1.6 across the catchment. The channel has moderate lateral stability due to its partially confined setting, although some channel migration occurs as bends shift laterally and translate downstream. Terraces limit the potential for movement in many cases. Past channel adjustment is marked by palaeochannels.
Bed material texture	Bed materials are dominated by gravels and cobbles. Some sands and boulders occur locally. The average B_{max} ranges from 120 mm. Occasional clasts up to 400 mm occur. Bars comprise smaller gravels of 30 mm B_{max}.
Channel geometry (size and shape)	Channel shape is asymmetrical on the meander bends and symmetrical between bends. Given the relatively fine grained texture of the floodplains, many banks are steep and show signs of erosion, such as bare vertical banks and ledges.

Geomorphic units (geometry, sedimentology)	**Instream** This River Styles is characterised by pool-riffle-point bar sequences in the instream zones. Other geomorphic units such as runs, lateral bars and ledges may be present. Many of the reaches lack instream geomorphic units, and have homogenous flat beds with evenly sloping banks. **Pool –** occur on the concave banks of bends which are typically abutting bedrock or terrace materials where they will be lined with bedrock or coarse materials. If bends are fully alluvial, pools are scour features lined with gravels and fines and organics. Pools range in size between 3 – 10 m long, and can be several metres deep. **Riffle –** are accumulations of gravel that separate pools. Gravels range, approximately between 120 – 400 mm B_{max}. **Point bar** – arcuate bank-attached feature located on the inside of meander bends. They are areas of gravel and cobble accumulation, and may have a compound morphology comprising of a range of other geomorphic units such as chutes and ridges. The size of point bars is proportional to the curvature of the bend and the size of the channel. They tend to be over 5 m long, 2.5 m wide and 1 m high. **Lateral bar** – occurs along straighter sections of river between meander bends. They are shallow features that are attached to the bank and can be up to 20 m wide and 40 m long. **Run** – accumulations of gravels forming planar gravel sheets that extend between pools. **Bench** – Stepped depositional features that are attached to the bank and are comprised of coarse sands. **Ledge** – Narrow, stepped feature attached to the bank. They are eroded into the bank, often less than 1 m wide, discontinuous along the bank, and comprised of fine sediment.
	Floodplain The floodplain along this River Style tends to be relatively flat-topped. However, palaeochannels and floodrunners may occur. Floodplain sedimentology consists of silt, sand and basal gravel. Along the valley margins terraces occur and can act as a confining feature. **Palaeochannel –** remnants of the palaeo river configuration and can be several hundreds of metres long, up to 10 m wide and 0.5 m deep. The bed may comprise gravels overlayed with sand and silt. Can be in the form of meander cutoffs where bends have been short circuited and a straighter channel formed. **Floodrunner –** relatively straight floodplain depressions the beds of which consist of sand with silt and some exposed gravels. Can be up to 5 m wide and 1 m deep. **Terrace** – Stepped features that occur along the valley margin and can sit up to 10 m above the contemporary channel bed. Along Kingdon Ponds the town of Wingen is built on a terrace and these features dominate the valley floor in terms of area. Floodplain occurs in pockets inset within the terraces. Comprised of orange sand-sized sediments and large gravels-cobbles, clearly banded.
Vegetation associations	**Instream geomorphic units** Willows are found within channel and on banks. Poplars and casuarinas on banks. Weeds such as thistles, blackberries are found on benches and bar deposits. Pasture grasses also found on banks.
	Floodplain geomorphic units Improved pasture with occasional eucalypt and bottle brush.

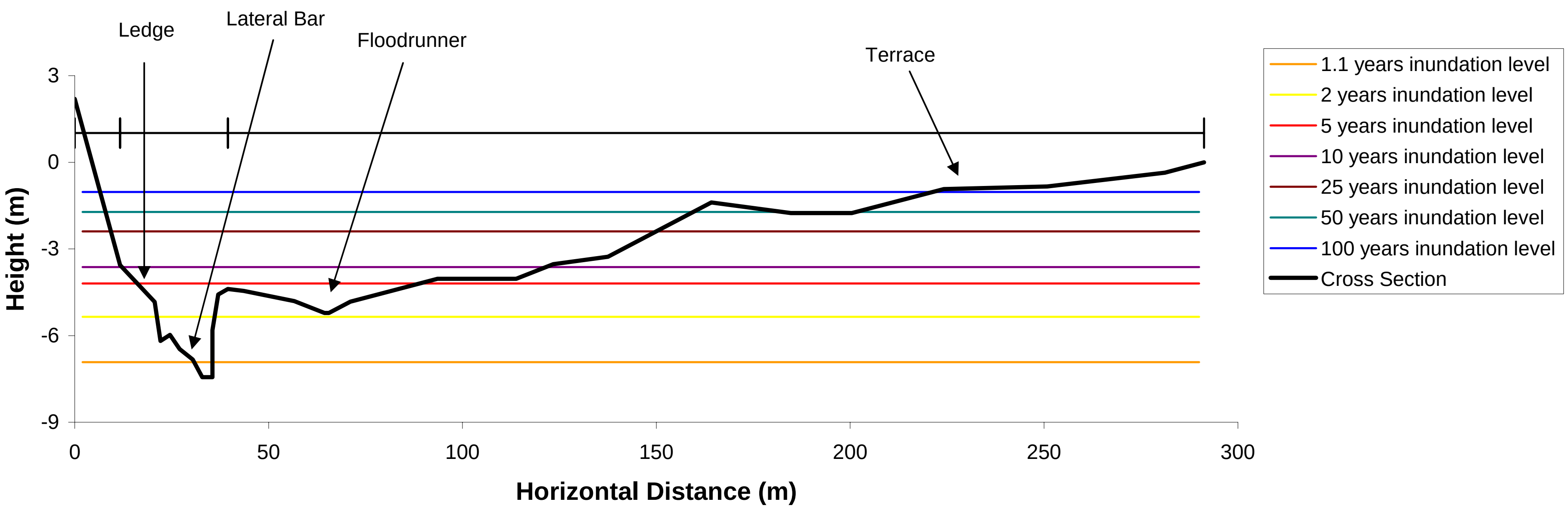
RIVER BEHAVIOUR
Low flow stage The channel is contained between vertically accreted floodplains and is stable at low flow stage. The channel bed forms are composed of gravel and boulder size sediment and are stable. Low flow maintains the pool and riffle sequences with much of the flow subsurface. Deposition of fine sands occurs in pools and on bars. **Bankfull stage** At this flow stage pool-riffle sequences are maintain as pool scour and riffle deposition occurs. The higher flow reworks the bed material and can reconfigure bars and bed forms. Scouring of bar surfaces produces compound features, such as, chutes and ridges. Where banks are eroding ledges may form (particularly around willows). Some sort of meander progression occurs during bankfull flows. However, given the fine grained nature of the floodplains this is a slow process. Post European adjustments probably included channel widening and bed incision down to the gravel lag. Secondary process responses are responsible for bench (contraction) and ledge (expansion) formation. Channel aggradation occurs in places during the waning stages of flood events. **Overbank stage** During overbank flows, energy is dissipated over floodplain and deposition of sand and silt occurs, thereby, vertically accreting the floodplain. If significant energy is generated, channel shifting occurs leaving a palaeochannel or meander cutoff on the floodplain surface. Where floodwaters short circuit a floodplain pocket, floodrunners are scoured into the floodplain surface, and act as a preferred flow path in high flow events. However, wherever meander bends impinge on bedrock or terrace materials, the degree to which bends can adjust is severely limited. Adjustments during large magnitude events include bed degradation and channel avulsion.

CONTROLS	
Upstream catchment area (km^2)	Catchment area varies across the catchment, but are relatively low compared to other River Styles. Upstream areas range from 98 km^2 along the Pages River to 126 km^2 along Dart Brook. Average catchment area = 91.193 km^2
Landscape unit and within-Catchment position	This River Style is found in the **Rugged and Hilly** landscape unit that covers the majority of the catchment. It usually occurs in mid catchment locations where there is sufficient accommodation space for the development of floodplains. Often found downstream of, or in alternating sequences with the Low Sinuosity Planform Controlled Discontinuous Floodplain River Style.
Process zone	This River Style acts as a sediment transfer zone with a balance between erosion (on the outsides of bends) and deposition (on the insides of bends). Over time sediment inputs and outputs from these reaches is roughly balanced.
Valley morphology (size and shape)	Formed in relatively straight valleys, where accommodation space allows for some degree of river meandering and channel adjustment over the valley floor. Valleys are between 200 m and 1 km wide and tend to widen downstream.
Slope	Valley and channel slopes tend to be relatively low, allowing the meandering planform to develop. Average valley slope is 0.009.

Stream power

Meandering Planform Controlled Discontinuous Floodplain (Kingdon Ponds 992700 Muswellbrook 9033) (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)	421.8	9436.5	32807.9	62879.5	124722.6	192895.3	284025.5
Energy Slope	0.0135765	0.0135765	0.0135765	0.0135765	0.0135765	0.0135765	0.0135765
Critical Flow (m^3/s)	3.1670248	70.852623	246.33328	472.12191	936.46128	1448.3263	2132.5643
Water Level is (m)	-6.85	-5.29	-4.15	-3.59	-2.37	-1.7	-1.02
Critical Surface Width (m)	4.6	14.8	72.7	109.2	140.7	193.3	214.8
Unit Stream Power (Watts/m^2 or $N/m^2/s$)	91.7	637.6	451.3	575.8	886.4	997.9	1322.3

Figure 28: Schematic valley cross section, Meandering Planform Controlled Discontinuous Floodplain River Style (Kingdon Ponds 992700 Muswellbrook 9033)



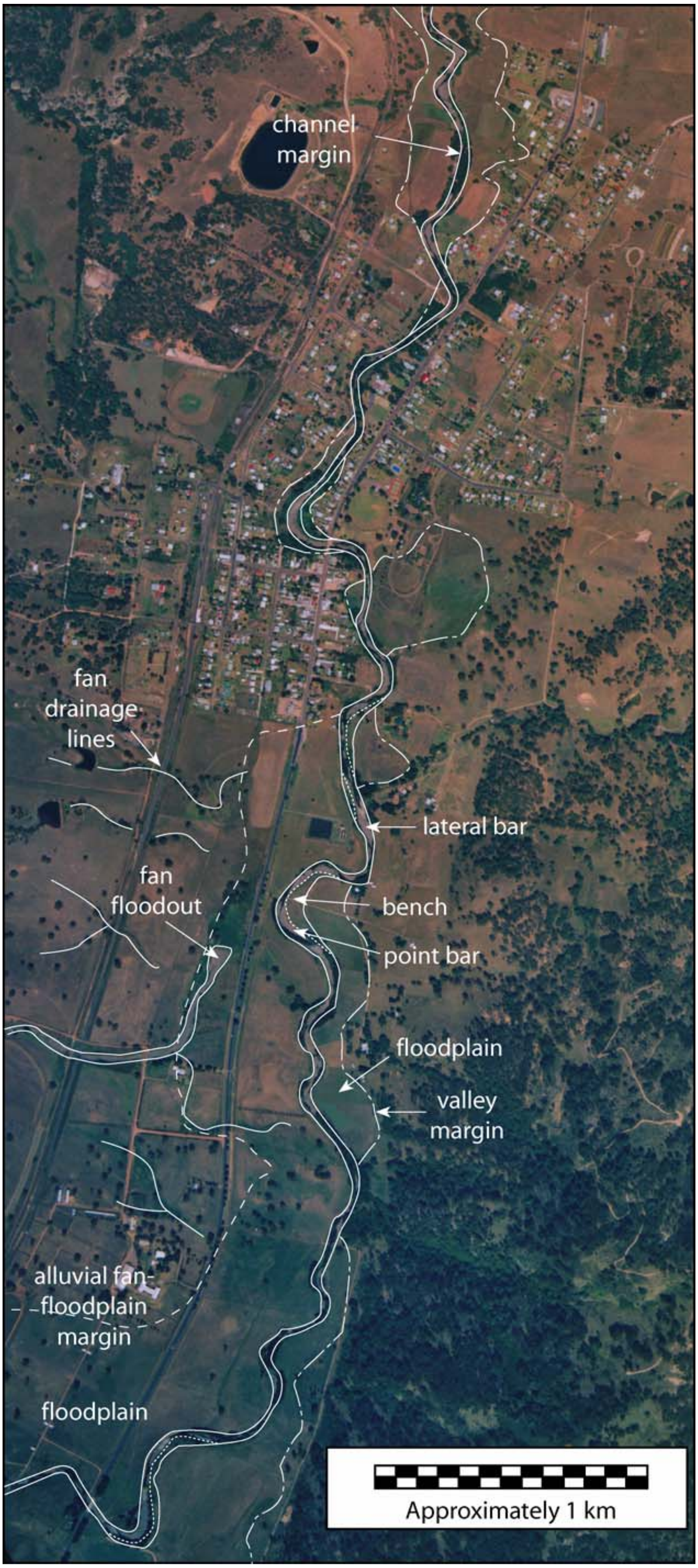


Figure 29: Aerial view of a Meandering Planform Controlled Discontinuous Floodplain River Style reach, Pages River

Figure 30: Meandering Planform Controlled Discontinuous Floodplain River Style reach on Kingdon Ponds, looking upstream

3.2.4.6 Partly Confined Valley with Low Sinuosity Planform-Controlled Discontinuous Floodplain River Style

Defining attributes of River Style (from River Styles tree): This River Style is set within an irregular valley with the channel contacting the valley margin along 10 - 50% of its length. It is relatively straight with a sinuosity of less than 1.3. The channel switches from one valley margin to the other, resulting in discontinuous floodplains. The valley is moderately wide allowing the channel to adjust its planform and its position producing palaeochannels and floodrunners on the floodplain. Along the Pages River, major tributaries and **alluvial fans** have pinned the river to the opposite valley margin. Characteristic instream geomorphic units include pools, riffles, runs, bank-attached bars, lateral bars, benches and ledges. Floodplain geomorphic units include terraces, floodrunners and palaeochannels. Bed sediments range in size from boulders to sand.

Subcatchments in which River Style is observed: Hunter River, Pages River, Stewarts Brook, Isis River

DETAILS OF ANALYSIS
Representative Reach: Pages River ***Map sheet(s) air photographs used:*** Murrurundi 9034-II-N 1:25,000 ***Analysts:*** Deanne Bird, Deirdre Wilcock, Rachel Hannan, Mick Hillman ***Date:*** 29/03/2003

RIVER CHARACTER	
Valley-setting	Partly confined valley
River planform • Sinuosity • Number of channels • Lateral stability	This River Style has a single, low sinuosity (< 1.3) channel that switches from one valley margin to the other. As a result discontinuous pockets of floodplain are formed. Given that the channel is pinned against a bedrock valley margin, the channel is laterally stable where channel abuts bedrock or terraces, however it is prone to adjustment where floodplain pockets occur. Hence lateral stability is locally variable depending on confinement. Past channel adjustment is marked by palaeochannels.
Bed material texture	Bed materials are dominated by gravels in a sandy matrix. Some cobbles and boulders are present. The average B_{max} is 164 mm. Occasional clasts up to 400 mm occur.
Channel geometry (size and shape)	Channel shape varies between symmetrical and irregular. Channels can range in size from 40 – 130 m wide and up to 6 m deep depending on their condition.

Geomorphic units (Geometry, sedimentology)	Instream geomorphic units are dominated by pool and run sequences. Occasional riffles and bedrock outcrops/steps occur. Bank-attached lateral bars, benches and ledges occur along the channel margin. **Pool** – Elongate features scoured from the channel bed. Can be bedrock based or comprised of coarse sands and gravels. Dimensions are roughly 20 - 100 m in length, 1 - 2 m in depth and can be up to 80 m long. **Run** – occur at the entrance and exit to pools, these planar features can be comprised of coarse sands and gravels and range from 15 - 50 m in length. **Riffle** – these features are steeper than runs. They are accumulations of gravel deposited between pools. They tend to be localised features with sizes up to several metres long. **Bench** – Stepped, depositional features formed adjacent to banks. Comprised of sand deposits and sit up to 1m above the channel bed and are around 0.5 m wide. **Ledge** – Stepped, erosional features formed adjacent to banks. They are comprised of the same materials as the adjacent floodplain (i.e. sands and silts)and range between 2-8 m wide and sit up to 1 m above the channel bed. They can be several hundred metres long. **Lateral bar** – Bank-attached bars that occur along straighter sections of the channel. Comprised of poorly sorted gravels with B_{max} varying between 5 - 140 mm. Size can be up to 6 m wide and 40 m long. Small lateral bars that are about 1 m wide and 2 m long consist of sand and silts. **Bedrock steps** – occasionally outcrop along the channel bed where the channel is pinned against the valley margin. They form small steps in the channel bed.
	<u>Floodplains</u> The floodplain pockets of this River Style are up to 500 m wide and can be several hundreds of metres long. Their sedimentology consists largely of vertically accreted silts and sands that sit on top of a basal gravel lag. The floodplains tend to be relatively flat-topped with floodrunners and palaeochannels occurring on their surfaces. However, where these floodplains interact with **alluvial fans** or piedmont zones, which extend from the adjacent tributary valleys, coarse gravels may inter-finger with the finer floodplain deposits. As a result the floodplains tend to be relatively flat topped, or inclined gently up towards the valley margin where **fans** or piedmont zones occur. Terraces may also occur along the valley margins, and can be either alluvial or strath terraces. **Floodrunner –** relatively straight floodplain depressions the bed of which consist of sand with silt and some exposed gravels. Can be up to 3 m wide and 0.5 m deep. **Palaeochannel** – maintain the palaeo river configuration and can be several hundreds of metres long, up to 6 m wide and 1 m deep. The bed may comprise gravels overlayed with sand and silt. **Terrace** – are localised and can sit several metres above the floodplain surface. **Alluvial fans and/or piedmont zone –** extend from tributary confluences or adjacent valley margins. Convex surfaces that extend in the trunk stream valley and inter-finger with floodplain sediments. Comprise coarse gravels deposited in debris flows. Represent old palaeo-features.
Vegetation associations	**<u>Instream geomorphic units</u>** Casuarinas and poplars colonise the banks, willows colonise the bed and banks. Weeds such as thistles, blackberries, and grasses are found on benches and bar deposits. There is minimal woody debris.
	<u>Floodplain geomorphic units</u> Dominated by pasture, localised willows, rye grass and sedge. Occasional eucalypt.

RIVER BEHAVIOUR
Low flow stage Low flow maintains the pool and run sequences with much of the flow subsurface. Deposition of fine sands occurs in the minor lateral bars lining the channel and within the pools and runs. **Bankfull stage** Localised scouring around vegetation and undercutting of riverbanks occurs along the channel as flow reaches bankfull stage. Reworking of lateral bars and scouring of pools will also occur as the flow reaches critical level. Channel incision has occurred in the past, inducing a range of secondary process responses manifest in bench and ledge development. If deposition occurs along the channel margin, benches form and the channel contracts. If erosion of the banks occurs, ledges may form and the channel expands. Some sections of these rivers have experienced incision and channel expansion during bankfull flood events when energy is confined within the channel. **Overbank stage** During overbank flows, energy is dissipated over the floodplain. The floodplain vertically accretes as deposition of sand and silt occurs. Along the Pages River, the high floodplain surfaces are rarely inundated as the channel ahs high capacity. The channel has high capacity because of channel incision and expansion. Along relatively wide sections of the partly-confined valley the channel has sufficient space for lateral adjustment. If significant energy is generated, channel shifting occurs leaving a palaeochannel on the floodplain surface. Where floodwaters short circuit a floodplain pocket, floodrunners are scoured into the floodplain surface, and act as a preferred flow path in high flow events. Where the channel abuts bedrock valley walls the degree to which the channel can adjust its position is limited. In addition, the alluvial fans and piedmont zones effectively pin the channel in place limiting lateral adjustment potential. Along the Pages River the major tributary fans of Warlands Creek and Scotts Creek force the contemporary channel towards the opposite valley margin. Along these sections of valley the channel has limited capacity to adjust.

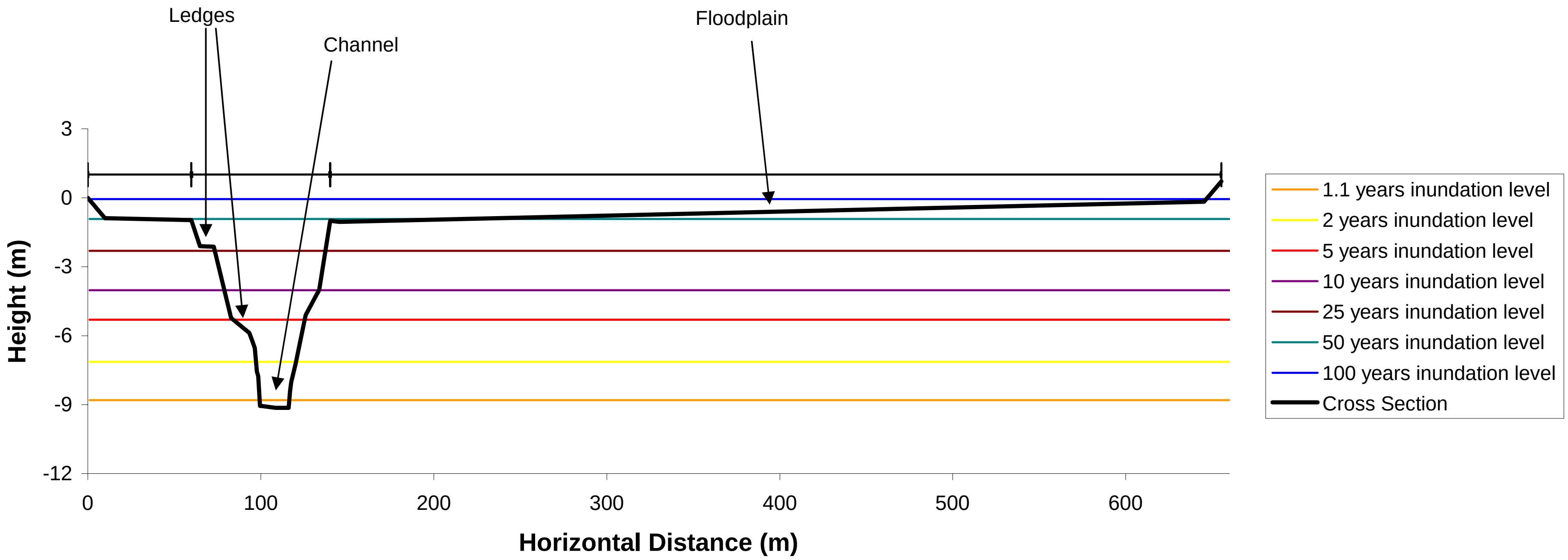
CONTROLS	
Upstream catchment area	Catchment area varies depending on the position of this River Style in the catchment. Catchment areas range from 89 - 338 km^2. Average catchment area = 107 km^2
Landscape unit and within-Catchment position	This River Style is found in the **Rugged and Hilly** landscape unit that covers the majority of the catchment. This River Style occurs where there is sufficient accommodation space, within a valley, for floodplains to develop. Hence, this River Style is found in areas downstream of steep headwater zones, in middle catchment locations. Often found immediately upstream of the Meandering Planform Controlled Discontinuous Floodplain River Style.
Process zone	Sediment transfer is the dominant contemporary process, however, extensive floodplain and alluvial sediment stores reflect sediment accumulation in the past.
Valley morphology (size and shape)	This River Style tends to occur in irregularly shaped valleys. Valley widths can vary from several hundreds of metres to several kilometres. Along the Pages River valley width varies between 0.4 – 2.6 km wide.
Valley slope	Average slope = 0.008

Stream power	

Low Sinuosity Planform Controlled Discontinuous Floodplain (Pages River - 023802 Murrurundi 9034)
(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)	97.9	2195.4	7551.2	14395.1	28412.7	43821.9	64383.8
Energy Slope	0.0029417	0.0029417	0.0029417	0.0029417	0.0029417	0.0029417	0.0029417
Critical Flow (m^3/s)	3.392564	76.077616	261.66995	498.82951	984.57632	1518.5442	2231.0686
Water Level is (m)	-8.71	-7.06	-5.25	-3.98	-2.28	-0.91	-0.06
Critical Surface Width (m)	17.1	23.1	41.1	54.5	63.8	185.9	645.9
Unit Stream Power (Watts/m^2 or $N/m^2/s$)	5.7	95	183.7	264.1	445.3	235.7	99.7

Figure 31: Schematic valley cross section, Low Sinuosity Planform Controlled Discontinuous Floodplain River Style
(Pages River - 023802 Murrurundi 9034)



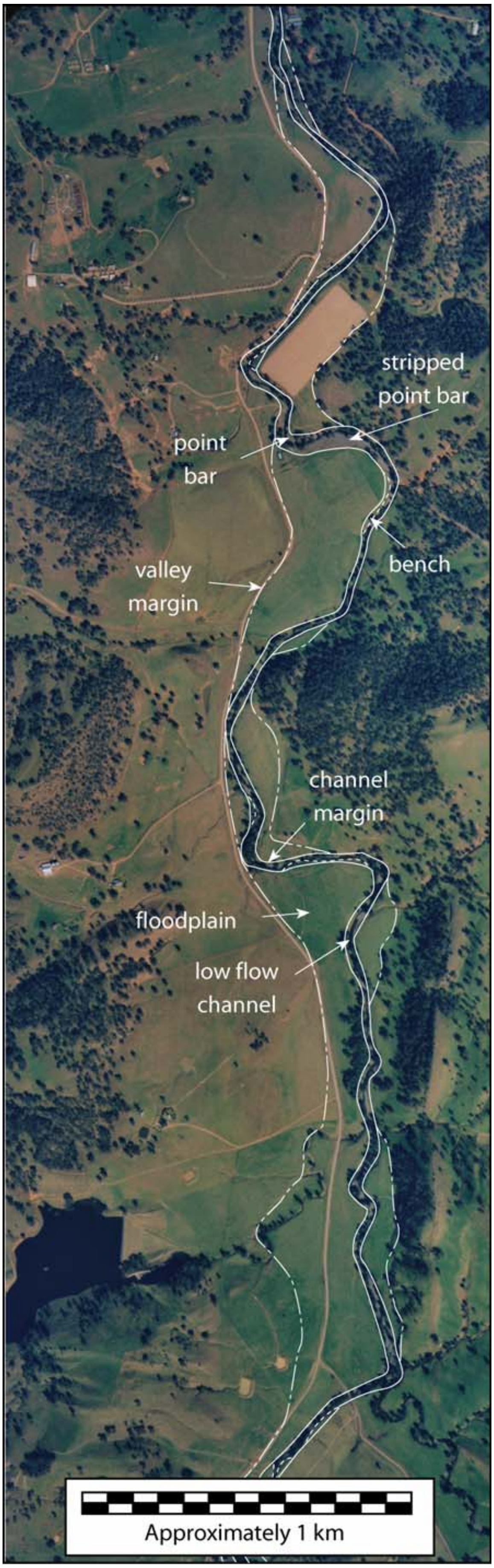


Figure 32: Aerial View of a Low Sinuosity Planform Controlled Discontinuous Floodplain River Style reach, Hunter River

Figure 33: Low Sinuosity Planform Controlled Discontinuous Floodplain River Style reach on Pages River, looking upstream

3.2.4.7 Low Sinuosity Entrenched Gravel Bed River Style

Defining attributes of River Style (from River Styles tree): Laterally unconfined valley setting. The wide floodplain is continuous along both sides of the channel, bedrock abutments are rare (<10% of bed or bank composition). The river has a single continuous channel with a low sinuosity (< 1.3). The geomorphic unit assemblage of this River Style is relatively simple with the instream zone characterized by gravel sheets, pools, ledges, lateral bars and the floodplain zone characterised by shallow levees, palaeochannels, flood runners, and terraces. The channel has high stability given the very low slope and the fine grained cohesive nature of the banks. The adjustment of the channel is most likely to be channel incision and expansion, although avulsion is possible. Bed sediments are dominated by a gravel lag, exposed via incision and nickpoint retreat (not supplied from upstream). The sediment transport regime of this River Style is suspended load dominated.

Subcatchments in which River Style is observed: This River Style is unique to Kingdon Ponds and is not found anywhere else in the upper Hunter catchment.

DETAILS OF ANALYSIS
Representative Reach: Kingdon Ponds ***Map sheets and air photographs used:*** Muswellbrook 9033 1:100,000; Murrurundi 9034 1:100,000; Aberdeen 1:25,000; Scone 1:25,000; Parkville 1:25,000; Muswellbrook 1998 runs 1-6 ; Murrurundi 1998 runs 12-13 ***Analysts:*** Kirsty Hughes, Alex Spink ***Date:*** 29-30 March 2003

RIVER CHARACTER	
Valley-setting	Laterally-unconfined
River planform • Sinuosity • Number of channels • Lateral stability	There is a single, continuous channel. Sinuosity is low, within the range 1 to 1.3. The Kingdon Ponds reach has a sinuosity of 1.135. Lateral channel stability tends to be high but varied, depending on bank material texture and amount of vegetation. The Kingdon Ponds reach was created post-1938.
Bed material texture	Channel bed materials are dominantly gravels with drapes of sand and clays. The gravels are considered to be a lag, exposed via channel incision, which can armoured the channel bed. Gravels range in size from B_{max} 90 – 100 mm along Kingdon Ponds. Gravels appear unsorted. The sediment transport regime of this River Style is dominated by suspended load materials that are effectively flushed, and on occasion become draped over the channel bed. As a result sands and silts are present on the channel bed.
Channel geometry (size and shape)	The channel is entrenched and symmetrical throughout. The lower 1m, or so, of the banks tend to be bare and vertical. The channel has a homogenous flat bed, although there is an occasional thalweg, and the banks have similar geomorphic units of the same dimensions on both sides. Banks are comprised of cohesive fine-grained sediments with the basal gravel lag exposed at the base. Evidence of channel slumping can be seen along Kingdon Ponds.

Geomorphic units (Geometry, sedimentology)	<u>**Instream**</u> The geomorphic structure of the instream zone along this River Style tends to be relatively simple. Gravel lag deposits are locally reworked and form gravel sheets. Along the channel margins, fine grained floodplain materials are eroded, forming ledges. Where localised deposition of sand materials occurs, lateral bars form. **Gravel sheet –** Cover the entire channel bed and have little in the way of geomorphic structure. They tend to be planar and are the result of reworking of the gravel lag. **Lateral bar –** Only occasional occurrences. Longitudinal, bank-attached features. Consist of gravels with minimal sorting. **Ledges –** stepped features adjacent to the channel bank. They vary in height from 1 - 2 m and 1 - 3 m wide, and form a step that sits 2 – 3 m from the top of the bank. Some slumping has occurred, creating rounded edges, but generally ledges are discreet. Sediment composition is fine grained and cohesive. **Pools** - Better described as small ‘depressions’ with no water, these pools have very low relief, no greater than 10 - 20cm deep and 3 m in length and occur only occasionally. The sedimentology is continuous with the rest of the bed. Most are gravel, others have fine grained sediment drapes. **Occasional thalweg** - not a continuous channel feature, but a thread between pools which could be described as a dry depression, roughly 20cm deep. Sedimentology is similar to the pools (possibly less fines).
	<u>**Floodplains**</u> The floodplain of this River Styles tends to be relatively flat-topped with subdued topography and little in the way of geomorphic structure. Floodplains are wide, extending up to several kilometres. Shallow levees occur along the channel margin. Palaeochannels are evident and record former channel positions. Floodrunners occur on the floodplain surface. Terraces occur along the valley margins representing palaeo-floodplain surfaces. **Levees** – ridge like features that occur on the channel-floodplain margin. They are shallow, subdued features with a height of 50 cm and a width of 50 m and are comprised of fine sands and clays. The levee slopes gently (at an angle of not more than 1 degree) from its ridge to the surface of the floodplain. **Palaeo-channel -** “Cross Creek” palaeochannel has a trench-like morphology and is over 1m deep, 2m wide and has some near vertical banks. The bed and banks is comprised of fine sediment. **Flood runners** – are shallow elongated depressions scoured into the floodplain surface. They are up to 50 cm deep and 2 metres wide, with beds comprised of fine sediment. **Terraces** – occur along the valley margins and sit up to 2 m above the floodplain. Are a more prominent feature in upstream reaches of this River Style.
Vegetation associations	<u>**Instream geomorphic units**</u> Vegetation is sparse and dominated largely by pasture grasses. Where vegetation does occur, pools and the channel bed are cover with by weeds with, pumpkin-weed is a dominant weed species. Occasional Casuarinas, willows and red gums grow on some ledges.
	<u>**Floodplain geomorphic units**</u> The floodplain is dominated by pasture. Tussocky grasses do occur on some levees.

RIVER BEHAVIOUR
Low flow stage Water flow in the thalweg is possibly discontinuous at low flow stage. Deposition of some fine sediment occurs, but in general low flows are incapable of performing geomorphic work on gravel sized particles. Banks show evidence of scour, indicating that the 1.1 to 2 year events can slowly widen the channel by reworking the less coherent lower layers. This scouring occurs, particularly, where banks are less cohesive or are not protected by vegetation. **Bankfull stage** Bankfull flows can moderately reworked coarse bed materials and form the subtle geomorphic units observed in the channel. However, the load is dominantly suspended. The narrow channel concentrates flow and fine sediment is flushed through the reach. Bed destabilisation has occurred in the past, leading to bed incision, channel expansion, and

the formation of ledges.

Overbank stage

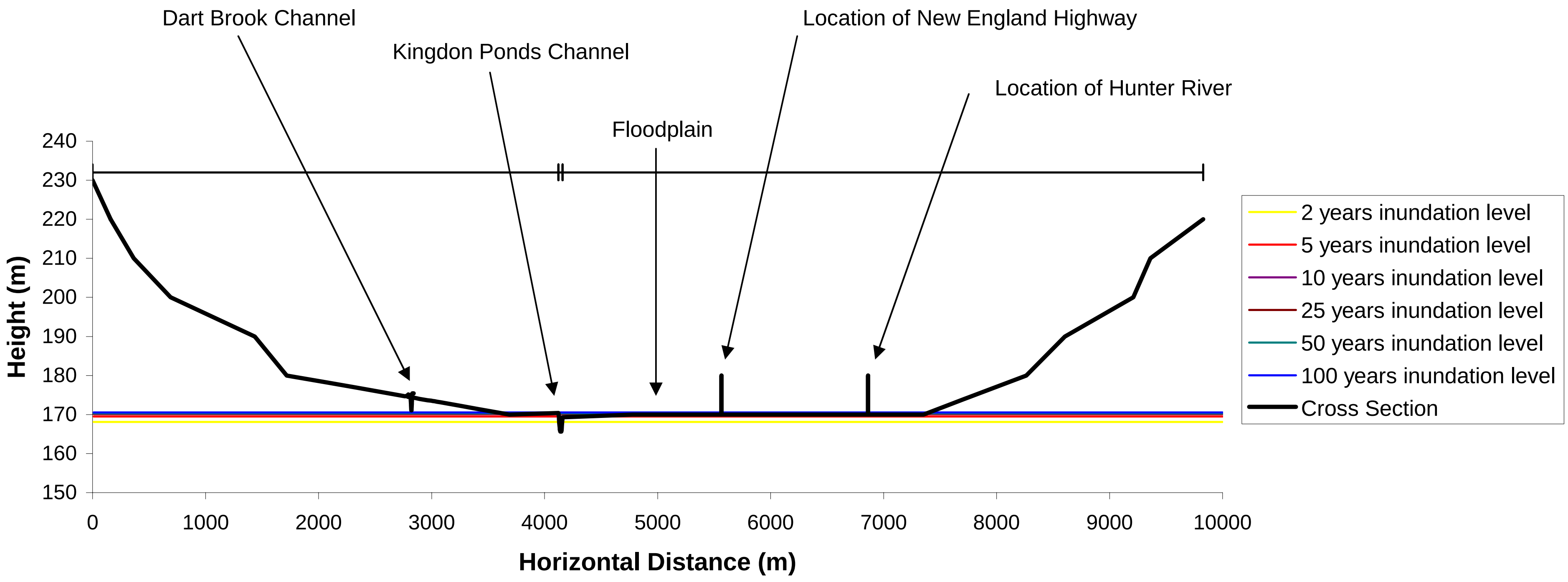
Due to the wide, flat, low gradient floodplains, overbank flow is dispersed over a large area. In more moderate events the water recharges the floodplain and, close to the channel, small levees vertically accrete. Where flows scour depressions, as floodwaters short circuit the floodplain, floodrunners are formed. Water flows in these floodrunners during subsequent overbank events. Overbank events are relatively frequent due to the large catchment area, low slopes and small channel capacity. At higher flows floodwaters from Dart Brook, Kingdon Ponds and Hunter River interact influencing floodplain deposition and scour. Channel avulsion can potentially occur.

CONTROLS	
Upstream catchment area	Average catchment area = 358.281 km^2.
Landscape unit and within-Catchment position	This River Style is found in the western portion of the catchment in the **Undulating Plain** landscape unit. This River Style is only found in the lower catchment adjacent to the Hunter trunk stream. It is the most downstream River Style along Kingdon Ponds.
Process zone	This River Style is largely a sediment transfer and accumulation zone. Sediment is dominantly transported as suspended load.
Valley morphology (size and shape)	The valley is very wide, averaging 5 km between margins and up to 10 km wide. Toward the downstream end of Kingdon Ponds, Kingdon Ponds and the Hunter River share the same alluvial valley.
Valley slope	This River Style occurs on very low slopes. Valley slopes are slightly steeper than for the Meandering Entrenched Gravel Bed River Style at around 0.003 along Kingdon Ponds. Channel slopes are roughly equivalent range at 0.002. Average slope = 0.002
Stream power	(see table below)

Low Sinuosity Entrenched Gravel Bed (Kingdon Ponds - 989412 Muswellbrook 9033)
(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)	50.1	1125.9	3847.5	7310.8	14386.6	22151.2	32500.9
Energy Slope	0.0014425	0.0014425	0.0014425	0.0014425	0.0014425	0.0014425	0.0014425
Critical Flow (m^3/s)	3.542921	79.560887	271.89423	516.63429	1016.6525	1565.3553	2296.737
Water Level is (m)		168.11	169.53	170.09	170.21	170.33	170.5
Critical Surface Width (m)	0	26.2	225.5	3691	3723.9	3760	3808.1
Unit Stream Power (Watts/m^2 or N/m^2/s)		43	17.1	2	3.9	5.9	8.5

Figure 34: Schematic valley cross section, Low Sinuosity Entrenched Gravel Bed (Kingdon Ponds - 989412 Muswellbrook 9033)

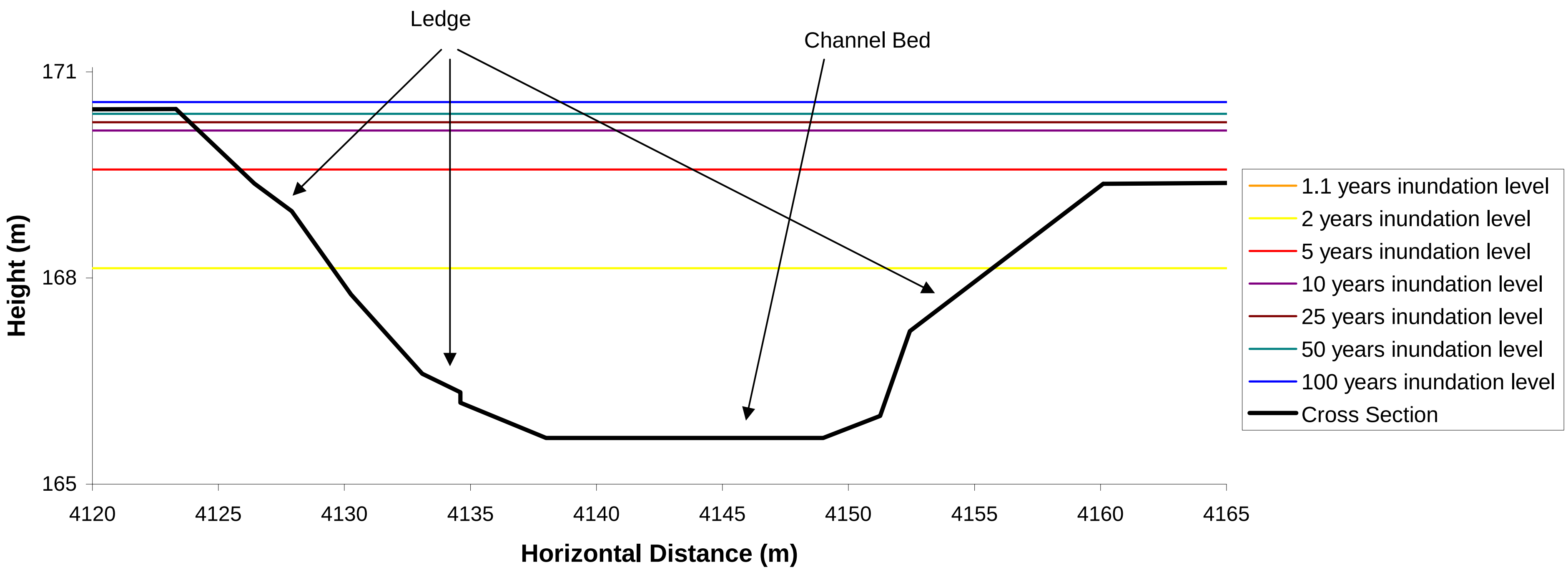


(This plot is a composite of channel survey data of Dart Brook and Kingdon Ponds collected on site and a valley cross section generated from a topographic map, Aberdeen 1:2500 9033-I-S.)

(The height of Dart Brook is interpolated between contour lines at may not be an accurate representation, it maybe closer to the level of Kingdon Ponds.)

Figure 35: Schematic valley cross section, Low Sinuosity Entrenched Gravel Bed (Kingdon Ponds - 989412 Muswellbrook 9033)

Channel Insert



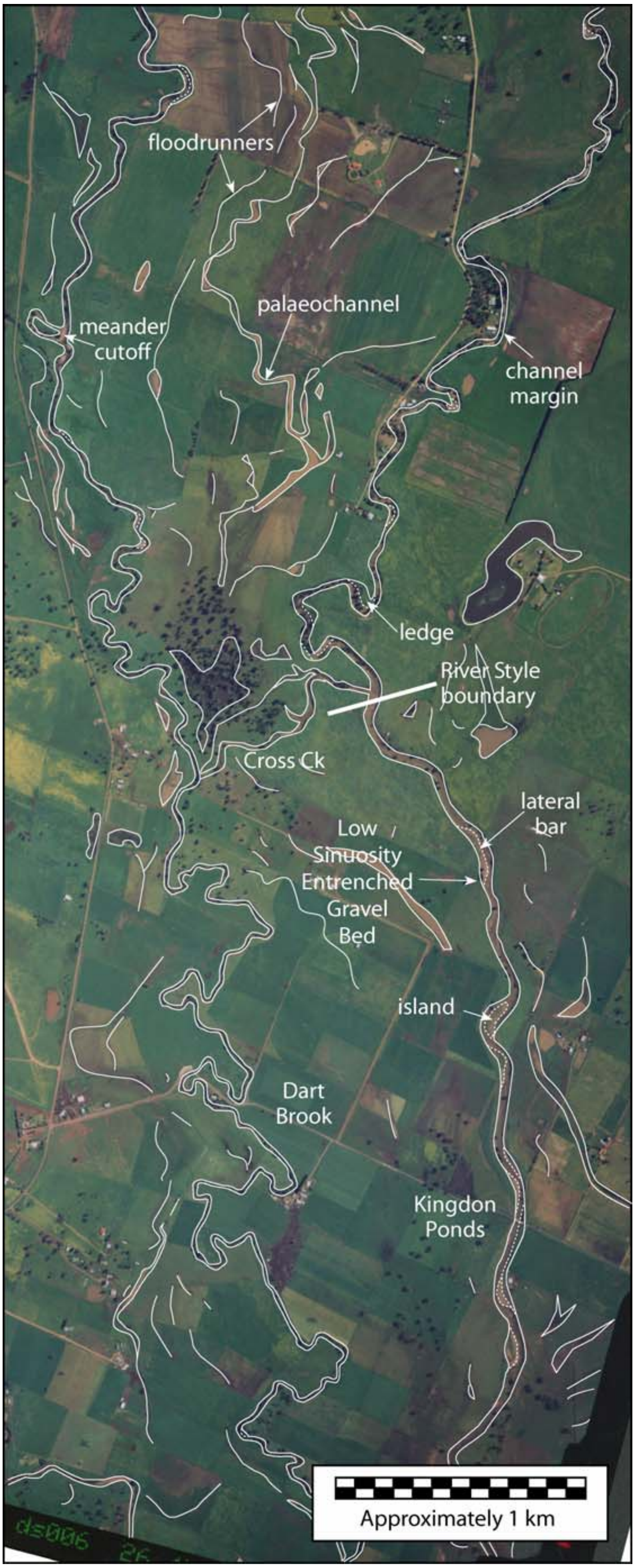


Figure 36: Aerial View of a Low Sinuosity Entrenched Gravel Bed and Meandering Entrenched Gravel Bed River Style reach, lower ends of Dart Brook and Kingdon Ponds

Figure 37: Low Sinuosity Entrenched Gravel Bed River Style reach on Kingdon Ponds, looking upstream

3.2.4.8 Meandering Entrenched Gravel Bed River Style

Defining attributes of River Style (from River Styles tree): Laterally unconfined valley setting. The wide floodplain is continuous along both sides of the channel, bedrock abutments are rare (<10% of bed or bank composition). River reaches are meandering (sinuosity >1.3) with single continuous channels. The geomorphic structure of this River Style is relatively simple with the instream zone characterised by gravel sheets, pools and ledges and the floodplain zone characterised by shallow levees, palaeochannels, flood runners, and terraces. The very low slope and the fine grained cohesive nature of the banks makes the channel very stability. Channel incision and expansion are the most likely form of channel adjustment, while channel avulsion is possible. Bed sediments are dominantly gravel, the source of the gravel is a gravel lag that has been exposed by incision and nickpoint retreat (not supplied from upstream). In this River Style sediment is transported predominantly as suspended load.

Sub-catchments in which River Style is observed: This River Style is unique to Dart Brook, Kingdon Ponds, and Middle Brook and is not found anywhere else in the upper Hunter catchment.

DETAILS OF ANALYSIS
Representative Reach: Kingdon Ponds, Dart Brook ***Map sheets and air photographs used:*** Muswellbrook 9033 1:100,000; Murrurundi 9034 1:100,000; Aberdeen 9033-I-S 1:25,000; Scone 9033-I-N 1:25,000; Parkville 9034-II-S 1:25,000; Muswellbrook 1998 runs 1-6 ; Murrurundi 1998 runs 12-13 ***Analysts:*** Kirsty Hughes, Alex Spink ***Date:*** 29-30 March 2003

RIVER CHARACTER	
Valley-setting	Laterally-unconfined
River planform • Sinuosity • Number of channels • Lateral stability	Single, continuous channel with sinuosity greater than 1.3. Dart Brook has reaches with sinuosities of 1.44 and 2.1. The Kingdon Ponds reaches have sinuosities of 2.07 and 1.61. Lateral channel stability tends to be high but varied, depending on bank material texture and density of vegetation. Typically, channels with higher clay content and denser vegetation are more stable than those with less cohesive sediments and less vegetation.
Bed material texture	Channel bed materials are predominantly gravels with drapes of sand and clays. The source of the gravels is considered to be a gravel lag, exposed during channel incision. In some reaches the gravel forms an armoured bed. Gravels range in size from B_{max} 70 – 300 mm with the dominant size averaging 20 mm. The gravels are poorly sorted. Sediment is transported predominantly as suspended load. The gravel bed can be draped with sand and silty material.
Channel geometry (size and shape)	**<u>Size</u>** The channel is entrenched, asymmetrical on the bends and symmetrical along straighter sections. The lower 1m, or so, of banks tend to be bare and vertical. The channel has a homogenous flat bed, although there is an occasional thalweg. Both sides of the banks have similar geomorphic units of similar dimensions. Banks are comprised of cohesive fine-grained sediments with the basal gravel lag exposed at the base.

<table>
<tr><td rowspan="2">Geomorphic units
(Geometry, sedimentology)</td><td><u>Instream</u>
The geomorphic structure of the instream zone along this River Style tends to be relatively simple. Gravel lag deposits are locally reworked and form gravel sheets. Along the channel margins erosion of fine grained floodplain material produces ledges.

Ledges – stepped features adjacent to the channel. They are 1 - 2 m in height and 1 - 3 m wide. They form a step that sits 1 – 3 m from the top of the bank. Some slumping has occurred, creating rounded edges, but generally ledges are discreet. They are composed of fine grained cohesive sediment.
Pools - Better described as small ‘depressions’ with no water, these pools have very low relief, no greater than 10 - 20cm deep and 3 m in length and occur only occasionally. Most have gravel beds, same have a drape of fine grained material over the gravels.
Gravel sheet – they cover the entire channel bed and have little in the way of geomorphic structure. The tend to be planar and are the result of reworking of the gravel lag. They may armour the bed.
Occasional thalweg - not a continuous feature along the channel. Better described as a small dry depression, roughly 20cm deep with gravel beds (possibly less fines than bed of pools).</td></tr>
<tr><td><u>Floodplains</u>
The floodplain of this River Styles tends to be relatively flat-topped with subdued topography and little in the way of geomorphic structure. Floodplains are wide, extending up to several kilometres. Shallow levees occur along the channel margin. Palaeochannels are present and mark former channel position. Where flood waters flow over the floodplain floodrunners can occur, they usually short circuit a bend in the channel. Terraces occur along the valley margins and represents palaeo-floodplain surfaces.

Levees – ridge like features that occur at the channel-floodplain margin. They are shallow, subdued features with a height of 50cm and a width of 50 m, and comprised of fine sands and clays. The levee slopes gently (at an angle of not more than 1 degree) from its ridge to the surface of the floodplain.
Palaeo-channel -. “Cross Creek” palaeochannel has a trench-like morphology and is over 1m deep, 2m wide and has some near vertical banks. The bed and banks is comprised of fine sediment.
Flood runners – are shallow depressions scoured into the floodplain surface, up to 50 cm deep and 2 metres wide, and comprised of fine sediment.
Terraces – occur along the valley margins and sit up to 2 m above the floodplain. They are a more prominent feature in upstream reaches of this River Style.</td></tr>
<tr><td rowspan="2">Vegetation associations</td><td><u>Instream geomorphic units</u>
Vegetation is sparse and largely dominated by pasture grasses. Where vegetation does occur, pools and the channel bed are covered by weeds, Pumpkin-weed prominent species. An occasional Casuarina or willow grows on some ledges.</td></tr>
<tr><td><u>Floodplain geomorphic units</u>
Floodplains are dominantly pasture. A small patch of remnant river red gum forest (<1km^2) does occurs. Tussocky grasses do occur on some levees.</td></tr>
</table>

RIVER BEHAVIOUR

Low flow stage

Flow is contained within the entrenched channel at low flow stage and little to no geomorphic work is done. Little to no work is done because the material that is available for transport, i.e. gravel, is too large to be moved by the low stream powers generated at this flow stage. Fine grained materials will be transported in suspension. The primary mechanism for bank failure at this stage is slumping.

Bankfull stage

The recurrence interval of bankfull flows at the surveyed cross section on Dart Brook is between 1.1 and 2 years. The lack of geomorphic diversity in the channel suggests that this level of flow is incapable of significantly altering channel morphology, with the exception of some minor scour creating the low relief thalwegs and pools. The channel is responding to the entrenched nature of the stream by expanding laterally through the process of banks erosion. However, the bank sediment is highly cohesive and the rate of erosion is slow (even with steep bank angles). When erosion does occurs ledges are formed. Because of the shape of the channel the bankfull flows are in contact with a large surface area of cohesive banks. Therefore large amounts of flow energy is dissipated as friction. This River Style has high frictional energy losses and low gradients, therefore flows in these reaches have low stream power. Suspended load is the dominant sediment transport mechanism.

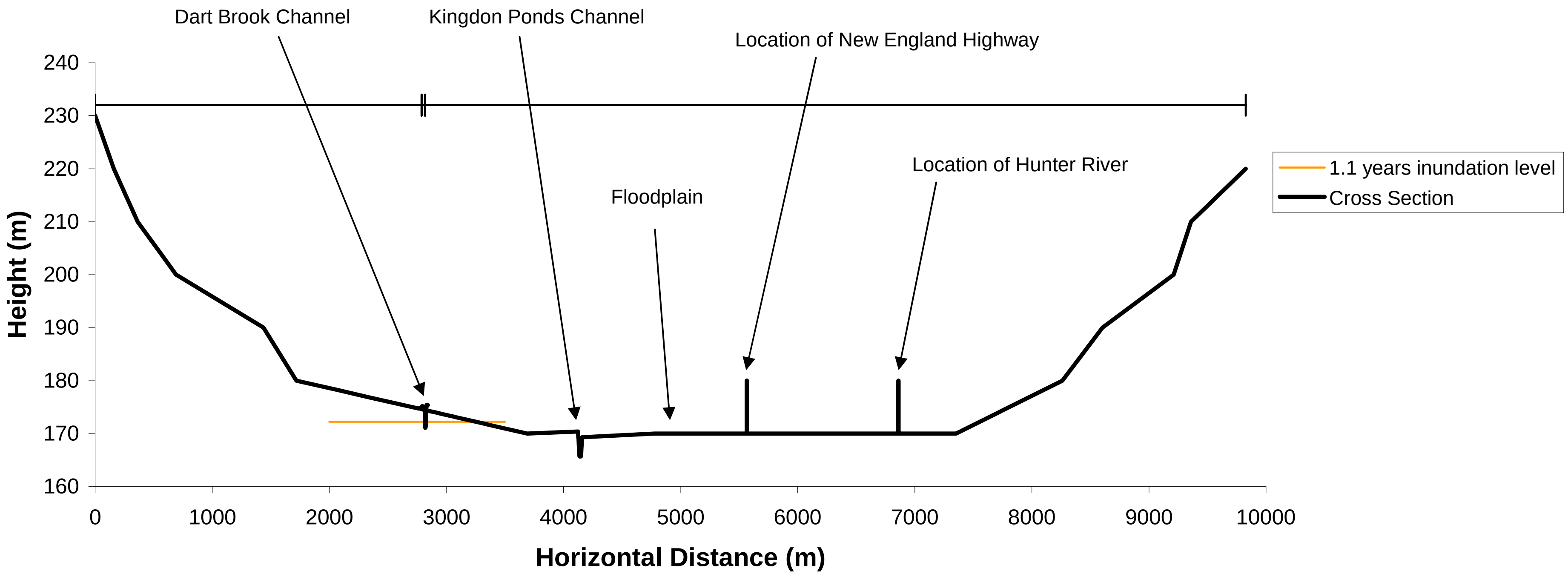
Overbank stage

Due to the wide, flat, low gradient floodplains, overbank flow is dispersed over a large area. In more moderate events the water recharges the floodplain and, close to the channel, small levees vertically accrete. Where flows scour depressions, as floodwaters short circuit the floodplain, floodrunners are formed. Water flows in these floodrunners during subsequent overbank events. Overbank events are relatively frequent due to the large catchment area, low slopes and small channel capacity. With Kingdon Ponds and Dart Brook sharing a floodplain there is potential for flow between the two channels. **Cross Creek palaeochannel and many of the flood runners attests to the exchange of water between these systems.** The close proximity of the Hunter River means it is also probable that these waters will interact in extreme events, influencing floodplain deposition and scour.

CONTROLS:	
Upstream catchment area	Upstream catchment area ranges from 67 km^2 on Middle Brook to 260 km^2 on Dart Brook. Average catchment area = 337 km^2.
Landscape unit and within-Catchment position	This River Style is only found in the western portion of the catchment in the **Undulating Plain** landscape unit. This River Style is found in the middle-lower catchment adjacent to the Hunter trunk stream along Kingdon Ponds, Middle Brook, and Dart Brook.
Process zone	Acts largely as a sediment transfer zone, suspended load is the dominant sediment transport mechanism.
Valley morphology (size and shape)	Wide valley, ranging from 1km wide at the top end of the mid-Dart Brook reach to 5km wide at the Lower Dart Brook reach. Average ~5 km between valley margins. In places, Dart Brook and Kingdon Ponds share the same floodplains.
Valley slope	This River Style occurs on very low slopes. Valley slopes range from 0.0003 – 0.005 and channel slopes range from 0.002 – 0.003. Average slope = 0.003
Stream power	

<table>
<tr><th colspan="8">Meandering Entrenched Gravel Bed (Dart Brook – 976413 Muswellbrook 9033)
(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>
<tr><th>Stream Power (N/s/m or Watts/m)</th><td>40.60</td><td colspan="6" rowspan="6">Unable to Model</td></tr>
<tr><th>Energy Slope</th><td>0.00105</td></tr>
<tr><th>Critical Flow (m^3/s)</th><td>3.96</td></tr>
<tr><th>Water Level is (m)</th><td>172.24</td></tr>
<tr><th>Critical Surface Width (m)</th><td>6.00</td></tr>
<tr><th>Unit Stream Power ($Watts/m^2$ or $N/m^2/s$)</th><td>6.80</td></tr>
</table>

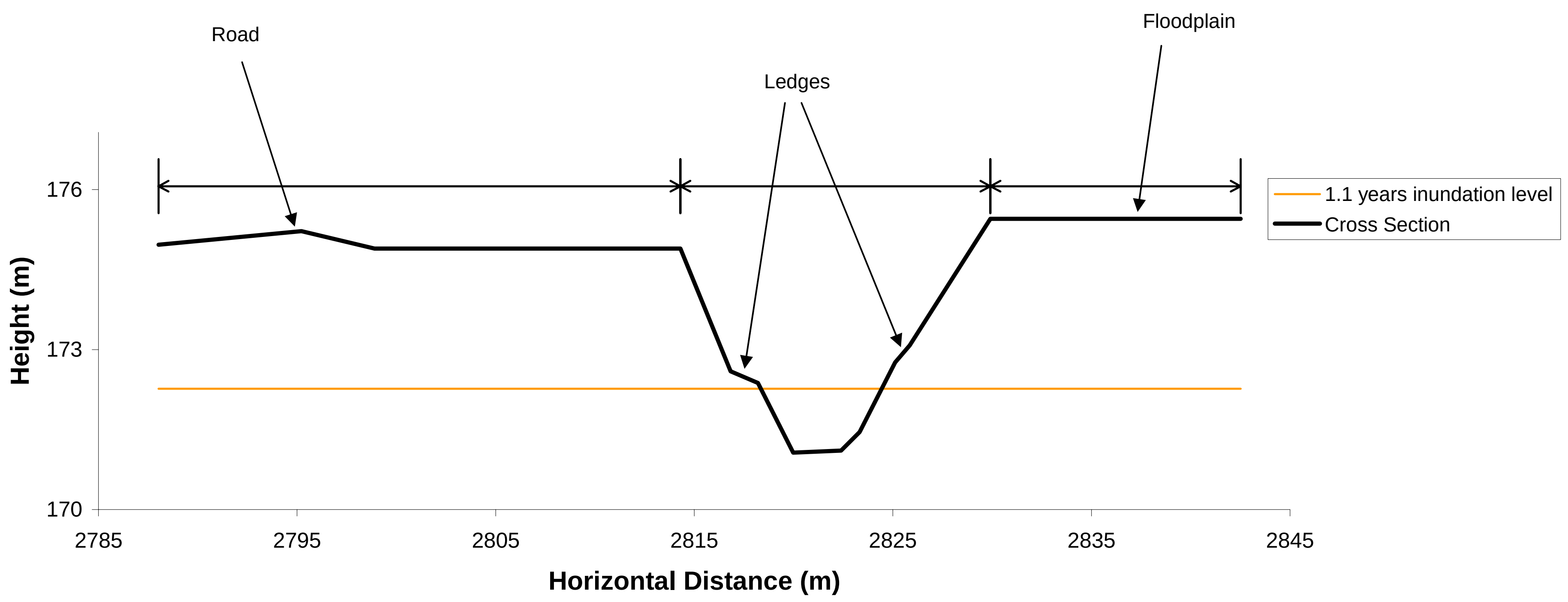
Figure 38: Schematic valley cross section, Meandering Entrenched Gravel Bed (Dart Brook 976413 Muswellbrook 9033)



(This plot is a composite of channel survey data of Dart Brook and Kingdon Ponds collected on site and a valley cross section generated from a topographic map, Aberdeen 1:2500 9033-I-S.)

(The height of Dart Brook is interpolated between contour lines at may not be an accurate representation, it maybe closer to the level of Kingdon Ponds.)

Figure 39: Schematic channel cross section, Meandering Entrenched Gravel Bed (Dart Brook 976413 Muswellbrook 9033) Channel Insert



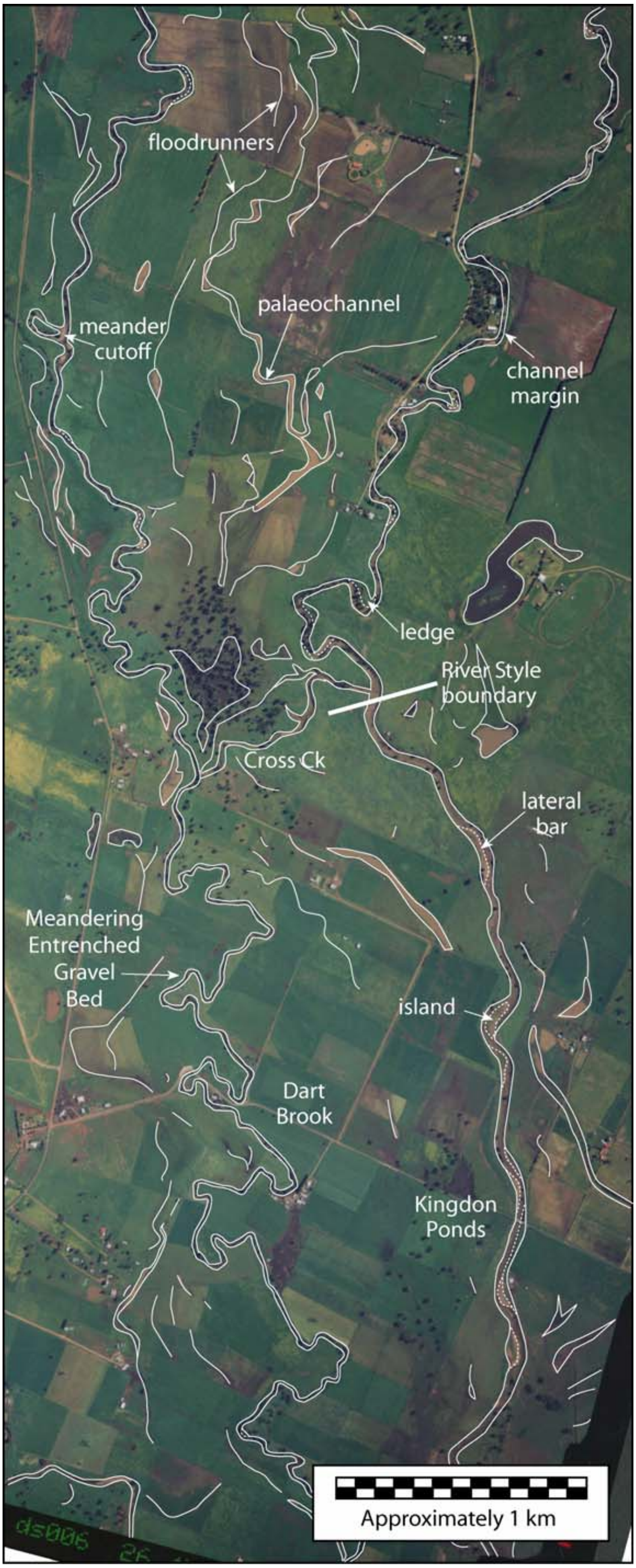


Figure 40: Aerial View of a Meandering Entrenched Gravel Bed and Low Sinuosity Entrenched Gravel Bed River Style reach, lower ends of Dart Brook and Kingdon Ponds

Figure 41: Meandering Entrenched Gravel Bed River Style reach on Dart Brook, looking upstream

3.2.4.9 Low Sinuosity Gravel Bed River Style

Defining attributes of River Style (from River Styles tree): This River Style is found in a laterally-unconfined valley and has a low-moderate sinuosity (<1.3). Occasional meander bends occur, but along the majority of its length this River Style is a relatively straight single channel. The wide relatively shallow macrochannel contains a diverse range of instream geomorphic units including lateral bars, islands and longitudinal mid-channel bars, pools, runs and benches. The floodplain contains an array of palaeochannels, floodrunners, and in some places levees. Terraces line the valley margins. Lateral stability of the macrochannel is considered to be low. There is significant capacity for the channel to incise and expand laterally. There is significant capacity for the low flow channel to adjust within the macrochannel. Bed sediment is dominantly gravel and cobbles with occasional boulders.

Subcatchments in which River Style is observed: Pages River, Dart Brook, and the Hunter River

DETAILS OF ANALYSIS
Representative Reach: Pages River reach 9 (site 5) ***Map sheet(s) air photographs used:*** Muswellbrook 9033-II-N 1:25,000 ***Analysts:*** Deanne Bird, Deirdre Wilcock, Rachel Hannan ***Date****:* 29-30/03/2003

RIVER CHARACTER	
Valley-setting	Laterally unconfined
River planform • Sinuosity • Number of channels • Lateral stability	This single thread, continuous channel is of low sinuosity (< 1.3). The channel is over-widened, laterally unstable, and has the capacity to expand laterally. The low flow channel has the ability to adjust laterally within the macrochannel. Continuous floodplains line the channel margin with the channel occasionally impinging on bedrock (<10%)
Bed material texture	Mainly poorly sorted coarse gravels and sands. Some cobbles and a few boulders of Bmax 169 cm (Pages). Fine silts are draped over the gravel sheets and in the interstices between gravels.
Channel geometry (size and shape)	The channel is a compound channel with a range of benches and bank-attached geomorphic units producing a stepped morphology. The channel is up to 200 m wide, but is relatively shallow and commonly less than 2 m deep. Bank composition is fine sand and silt.

Geomorphic units (Geometry, sedimentology)	**Instream** A diverse array of instream geomorphic units occur along this River Style. There are a range of mid-channel features including longitudinal bars and islands. Bars are dominantly lateral bars, but point bars do occur on the infrequent bends. Where there is reworking of geomorphic units, compound features result. Benches occur along the channel margins forming an inset floodplain within the macrochannel. Pool-run sequences dominate the channel bed. **Lateral bar** – are longitudinal bank attached features that occur along straighter sections of the reach. They are comprised of gravels and coarse sands with a finer subsurface fraction. **Longitudinal bar** – A mid-channel bar comprising coarse sand and gravel. They are up to 100 m long, 0.5 m high, and 40 m wide. Many of these bars are compound features consisting of vegetated ridges, chute channels and dissected platforms. **Chute** – Dissection features that occur on longitudinal and point bars. They are comprised of coarse gravels and are up to 100 m long, 2 m wide and 0.5 m deep. **Ridge** – Depositional features (commonly around vegetation) that occur on longitudinal and point bars. They are comprised of coarse sand and gravel and are up to 100 m long, 2 m high, and 4 m wide. **Island** – a vegetated mid-channel longitudinal bar. They are comprised mainly of gravels, but finer materials may trapped by vegetation. **Point bar** – arcuate feature attached to the insides of meander bends. They are comprised mainly of gravel. Coarse sands may be present in the near surface interstices of the gravels, while the material in the subsurface interstices tends to be finer. Many of these bars are compound features consisting of vegetated ridges, chute channels and dissected platforms. **Pool** – scour feature at the outsides of meander bends and are up to 1 m deep and 3 m wide. Pools tend to occur on straighter reaches and are irregularly spaced. The bed of the pools is comprised of gravels covered with fine material. **Run** – shallow, planar features that occur adjacent to bars and at the entry to pools. They are comprised mainly of coarse sand and gravels. They can be up to ~ 40 m long and ~ 3 m wide. **Gravel sheet** – They cover the entire channel bed are composed mainly of coarse gravel and cobbles which may have a drape of fine silts and sands. They are up to ~ 100 m long and ~ 40 m wide. **Bench** – stepped feature deposited against the bank of the macrochannel. Comprised largely of interbedded gravels and sands with occasional finer material. **Secondary channel** – occur adjacent to mid-channel bars and islands. They flank the bank that is opposite to the primary channel, have beds consisting of coarse sand and gravel, and may accumulate finer materials.
	Floodplain – The floodplain along this River Style can be several kilometres wide. Tend to be relatively flat-topped with palaeochannels and floodrunners on the surface. Terraces line the valley margins. The floodplain is comprised largely of fine sand and silt. **Palaeochannels** – Long sinuous remnant channels preserved on the floodplain. Contain a fine grained infill that can extend up to 5 m in thickness. **Terraces** – Line the valley margins and are composed of fine to coarse sand. They are up to 150 m long and 45 m wide. **Floodrunner** – Elongate, relatively straight scour depressions. They are between 5 - 8 m wide and about 1- 3 m deep. **Backswamp** – occur along the valley margin, are irregular in shape, accumulate fine material, and hold permanent water. **Levee** – occasionally present along the channel margin. They are shallow features with low surface angles and are composed of fine sands and silts.
Vegetation associations	**Instream geomorphic units** Some sections of the channel are extensively vegetated. Casuarinas and willows are becoming establish along chute channels, ridge features and islands. A range of grasses, thistles, blackberries and various other weeds have invaded the channel. Some surfaces of the gravel bars and sheets are unvegetated.
	Floodplain geomorphic units Improved pastures dominates the floodplain, with some native eucalypts still persisting. Willows are abundant in the riparian zone.

RIVER BEHAVIOUR

Significant channel incision and expansion has occurred. Sediment release from upstream has choked the channel with gravel, resulting in a relatively straight, wide, and shallow channel in places.

Low flow stage

Flow is confined to the low flow channel. Fine materials tend to be deposited in the interstices of gravels. Some banks are undercut inducing slumping and channel expansion. Along the Pages River, large volumes of sediment have accumulated within the over-expanded channel choking some parts of the river with gravel. Subsurface flow now occurs during low flow stage.

Bankfull stage

During bankfull flows gravel is entrained and bedload transport occurs. Bars and benches are reworked, pools are scoured, and fines are flushed downstream. Channel incision and expansion occurs under high energy conditions. As flows recede, sediments are deposited on bars and benches.

The moderately deep pools within the active channel indicate that removal of sediment accumulations occurs during bankfull flow. During these flows energy is concentrated within the macrochannel. Scouring and deposition occur on mid-channel and bank-attached bars resulting in the formation of ridges and chute channels. At bankfull flow gravel sheets can be active, though some gravel sheet surfaces appear to be armoured and are not scoured. The deposition of finer sediments over mid-channel features occurs as floodwaters wan. The existence of benches indicates that channel contraction may be occurring although significant reworking of these features occurs.

Overbank stage

During over-bank stage the flow energy is dissipated over a wide floodplain. Scour is induced by willow embankments and floodrunners are formed and maintained adjacent to these embankments. Water flows in palaeochannels during overbank stage.

CONTROLS

Upstream catchment area	This River Style drains a significant catchment area. On the Pages River the upstream catchment area is 1103 km^2, and along the Hunter River is 1750 km^2.
Landscape unit and within-Catchment position	This River Style is only found in the **Undulating Plain** landscape unit in the lower catchment.
Process zone	There is significant sediment accumulation in the channel zone of this River Style. Hence, it is presently acting as a sediment accumulation zone with a gravel slug effectively ‘stuck’ at this position in the catchment.
Valley morphology (size and shape)	This River Style is formed in a wide valleys that ranges in width from 1.7 km to over 10 km wide. Significant accommodation space in the valley has been created within which continuous floodplains have formed.
Valley slope	Slopes tends to be relatively low given the location of the river within a wide alluvial valley in the lower part of the catchment. Average slope is 0.003

Stream power	

Low Sinuosity Gravel Bed (Pages River - 049452 Muswellbrook 9033)

(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)	64.1	1449.2	4795.9	8961.5	17358.4	26486.5	38580.5
Energy Slope	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014
Critical Flow (m^3/s)	4.54	102.57	339.42	634.23	1228.51	1874.54	2730.47
Water Level is (m)	-4.30	-2.89	-1.87	-1.0	-0.9	-0.7	-0.3
Critical Surface Width (m)	57.80	230.30	237.50	243.4	1044.7	1349.7	1357.6
Unit Stream Power (Watts/m^2 or $N/m^2/s$)	1.10	6.30	20.20	36.8	16.6	19.6	28.4

Figure 42: Schematic valley cross section, Low Sinuosity Gravel Bed River Style (Pages River - 049452 Muswellbrook 9033)

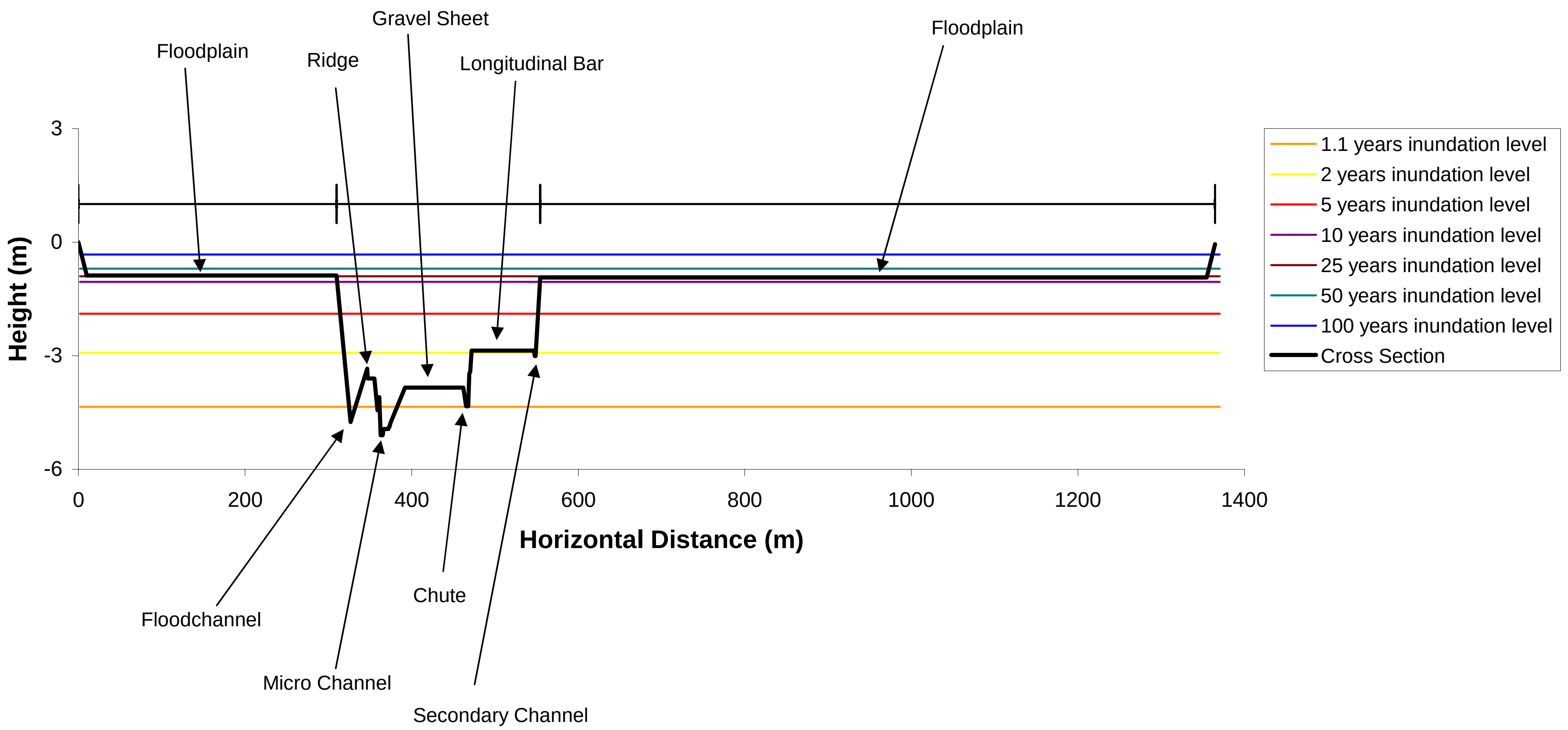


Figure 43: Aerial View of a Low Sinuosity Gravel Bed River Style reach, Pages River

Figure 44: Low Sinuosity Gravel Bed River Style reach on Pages River, looking upstream at Leighton Park Road

3.2.4.10 Meandering Gravel Bed River Style

Defining attributes of River Style (from River Styles tree): This River Style is found in a laterally-unconfined valley and has a sinuous (sinuosity >1.3) single channel. The macrochannel contains a diverse range of instream geomorphic units including lateral bars, point bars, pools, riffles, runs, and benches. The floodplain contains an array of sinuous palaeochannels. Terraces line the valley margins. Lateral stability of the macrochannel is considered low, however this varies depending on the curvature of meander bends and the sedimentology of the floodplain. The most likely form of macrochannel adjustment is channel incision and expansion. There is significant capacity for the low flow channel to adjust within the macrochannel.. Bed sediment is dominantly gravel.

Subcatchments in which River Style is observed: Hunter River

DETAILS OF ANALYSIS
Representative Reach: Hunter River near Muswellbrook (UHRRI study reach). ***Map sheet(s) air photographs used:*** ***Analysts:*** James Lander, Kirsty Hughes, Elizabeth Lamaro ***Date**:* 29-30/03/2003

RIVER CHARACTER	
Valley-setting	Laterally unconfined
River planform • Sinuosity • Number of channels • Lateral stability	The channel is a single continuous macrochannel with a sinuosity > 1.3. The over-widened channel is laterally unstable and has the capacity to laterally expand. The low flow channel has the ability to laterally adjust within the macrochannel. Research undertaken on the UHRRI study reach (which is within this River Style) has shown that the study reach has three zones of lateral stability. They are named high, intermediate, and low adjustment zones and are determined by their lateral activity and planform
Bed material texture	The bed of the macrochannel is dominantly gravel, there are some coarse sands and fines in the interstices between gravels.
Channel geometry (size and shape)	The channel has stepped morphology, it is a compound shape with a range of benches. Has straighter sections which are symmetrical and entrenched, while the meander bends are asymmetrical. Bank are composed of silts and fine sands.

<table>
<tr><td rowspan="2">Geomorphic units
(Geometry, sedimentology)</td><td>Instream
A diverse array of instream geomorphic units occur along this River Style. The wide high adjustment zones have the greatest array of geomorphic units, while the entrenched low adjustment zones are relatively simply and homogenous. Benches occur along the channel margins forming an inset floodplain within the macrochannel. Point bars occur along the insides of meander bends and lateral bars are attached to the banks of straighter sections. Pool-riffle-run sequences dominate the channel bed.
Bench – stepped feature deposited against the bank of the macrochannel. There may have multiple surfaces reflecting different phases of channel contraction and reworking. They are composed largely of interbedded gravels and sands with occasional finer material.
Point bar – arcuate feature attached to the insides of meander bends. The surface sediment is composed mainly of gravels. Coarse sands may occur in the near surface interstices of the gravels, while subsurface interstices tend to contained finer material. Many of these bars are compound features consisting of vegetated ridges, chute channels and dissected platforms.
Lateral bar – longitudinal bank-attached features that occur along straighter sections of the reach. They are composed of gravels and coarse sands. The subsurface sediment tends to be finer.
Pool – up to 3.5 m deep, tend to occur on the outsides of meander bends and as deep scour holes along straighter reaches. They are irregularly spaced along the reach. The beds of pools are gravels with finer material deposited on top.
Riffle – accumulations of gravels that occur between pools and at the heads of bars.
Run – shallow, planar features formed between pools. They tend to be located in straighter sections of the River Style and are composed mainly of gravels.</td></tr>
<tr><td>Floodplain
The floodplain along this River Style comprises a mosaic of sinuous, low capacity palaeochannels. These represent the position of old channels. Terraces line the valley margins. The floodplain is composed mainly of fine sand and silt.
Palaeochannels – Long sinuous remnant channels preserved on the floodplain. Contain a fine grained infill that can be up to 5 m thick.
Terraces – Line the valley margins.</td></tr>
<tr><td rowspan="2">Vegetation associations</td><td>Instream geomorphic units
Bar surfaces tend to be either unvegetated or covered by exotic weeds. Some tussock and native grasses do occur adjacent to banks. Have recently been planted with native tube stock.</td></tr>
<tr><td>Floodplain geomorphic units
Floodplain vegetation is dominantly pasture. The riparian zone vegetation is dominantly willows and other exotics with occasional acacias, river red gums, and other eucalypts. Palaeochannels can be swampy and support some tussock grass.</td></tr>
</table>

RIVER BEHAVIOUR

Low flow stage

Flow is confined to the low flow channel. Fine materials tend to be deposited in the interstices of gravels. Some banks are undercut during base flows.

Bankfull stage

During bankfull flows gravel is entrained and bedload transport occurs. Bars, benches, and riffles are reworked, pools are scoured, and fines are flushed downstream. Channel expansion and channel migration may occur in high and intermediate adjustment zones. As flows recede, sediments are deposited on bars and benches. This stage occurs between the 1 in 50 and 1 in 100 year events.

Overbank stage

During over-bank stage the flow energy is dissipated over a wide floodplain. Water flows in palaeochannels during overbank stage. Fine grained vertical accretion of the floodplain occurs at a very slow rate.

CONTROLS	
Upstream catchment area	Average catchment area = 4018 km^2.
Landscape unit and within-Catchment position	This River Style is only found in the low lying, **Undulating Plain** landscape unit of the lower catchment and is the most downstream River Style in this catchment, and is confined to the Hunter trunk stream.
Process zone	Very fine material is transferred through the reach as suspended load. Gravels can be moved during high magnitude events. Floodplains vertically accumulate.
Valley morphology (size and shape)	Wide valley, 1-2 km across. Significant accommodation space in the valley has been created within which continuous floodplains have formed.
Valley slope	Average Slope 0.002
Stream power	

Meandering Gravel Bed (Hunter River 957243 Muswellbrook 9033)
(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)	37.7	862.8	2711	4921.8	9266.6	13903.4	19973.1
Energy Slope	0.0004742	0.0004742	0.0004742	0.0004742	0.0004742	0.0004742	0.0004742
Critical Flow (m^3/s)	8.1143338	185.46528	582.7503	1057.9657	1991.8872	2988.5885	4293.3015
Water Level is (m)	124.01	127.39	130.01	131.74	132.1	132.27	133.05
Critical Surface Width (m)	36.2	119	136.4	1005.8	1014.4	1190.7	1477.2
Unit Stream Power (Watts/m^2 or $N/m^2/s$)	1	7.3	19.9	4.9	9.1	11.7	13.5

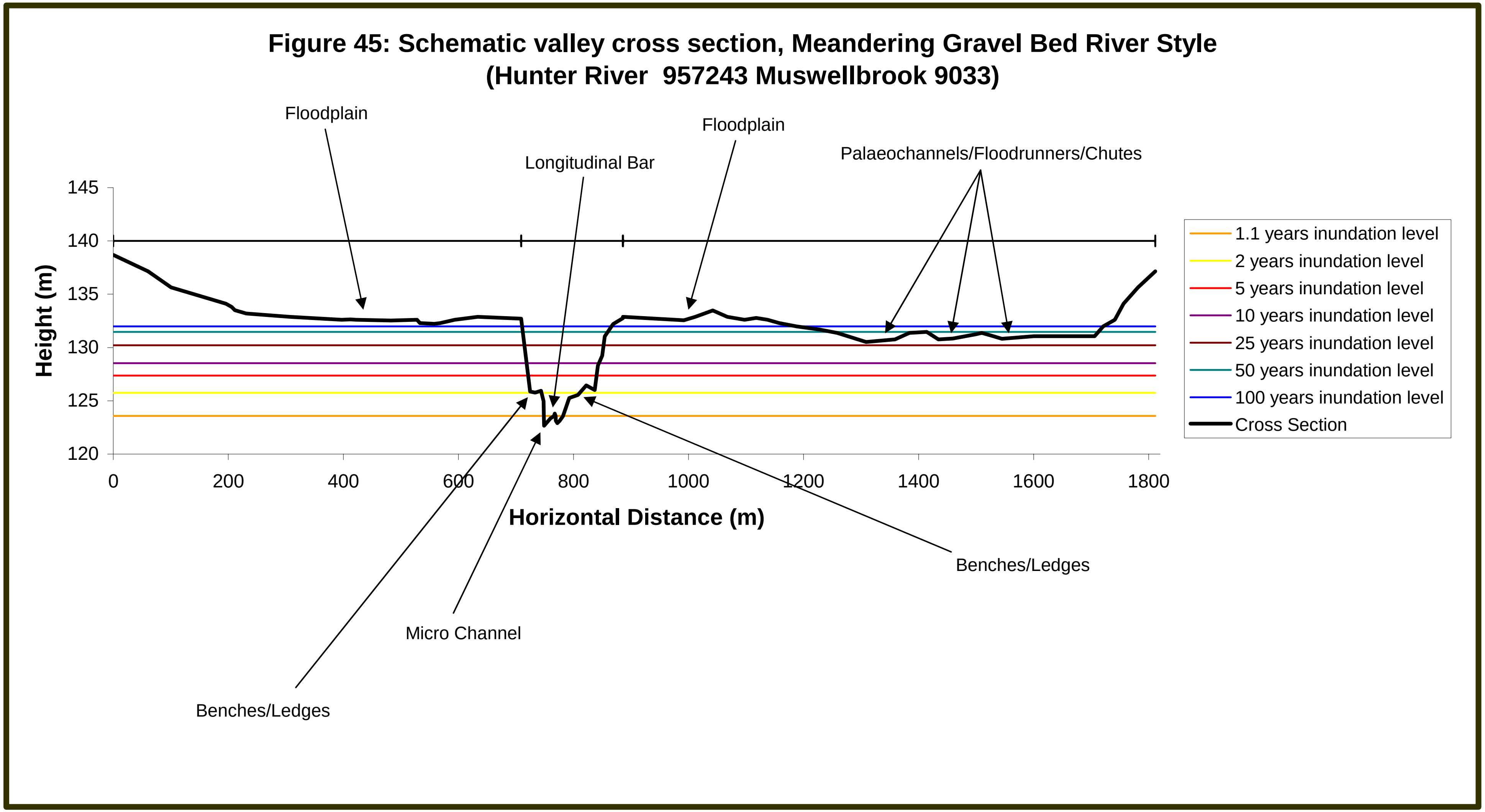


Figure 45: Schematic valley cross section, Meandering Gravel Bed River Style
(Hunter River 957243 Muswellbrook 9033)
Floodplain
Floodplain
Longitudinal Bar
Palaeochannels/Floodrunners/Chutes
Height (m)
145
140
135
130
125
120
0
200
400
600
800
1000
1200
1400
1600
1800
Horizontal Distance (m)
1.1 years inundation level
2 years inundation level
5 years inundation level
10 years inundation level
25 years inundation level
50 years inundation level
100 years inundation level
Cross Section
Benches/Ledges
Micro Channel
Benches/Ledges

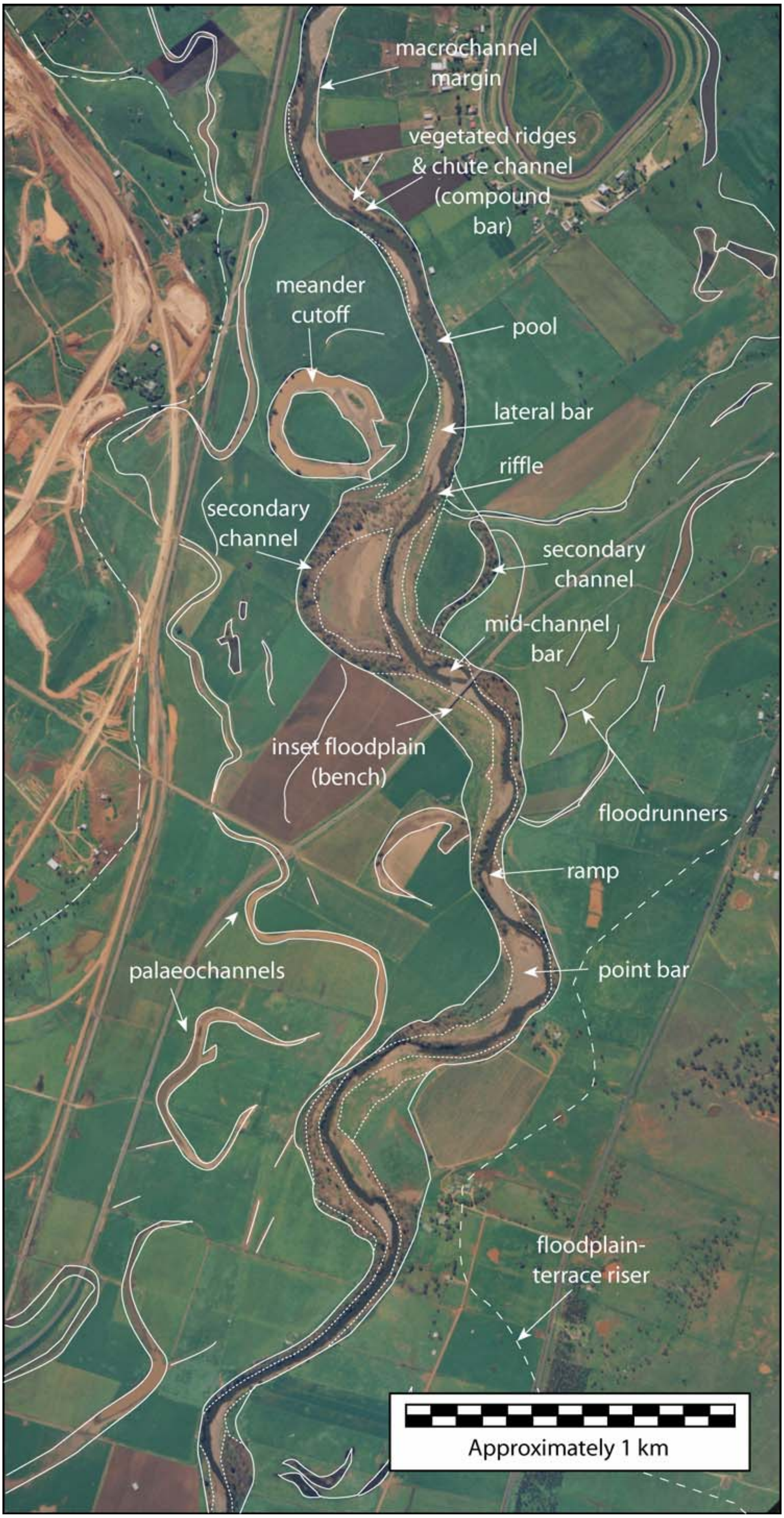


Figure 46: Aerial View of a Meandering Gravel Bed.River Style reach, Hunter River

Figure 47: Meandering Gravel Bed River Style reach on The Hunter River, looking downstream at Keys Bridge

3.3 STAGE ONE, STEP THREE: INTERPRETATION OF CONTROLS ON THE CHARACTER, BEHAVIOUR, AND DOWNSTREAM PATTERNS OF RIVER STYLES

Controls on the character and behaviour of River Styles in the Upper Hunter Catchment are summarised in Table 7. Attributes, such as, position in the catchment, slope, and valley confinement vary between River Style. When the variation between the attributes of the River Styles are compared across the catchment, it can be seen that a distinct set of attributes control the character and behaviour of each River Style. When the downstream succession of River Styles is assessed for each stream across the catchment, distinct downstream patterns of River Styles can be identified. In the Upper Hunter Catchment, these patterns reflect the underlying geological structure and landscape configuration of the catchment.

Table 7: Controls on river character and behaviour in the Upper Hunter Catchment

River Style	Average Catchment Area (km^2)	Average Elevation	Average Slope	Average Gross Stream Power (2 year event)	Unit Stream Power at surveyed cross section (Wm^{-2})						
					Recurrence Interval						
					1 in 1.1	1 in 2	1 in 5	1 in 10	1 in 25	1 in 50	1 in 100
Steep Headwater.	6.739	888.667	0.139	94608.328							
Occasional Floodplain Pockets	47.583	505.529	0.020	13562.279	62.2	460.9	363	669.7	1255.6	1818.6	2502.7
Gorge	144.442	462.323	0.023	16334.224	5.7	175.6	542.9	961.3	1723.2	2548.1	3586.5
Bedrock Controlled Discontinuous Floodplain	422.736	402.533	0.007	5432.159	33.40	374.20	971.80	1530.0	2147.5	1445.5	1736.5
Low Sinuosity Planform Controlled Discontinuous Floodplain	107.009	437.319	0.008	5548.278	5.7	95	183.7	264.1	445.3	235.7	99.7
Meandering Planform Controlled Discontinuous Floodplain	91.193	290.822	0.009	6059.554	91.7	637.6	451.3	575.8	886.4	997.9	1322.3
Low Sinuosity Entrenched Gravel Bed	~358.281	~174.846	<0.002	~1546.116		43	17.1	2	3.9	5.9	8.5
Meandering Entrenched Gravel Bed	336.934	199.145	0.003	2143.751	6.8						
Low Sinuosity Gravel Bed	1561.870	182.270	0.003	3749.145	1.1	6.3	20.2	36.8	16.6	19.6	28.4
Meandering Gravel Bed	4018.436	125.936	0.002	2740.344	1	7.3	19.9	4.9	9.1	11.7	13.5

3.3.1 Controls on the character and behaviour of River Styles in Upper Hunter catchment

In general, a continuum of energy conditions occurs from confined rivers, through partly confined rivers to laterally unconfined rivers. Gross stream power reflects a combination of discharge and slope conditions along river courses. The energy of a river drives the way water interacts with sediment, so that sediment is eroded from a source, transferred or stored along a river course. This interaction dictates the character and behaviour of the river. In the Upper Hunter Catchment, the highest gross stream powers are generated in the confined valleys within plateau slopes and rugged and hilly landscape units. The gross stream powers in the partly confined valleys are relatively high. This indicates the significant potential for flow to rework sediments stored along these river courses and to throughput sediment. Gross stream power are lowest along laterally-unconfined rivers reaches found within the undulating plain landscape unit.

3.3.1.1 River Styles found in the Confined valley setting

The **steep headwater** River Style is set within the slopes of the remnants of a dissected plateau. It is located within the plateau slopes zone of all subcatchments. This River Style is the steepest in the catchment (average 0.139). The narrow width, slope, and alignment of the valleys dictate the local morphology and assemblage of geomorphic units of this River Style. Given that these are the most upstream River Styles, catchment areas are low, average 6.7 km^2. Given the high slope-low catchment area relationship, unit stream powers are probably high for floods up to the 5 year recurrence interval event. The valley hillslopes and the channel are strongly connected (coupled) in this River Style.

The **occasional floodplain pockets** River Style is found in elongate, confined valleys of the tributaries and trunk streams (width 20-75 m). Valley slope is generally high (average 0.02), but highly variable given the bedrock character of the channel bed. As this River Style is toward the top of the subcatchments, catchment areas are relatively low, (average 47.6 km^2). This overlaps significantly with other confined and partly confined River Styles which occur at similar positions in the catchment. Given the variability in the catchment area under which this River Style is found, a wide range of formative (bankfull-stage) flows occurs. In most instances, floodplain is absent and all flows utilise the entire valley floor. In other sections there are occasional floodplain pockets up to several metres thick, these pockets are characteristically only present on one side of the valley. Given the confined valley setting and relatively steep slopes, reaches of this River Style generate among the highest stream powers in the catchment. Along these river reaches sediments is readily reworked. At the surveyed cross section for this River Style unit stream powers range from around 461 Wm^2 for a 1 in 2 year event to over 2502 Wm^{-2} for the 1 in 100 year event. Figure 20 shows the inundation levels at the surveyed cross section. It can be seen in figure 20 that the valley hillslopes are proximal to the channel and the valley floor is often inundated. This has two important implications; firstly, the exchange of organic material, dissolved nutrients, and sediment between the channel and floodplain is very active; secondly, sediment moving down the hillslope (hillslope processes) can easily be incorporated into the river system and moved downstream (fluvial processes). The valley hillslopes and the channel are strongly connected (coupled) in this River Style.

The **gorge** River Style is set within a deeply incised V-shaped, narrow valley (<40 m wide). All gorges in the Upper Hunter Catchment are found in mid-catchment locations. Upstream catchment areas are variable, and there is a wide slope-catchment area range for this River Style. These gorges can drain relatively large catchment areas and channel slopes are moderate. The large catchment areas combined with the confined valley-settings generate the highest unit stream powers in the catchment. Along these river reaches sediment is readily flushed downstream. At the surveyed cross section for this River Style unit stream powers range from around 460.9 Wm^{-2} for a 1 in 2 year event to over 3587 Wm^2 for the 1 in 100 year event. Figure 23 shows the inundation levels at the surveyed cross section. It can be seen in figure 23 that there is on distinction between the valley hillslopes and the sides of the channel and there is no distinction between the valley floor and the channel bed. Therefore, sediment and organic matter moving down the hillslope (hillslope processes) can easily be incorporated into the river system and moved downstream (fluvial processes). The valley hillslopes and the channel are very strongly connected (coupled) in this River Style.

3.3.1.2 River Styles found in the Partly confined valley setting

The **partly confined valley with bedrock-controlled discontinuous floodplain** River Style is formed in sinuous valleys. Hence, the primary control on channel alignment is valley configuration. The valleys are generally wider and the slopes gentler (average 0.007) than along the confined valley with occasional floodplain pockets River Style. Hence, the slope catchment area range for this River Style is distinct from that of the confined with occasional floodplain pockets River Style. In the Upper Hunter catchment the morphology of the valleys in which the bedrock-controlled discontinuous floodplain River Style occurs is variable. Some sections are broad while others are narrow. The confining valley margin can be alluvial or strath terrace, or bedrock. The surveyed cross section of the partly-confined valley with bedrock-controlled discontinuous floodplain River Style experiences bankfull events between a recurrence intervals of 50 and 100 years. This reflects the gentler slopes and wider valleys in which this River Style forms. At the surveyed cross section for this River Style unit stream powers range from around 374 Wm^{-2} for the 1 in 2 year event to 1736.5 Wm^{-2} for the 1 in 100 year event. These conditions effectively rework and redistribute the material stored in this River Style, roughly maintaining a balanced between sediment transfer into and out of the reach. Figure 25 shows the inundation levels at the surveyed cross section. It can be seen in figure 25 that the valley hillslopes are not far from the channel, but the floodplain is infrequently inundated (1 in 100 yr recurrence interval). That is, most flows are contained within the channel. This has two important implications; firstly, the exchange of organic material, dissolved nutrients, and sediment between the channel and floodplain is almost inactive; secondly, sediment moving down the hillslope (hillslope processes) cannot easily be incorporated into the river system and moved downstream (fluvial processes). The valley hillslopes and the channel are only moderately connected (moderately coupled) in this River Style.

The **partly confined valley with meandering planform controlled discontinuous floodplain** River Style is formed in valleys that have a relatively straight or irregular planform morphology. This River Style may alternate with the low sinuosity planform controlled discontinuous floodplain River Style. The primary control on channel alignment is the lateral or downstream movement of the channel within the floodplain. Most valleys that contain this River Style are characterized by low lying alluvial fans that extend onto the valley floor from lower order drainage lines. These coarser-grained sediments effectively ‘pin’ the channel against the opposite valley margin, forcing flow around the alluvial fan and along the valley margin. At the surveyed cross section of the meandering planform controlled discontinuous floodplain River Style, bankfull events occur moderately frequently (> 1 in 5 years). River reaches of this River Style generate among the lowest (but slightly higher than low sinuosity planform controlled discontinuous floodplain River Style) stream powers of all River Styles. This reflects the gentler slopes and wide valleys in which this River Style forms. At the surveyed cross section for this River Style unit stream powers range from around 637.6 Wm^{-2} for the 1 in 2 year event to 1322.3 Wm^{-2} for the 1 in 100 year event. These conditions effectively rework and redistribute the material stored in this River Style, maintaining roughly balanced sediment transfer along the channel bed. Figure 28 shows the inundation levels at the surveyed cross section. It can be seen in figure 28 that the valley hillslopes are proximal to the channel and the valley floor is often inundated. This has two important implications; firstly, the exchange of organic material, dissolved nutrients, and sediment between the channel and floodplain is active; secondly, sediment moving down the hillslope (hillslope processes) can be incorporated into the river system and moved downstream (fluvial processes). The valley hillslopes and the channel are moderately to strongly connected (coupled) in this River Style.

The **partly confined valley with low sinuosity planform controlled discontinuous floodplain** River Style is formed in valleys that have an irregular or straight planform morphology. The primary control on channel alignment is the movement of the channel within the floodplain. Most valleys that contain this River Style are characterized by low lying alluvial fans that extend onto the valley floor from lower order drainage lines. These coarser-grained sediments effectively ‘pin’ the channel against the opposite valley margin, forcing flow around the alluvial fan and along the valley margin. The valleys are generally wider and slopes gentler (average 0.008) than those of the bedrock controlled discontinuous floodplain River Style. In each system this River Style occurs, the downstream boundary of the River Style is characterised by a narrowing of the valley. This constriction acts as a barrier behind which the valley fill accumulates and floodplains form. Along the low sinuosity planform controlled discontinuous floodplain River Style, bankfull events have, approximately, a 1 in 50 year recurrence interval. River reaches of this River Style generate the lowest stream powers of all the partly confined River Styles. This reflects the gentler slopes and wide valleys in which this River Style forms. At the surveyed cross section for this River Style unit stream powers range from around 95 Wm^{-2} for the 1 in 2 year event to 99.7 Wm^{-2} for the 1 in 100 year event. These conditions effectively rework and redistribute the material stored in this River Style, roughly maintaining a balanced between sediment transfer into and out of the reach. Figure 31 shows the inundation levels at the surveyed cross section. It can be seen in figure 31 that the valley hillslopes are not far from the channel, but the valley floor is infrequently inundated (1 in 50 yr recurrence interval). That is, most flows are contained within the channel. This has two important implications; firstly, the exchange of organic material, dissolved nutrients, and sediment between the channel and floodplain is not very active; secondly, sediment moving down the hillslope (hillslope processes) cannot easily be incorporated into the river system and moved downstream (fluvial processes). The valley hillslopes and the channel are only moderately connected (moderately coupled) in this River Style.

3.3.1.3 River Styles found in the Laterally-unconfined valley setting

The l**ow sinuosity entrenched gravel bed** River Style is formed within wide valleys with low slopes (<0.002). This combination produces very low stream powers, the unit stream power of the surveyed cross section is 43 Wm^{-2} for the 1 in 2 year recurrence interval event and 8.5 Wm^{-2} for the 1 in 100 year event. It is only found along Kingdon Ponds, just upstream of its confluence with Dart Brook. The straight, narrow and moderately deep trench-like channel is thought to have an anthropogenic origin. It appears that Kingdon Ponds terminated in a swamp which had a small out flowing creek (Cross Creek) and sometime since settlement a trench has been dug through the swamp to connect Kingdon Ponds to Dart Brook, thereby draining the swamp. At the surveyed cross section for this River Style unit stream powers is 6.8 Wm^{-2} for the 1.1 year recurrence interval event. Figures 34 and 35 show the inundation levels (not all were able to be modeled) at the surveyed cross section. It can be seen in these figures that the valley hillslopes are distal to the channel and although over bank flows occur frequently, flows that cover the entire valley floor occur infrequently. This has two important implications; firstly, the exchange of organic material, dissolved nutrients, and sediment between the channel and the immediately surrounding floodplain is active, but exchange between the channel and the entire valley floor is almost inactive; secondly, sediment moving down the hillslope (hillslope processes) cannot be easily incorporated into the river system and moved downstream (fluvial processes). The valley hillslopes and the channel are strongly disconnected (decoupled) in this River Style.

The **meandering entrenched gravel bed** River Style is formed in low slope (average 0.003) wide (~1000 to 4000 m) valleys along Dart and Middle Brooks and Kingdon Ponds. The valleys drain a large catchment area (~337 km^2). The channel is narrow and trench-like with a low width depth ratio and low capacity. At the surveyed cross section, modeled formative flows (bankfull) occur frequently (between 1 in 1.1yr and 1 in 2yr recurrence interval events). Most flows spill onto wide floodplains. As a result, energy is dissipated over the floodplain and stream powers are amongst the lowest in the catchment (average gross stream power 2144). At the surveyed cross section for this River Style unit stream powers is 6.3 Wm^{-2} for the 2 year recurrence interval event to 9.4 Wm^{-2} for the 100 year event. Figures 38 and 39 show the 1 in 1.1 yr recurrence interval inundation level at the surveyed cross section. These figures show that valley hillslopes are distal to the channel. It is not shown explicitly, as not all flood levels were able to be modeled, but over bank flows occur frequently, while flows that cover the entire valley floor occur infrequently. This has two important implications; firstly, the exchange of organic material, dissolved nutrients, and sediment between the channel and the immediately surrounding floodplain is active, but exchange between the channel and the entire valley floor is almost inactive; secondly, sediment moving down the hillslope (hillslope processes) cannot be easily incorporated into the river system and moved downstream (fluvial processes). The valley hillslopes and the channel are strongly disconnected (decoupled) in this River Style.

The **low sinuosity gravel bed** River Style is found in wide alluvial valleys (width <1000 m) with the channel aligned roughly down the centre of the valley. Reaches of this River Style occur on the lower sections of the Pages River and the Hunter River between Glenbawn Dam and Aberdeen where catchment areas are large (average 1562 km^2). Given that the channel is deep and wide, low frequency events are contained within the channel (including the 1 in 10 year event). At the surveyed cross section for this River Style unit stream powers is 6.3 Wm^{-2} for the 2 year recurrence interval event to 9.4 Wm^{-2} for the 100 year event. Figure 42 shows the inundation levels at the surveyed cross section. It can be seen in figure 42 that the valley hillslopes are distal to the channel and the valley floor is not frequently inundated (1 in 25 yr recurrence interval). This has two important implications; firstly, the exchange of organic material, dissolved nutrients, and sediment between the channel and floodplain is only moderately active; secondly, sediment moving down the hillslope (hillslope processes) cannot be easily incorporated into the river system and moved downstream (fluvial processes). The valley hillslopes and the channel are disconnected (decoupled) in this River Style.

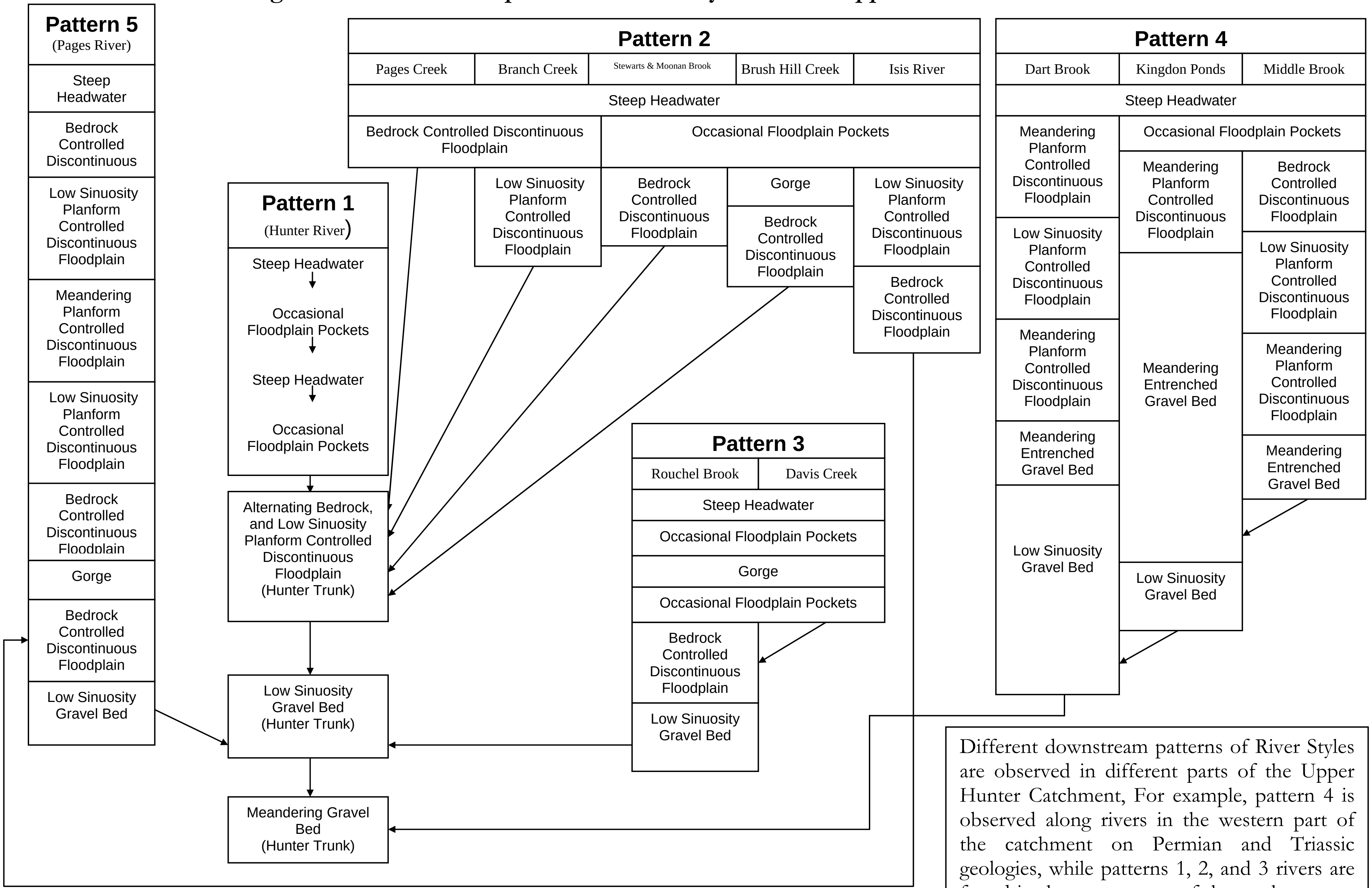
The **meandering gravel bed** River Style is located in wide alluvial valley settings (valley width <1000 m) with the channel meandering down the centre of the valley. Reaches of this River Style occur on the lower sections of the Upper Hunter River, where catchment areas are large average 4018 km^2). The slope of the valley floor is relatively low (average 0.002). Given that the channel is deep and wide, low frequency events are contained within the channel (almost including the 1 in 100 year event). At the surveyed cross section for this River Style unit stream power range from 7.3 Wm^{-2} for the 2 year recurrence interval event and 13.5 Wm^{-2} for the 100 year event. Figure 45 shows the inundation levels at the surveyed cross section. It can be seen in figure 45 that the valley hillslopes are distal to the channel and the valley floor is infrequently inundated. It can be seen in figure 42 that the valley hillslopes are distal to the channel and the valley floor is infrequently inundated (1 in 100 yr recurrence interval). This has two important implications; firstly, the exchange of organic material, dissolved nutrients, and sediment between the channel and floodplain is almost inactive; secondly, sediment moving down the hillslope (hillslope processes) cannot be easily incorporated into the river system and moved downstream (fluvial processes). The valley hillslopes and the channel are disconnected (decoupled) in this River Style.

3.3.2 Controls on the downstream patterns of River Styles in the Upper Hunter catchment

3.3.2.1 The downstream patterns of River Styles in the Upper Hunter Catchment

Five downstream patterns of River Styles were identified in the Upper Hunter catchment. (Figure 48). These five downstream patterns of River Styles can be explained by differing interdependent combinations of imposed boundary conditions including geology, valley morphology, slope, and upstream catchment area. Combinations of these produce distinctive valley types, and therefore distinct River Styles, throughout the subcatchments. The configuration of the catchment (i.e. how topographic settings fit together), and the resultant pattern of the valley settings reflects the interdependent combination of geological structure and lithology and antecedent landscape evolution associated with long-term denudation of the Great Dividing Range. This dictates the contemporary valley morphology and the amount of accommodation space within which sediments are either stored or transferred. This controls the functioning of flux boundary conditions and the contemporary character and behaviour of rivers found in the catchment. Distinct patterns of River Styles results in significant within-catchment variability in the connectivity of biophysical processes in rivers, with associated implications for the downstream transfer of water and sediment.

Figure 48: Downstream patterns of River Styles® in the Upper Hunter catchment



Different downstream patterns of River Styles are observed in different parts of the Upper Hunter Catchment, For example, pattern 4 is observed along rivers in the western part of the catchment on Permian and Triassic geologies, while patterns 1, 2, and 3 rivers are found in the eastern part of the catchment on Carboniferous and Devonian geologies. The

Representative examples of each downstream pattern of River Styles in the Upper Hunter catchment are used to demonstrate the longitudinal controls on river character and behaviour (figures 49 to 53). Note that gross stream power and contributing area are plotted over the long profile, and a series of other imposed and flux parameters including valley confinement, sediment regime etc. are plotted below the long profile. Trends and relationships are described for each pattern.

Pattern 1 (Hunter River)
Pattern 1 occurs along the Hunter River. The Hunter begins with an alternating pattern of Steep Headwater and Occasional Floodplain Pockets River Styles. These reaches are followed by a short sequence of partly confined valley with Bedrock Controlled Discontinuous Floodplain and Low Sinuosity Planform Controlled Discontinuous Floodplain River Styles. From these short reaches to Glenbawn Dam the Hunter trunk stream is a partly confined valley with Bedrock-Controlled Discontinuous Floodplain River Style. Downstream of Glenbawn Dam, the Hunter River enters a laterally-unconfined valley setting. A Low Sinuosity Gravel Bed River Style occurs from slightly downstream of Glenbawn Dam to Aberdeen. The Meandering Gravel Bed River Style extends from Aberdeen, past Muswellbrook, to Denman. This pattern is observed when flow begins on the remnant plateau, continues down the plateau slopes, across the folded Devonian and Carboniferous meta-sediments in partly confined valleys that vary in width, and crosses the Hunter-Mooki fault onto the wide alluvial valley.

Pattern 2 (Pages Creek, Branch Creek, Stewarts Brook, Moonan Brook, Brush Hill Creek, Isis River)
Pattern 2 rivers occur along the tributary systems that join the Hunter River above Glenbawn Dam including Pages Creek, Branch Creek, Stewarts and Moonan Brooks and Brush Hill Creek. The Isis River is a slight variant as it joins the Pages River which in turn joins the Hunter downstream of Glenbawn Dam. These rivers are characterized by Steep Headwater and Occasional Floodplain Pockets River Styles along the steeper sections. The steeper sections are followed by the partly confined valleys with Bedrock Controlled Discontinuous Floodplain River Style which extends along the remainder of these river courses to their confluences with the Hunter River. There are slight disruptions to this pattern where mid-catchment Gorge or Low Sinuosity Planform Controlled Discontinuous Floodplain River Styles occur. This pattern is observed in those rivers that begin on the slopes of the remnant basalt plateau, flow across the folded Devonian and Carboniferous meta-sediments in partly confined valleys that vary in width.

Pattern 3 (Davis Creek, Rouchel Brook)
The majority of these two river courses are characteristics by a confined valley with an Occasional Floodplain Pockets River Style. This River Style occurs downstream of the Steep Headwater River Style and is disrupted by localized mid-catchment gorges. At the confluence of Rouchel Brook and Davis Creek the valley widens slightly and pockets of floodplain become more regular. A partly confined valley with Bedrock Controlled Discontinuous Floodplain River Style begins at the confluence and extends almost to the confluence with the Hunter River. This pattern is observed when flow begin on the slopes of the remnant basalt plateau, continues across the folded Devonian and Carboniferous meta-sediments in confined valleys, across Devonian and Carboniferous volcanic rocks, again across folded Devonian and Carboniferous meta-sediments in confined valleys, and onto a wide floodplain pocket of the Hunter River, and joins the Hunter River below Glenbawn Dam.

Pattern 4 (Middle Brook, Dart Brook, Kingdon Ponds)
This pattern occurs along Middle Brook, Kingdon Ponds, and Dart Brook. Middle Brook flows into Kingdon Ponds, which flows into Dart Brook, which joins the Hunter River between Muswellbrook

and Aberdeen. These western rivers have a distinct downstream pattern of rivers compared to their eastern counterparts. These are the only river courses where the entrenched variants of River Style are found. These rivers have short headwater areas that contain a variety of confined and partly confined river types. As the valleys widen, extensive lengths of partly confined valley with Meandering Planform Controlled Discontinuous Floodplain extend from these headwaters and are transitional to the wide alluvial valley where the Meandering Entrenched Gravel Bed River Style occurs. The three rivers share the same valley at this point. The Low Sinuosity Entrenched Gravel Bed River Style only occurs along lower Kingdon Ponds. Just upstream of the Hunter confluence along Dart Brook, a Low Sinuosity Gravel Bed river occurs. This pattern is observed where flow begins on the remnant basalt plateau, continues down the plateau slopes, across the Permian coal measures in partly confined valleys, and onto the Hunter River floodplain material on wide alluvial valleys.

Pattern 5 (Pages River)

Pattern 5 occurs along the Pages River. The headwaters contain the Steep Headwater River Style. This is followed directly by a partly confined valley with Bedrock Controlled Discontinuous Floodplain River Style. Around Murrurundi, within the partly confined valley a unique sequence of Meandering Planform Controlled Discontinuous Floodplain and Low Sinuosity Planform Controlled Discontinuous Floodplain River Style occurs. Along the length (about 15 km) of this unique sequence the valley is relatively wide and has extensive floodplain fills. The Pages River then flows into a more confined valley where a Bedrock Controlled Discontinuous Floodplain River Style occurs. This River Style is broken by a Gorge River Style which forms a ‘bulge’ in the longitudinal profile of the river. Several kilometers downstream of Gundy the valley widens substantially. A Low Sinuosity Gravel Bed River Style extends from the start of this wider valley to the Hunter confluence. This pattern is observed when flow begins on the remnant plateau, continues down the plateau slopes, across the Permian coal measures, onto Devonian and Carboniferous volcanic rocks, across the folded Devonian and Carboniferous meta-sediments, and crosses the Hunter-Mooki fault onto the wide alluvial valley and joins the Hunter River below Glenbawn Dam.

3.3.2.2 Explanations of controls on the downstream patterns in terms of landscape configuration

The Hunter-Mooki Thrust Fault runs roughly from the north west to the south east of the Upper Hunter catchment. West of this fault there are Tertiary, Triassic, and Permian rocks. East of the fault are Tertiary, Carboniferous, and Devonian rocks. A broad grouping of the downstream patterns of River Styles can be detected on either side of the fault. Patterns 2 and 3 occur east of the fault and pattern 4 occurs west of the fault. Patterns 1 and 5 along the Hunter trunk stream and the Pages River, respectively, cross over the Hunter-Mooki Fault and have characteristics of the eastern and western patterns. Some of the valleys in the Rugged and Hilly landscape unit appear to be position along geological faults, notably on sections of Dart Brook, Isis, and Hunter Rivers.

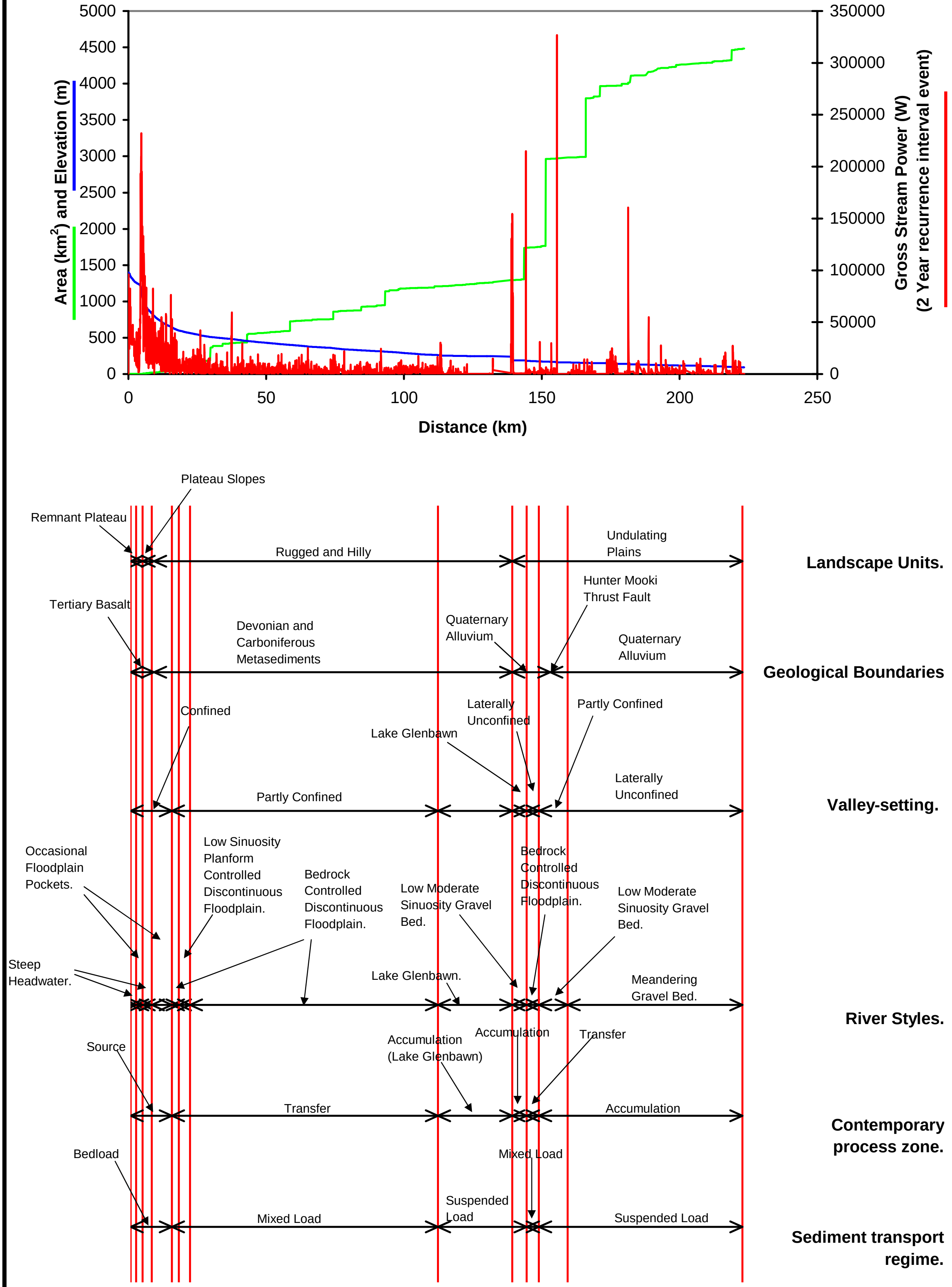
Pattern 1 rivers (Hunter River)
The Hunter River trunk stream begins on the remnant plateau, has a break in slope at the edge of the remnant plateau, and continues across the plateau slopes, the rugged and hilly landscape unit of Devonian and Carboniferous meta-sediments, and onto the undulating plain.

This pattern is distinct because there is a break in slope (slope increases) at the edge of the remnant basalt plateau. As slope is a major control of river character and behaviour this break in slope reflects a distinct downstream pattern of River Styles. Above the break in slope the confined valley and slope produce, firstly, the Steep Headwater River Style followed by Occasional Floodplain Pockets. The upstream progression of an erosional nickpoint (a response to base level change induce by tectonic uplift) has not reached the drainage divide. Therefore the headwaters are on a remnant plateau. This can be seen at the beginning of the longitudinal profile as a small concave up section where the slope begins to decrease as the river flows across the plateau. Downstream of the remnant plateau landscape unit the longitudinal profile is a smooth concave up shape.

The central section of the Hunter River, from the edge of the remnant plateau to where it crosses the Hunter-Mooki Fault (the Plateau Slopes and Rugged and Hilly landscape unit) is the same as pattern 2 and will be discusses below.

Downstream of Glenbawn Dam the Hunter River enters the wide valleys of the Undulating Plain landscape unit. The low gradients of these wide plains reduce stream power and allow extensive floodplains to develop. Directly below Glenbawn Dam the River Style on the Hunter is a Low Sinuosity Gravel Bed in a large floodplain pocket. As the river crosses the Hunter-Mooki fault the underlying geology changes to the Permian sedimentary strata. This rock is relatively soft and erodible. River valleys in this material are therefore wide with low gradients. The combination of large catchment areas, low slopes, and wide valleys produce the Low Meandering Gravel Bed River Style.

Figure 49: Controls on downstream patterns of River Styles along the Hunter River (Pattern 1)



Pattern 2 rivers (Pages Creek, Branch Creek, Stewarts Brook, Moonan Brook, Brush Hill Creek, Isis River)
Subcatchments that begin on the plateau slopes, continue across the Rugged and Hilly Devonian and Carboniferous meta-sediments, and join the Hunter River before it crosses the Hunter-Mooki fault.

On the slopes of the remnant basalt plateau the rivers are eroding through the basalt and into the underlying folded Devonian and Carboniferous meta-sediments. This process of erosion produces valleys that are confined with high slope, this combination produces River Styles with high stream powers, (e.g. Stewarts Brook Steep Headwater River Style average gross stream power 154763 W/m) therefore these river reaches have little sediment storage and are transfer zones. These are the steep headwater, gorge, and occasional floodplain pockets River Styles. The degree of confinement along these rivers appears to be related to whether valley incision has extended to the base of the basalt (note that the thickness of the tertiary basalt layer varies as it flowed over existing topography). Where valleys have eroded through the basalt and into the underlying Devonian and Carboniferous meta-sediment it would appear that the ratio between the rates of valley wall retreat and gorge extension changes relative to that of the valleys with basalt floors. The valleys with meta-sediment floors (e.g. Isis River) widen faster than valleys with basalt floors (e.g. Brush Hill Creek).

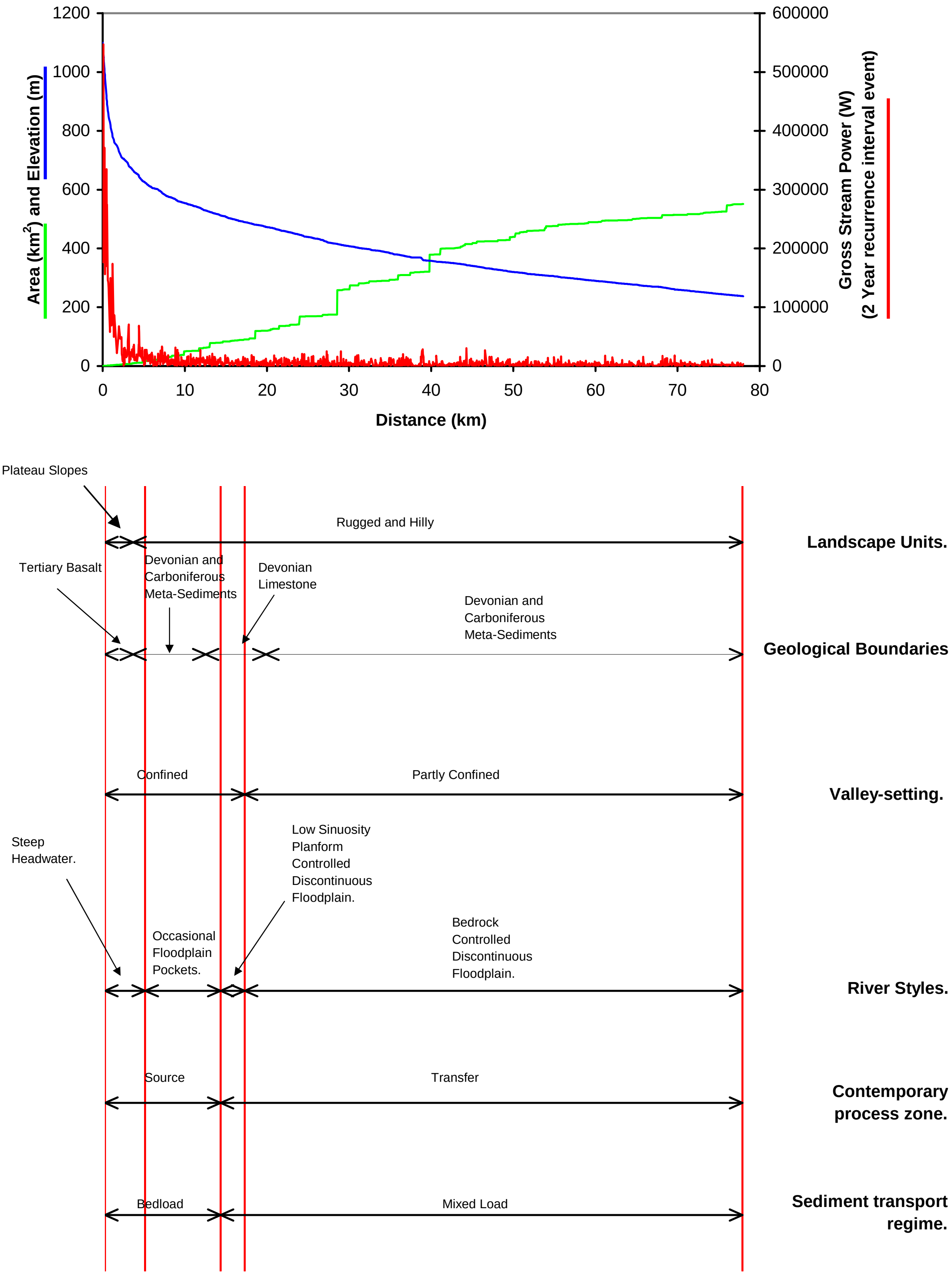
As the river flows beyond the valleys with basalt ridges the landscape is lower in altitude but rugged and hilly. Pattern 2 rivers in the Rugged and Hilly landscape unit are either Bedrock-Controlled Discontinuous Floodplain or Low Sinuosity Planform Controlled Discontinuous Floodplain River Styles. In this landscape unit there is considerable lithological variety. The interaction of geology and river processes determines the pattern of River Styles. Galloway (1963) suggests that valley width within Devonian and Carboniferous rocks is related to the relationship between valley alignment and the orientation (dip and strike) of the underlying rock strata. Initial field observation supports this suggestions. Where the valleys are parallel to the strike of the strata the valleys are wide and where valleys are perpendicular to the strike of the strata the valleys are narrow. In valleys with greater accommodation space (i.e. parallel to strike) the River Styles are Low Sinuosity Planform Controlled Discontinuous Floodplain. In valleys with less accommodation space (i.e. perpendicular to strike) the River Style is Bedrock Controlled Discontinuous Floodplain (in some cases the decision between Bedrock Controlled Discontinuous Floodplain and Occasional Floodplain Pockets is marginal).

Rock composition also influences valley width, for example the Low Sinuosity Planform Controlled Discontinuous Floodplain River Style on the Isis River is on a stretch of limestone. The major control on the downstream position of this River Style is the occurrence of the limestone substrate. In general the chemical and physical nature of limestone promotes relatively fast rates of erosion and hillslope retreat. Some of the products of limestone erosion are soluble and readily transported downstream. These processes create a locally wider section of valley and maintain a relatively flat valley floor and steep hill slopes with significant gullies incised perpendicular to the main valley. The material being transported through these gullies produce a valley margin of coalescing alluvial fans.

All pattern 2 subcatchments, with the exception of the Isis River, join the Hunter River trunk upstream of Glenbawn Dam within the Rugged and Hilly landscape unit (i.e. Devonian and Carboniferous meta-sediments).

As can be seen on figure 48 there is some variability in the pattern of River Styles that have been included in pattern 2. This reflects the geological variations within the Devonian and Carboniferous meta-sediments. The differing mechanical properties of the rock strata controls the degree of valley confinement so that the order of River Styles varies.

Figure 50: Controls on downstream patterns of River Styles along the Isis River (Pattern 2)



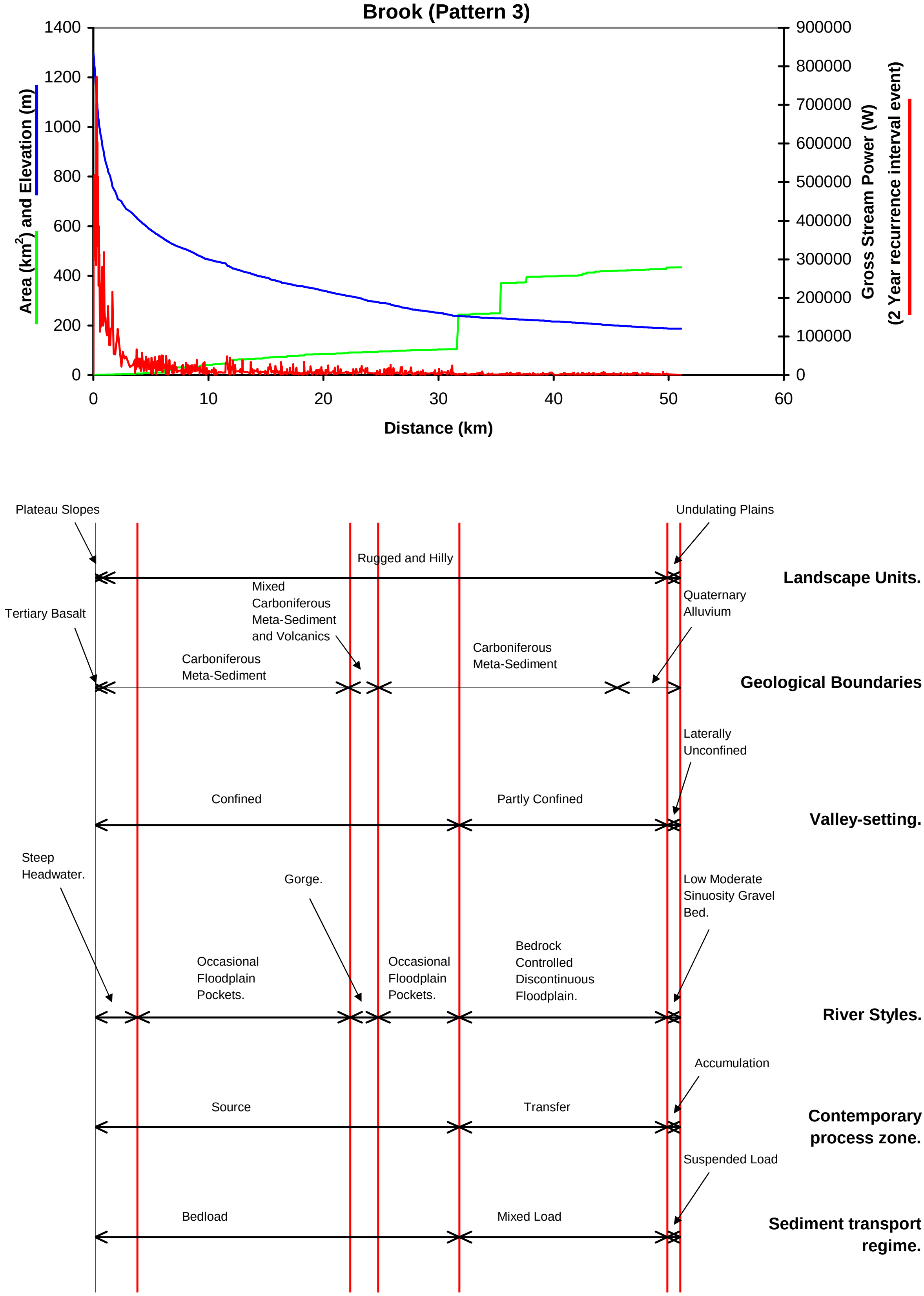
Pattern 3 rivers (Davis Creek, Rouchel Brook)
Subcatchments that begin in the Plateau Slopes landscape unit, continue across the Rugged and Hilly landscape unit with the majority of there length in confined valleys, and join the Hunter River at the downstream end of the rugged and hilly landscape unit.

Compared to the Devonian and Carboniferous meta-sediments along Pattern 2 rivers, the Devonian and Carboniferous meta-sediments found along Rouchel Brook and Davis Creek appear to be less erodible and there is a greater occurrence of faulting (there are several notable lengths of Rouchel Brook and Davis Creek where river alignment is directly above geological fault lines). In addition, these rivers cross Devonian and Carboniferous extrusive volcanics. As a result, the rate of gorge extension relative to valley side wall retreat differs to that occurring along other rivers in the area, a consequence of which is confined valleys. Rouchel Brook flows through a confined valley for more than half its length, the majority of which is confined valley with Occasional Floodplain Pockets River Style. Davis Creek, a tributary of Rouchel Brook, flows through a confined valley for its entire length. Both rivers have their lengths of Occasional Floodplain Pockets interrupted by reaches of the Gorge River Style. The location of these gorges is dictated by the occurrence of the Isismurra Formation. This is a Carboniferous geological formation consisting of conglomerate, sandstone, siltstone, shale and dacitic ignimbrites, the latter being an explosively emplaced extrusive volcanic rock. It would appear that this formation is slightly harder than the surround rock, resulting in a gorge River Style.

Immediately below the confluence of Rouchel Brook and Davis Creek, Rouchel Brook crosses the last ignimbrite outcrop in its path, after which the valley becomes partly confined and there is a long reach of bedrock controlled discontinuous floodplain River Style. This change in valley morphology is the result of a combination of a less hard lithology and increased catchment area (i.e. stream power).

Rouchel Brook joins the Hunter River a few kilometers downstream of Glenbawn Dam. The last 1 km, approximately, of Rouchel Brook is laterally unconfined with a Low sinuosity gravel bed River Style. This change occurs as Rouchel Brook flows on the Quaternary alluvium deposits of the Hunter River.

Figure 51: Controls on downstream patterns of River Styles along the Rouchel Brook (Pattern 3)



Pattern 4 rivers (Middle Brook, Dart Brook, Kingdon Ponds)
Subcatchments that begin in the Plateau Slopes landscape unit, continue across the Rugged and Hilly landscape unit, across the Undulating Plain landscape unit, and join the Hunter River within the Undulating Plain landscape unit.

Dart Brook, Middle Brook, and Kingdon Ponds fall into pattern 4. As with pattern 2 these rivers begin in the plateau slopes landscape unit where their headwaters are eroding into the basalt slopes of a remnant plateau. The steep slopes, confined valleys and low catchment areas produce the Steep Headwater and Occasional Floodplain Pockets River Styles observed in pattern 4.

The rivers then pass into the Rugged and Hilly landscape unit where the valleys are less steep, wider, and partly confined. This greater valley width and increased catchment area produces the three partly confined River Styles, Bedrock Controlled Discontinuous Floodplain, Low Sinuosity Planform Controlled Discontinuous Floodplain, and Meandering Planform Controlled Discontinuous Floodplains observed in pattern 4.

The rivers in pattern 4 then enter the Undulating Plain landscape unit where the valleys are wide with low slope. This produces the laterally unconfined Meandering Entrenched Gravel Bed River Style which dominates these sections of river. This River Style is transitional to other variants of laterally-unconfined river along their downstream courses.

The location of the Meandering Entrenched Gravel Bed River Style is control by the occurrence of Hunter River Quaternary alluvium. The rivers in pattern 4 flow over the Permian sedimentary strata, as the Hunter does, but long before their waters join the Hunter trunk they flow onto the Quaternary alluvial floodplain material of the Hunter River. The Meandering Gravel Bed River Style on the Hunter River in the Undulating Plains landscape unit flows on the Permian sedimentary strata where it deposits alluvial material and builds its floodplains. But in contrast the Meandering Entrenched Gravel Bed River Style on the pattern 4 rivers in the Undulating Plains landscape unit flow on the Quaternary alluvium of the Hunter River floodplain. These sediments are very cohesive. This mechanical property combined with the slope and catchment area at the location of the Meandering Entrenched Gravel Bed River Style induces the formation of a deep and narrow channel with low capacity. The low capacity means that bankfull flows often occur (1 in 2 year events).

Unlike the classic textbook description that channel capacity (i.e. channel width increases and channel depth decreases) always increase downstream, the change from Meandering Planform Controlled Discontinuous Floodplain to Meandering Entrenched Gravel Bed River Style along pattern 4 rivers represents a decrease in channel capacity (i.e. channel width decreases and channel depth increase).

The catchment area upstream of the Meandering Entrenched Gravel Bed River Style as measured from ridge top to ridge top probably over estimates the catchment area. It is possible that, due to the low gradient of the lateral valley slopes, rain falling over areas of the valley that are distal to the channel is evaporated, transpired, or held in the soil and does not add to the flow in the channel. If this is correct then these distal areas are effectively not part of the contributing catchment area.

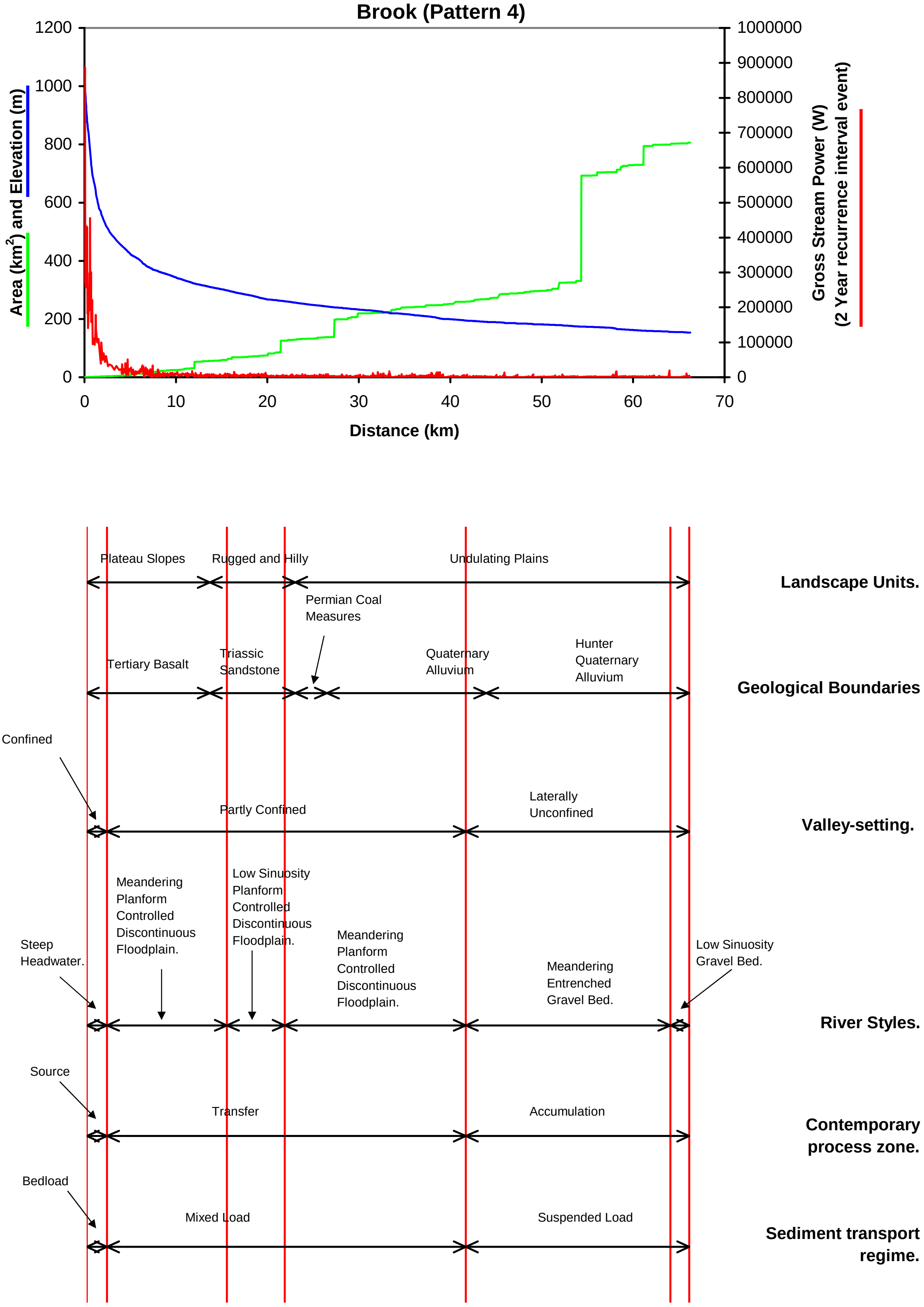
Because of their proximity it is a reasonable assumption that when Dart Brook, Middle Brook, and Kingdon Ponds are in flood the Hunter is also in flood. This means that when large formative flows are present in Dart Brook, Middle Brook, and Kingdon Ponds it is highly likely that the Hunter floodplain is inundated. Therefore the inundation level of flood waters on the Hunter floodplain would act as a local base level to Dart Brook, Middle Brook, and Kingdon Ponds. This means that when large formative flows are moving down Dart Brook, Middle Brook, and Kingdon Ponds their energy is dispersed as they flow into the floodwaters of the Hunter. It also follows that the higher the inundation level of flood waters on the Hunter floodplain (i.e. the bigger the flood) the higher the base level on Dart Brook, Middle Brook, and Kingdon Ponds. This means that as discharge and stream power increase in the Meandering Entrenched Gravel Bed river reaches a point is reached where stream power begins to decrease and geomorphic work in the channel decreases.

The River Style of Kingdon Ponds changes from a Meandering Entrenched Gravel Bed to a Low Sinuosity Entrenched Gravel Bed within the Hunter floodplain Quaternary alluvium. The change is anthropogenic, the Low sinuosity Entrenched Gravel Bed river reach is a man made trench.

The last few kilometers of Dart Brook, before it joins the Hunter Trunk is Low Sinuosity Gravel Bed River Style. This last reach of Dart Brook flows in at distal edge of the Hunter floodplain. Because the channel is at the distal edge it is probable that the sediment through which the channel flows is a mixture of alluvial material deposited by the Hunter River and colluvial material from the bedrock of the hillslopes that mark the boundary of the floodplain. This mixing of sediment has probably decreased the cohesive properties of the channel banks, hence the sinuosity of the channel has decreased.

At the edge of a floodplain the depth of sediment is, practically, always lower. In this shallow sediment the channel of Dart Brook has incised to a depth where bedrock outcrops occur. In this configuration the channel cannot adjust downwards but can adjust laterally. The combination of limited downward incision and the less cohesive banks are the prominent controls over the occurrence of the Low Sinuosity Gravel Bed River Style at this location.

Figure 52: Controls on downstream patterns of River Styles along the Dart Brook (Pattern 4)



Pattern 5 rivers (Pages River)
Subcatchments that begin in the Plateau Slopes landscape unit, continue across the Rugged and Hilly landscape unit, cross the Hunter-Mooki Fault, continue across the and Rugged and Hilly landscape unit and join the Hunter River within the Undulating Plain landscape unit.

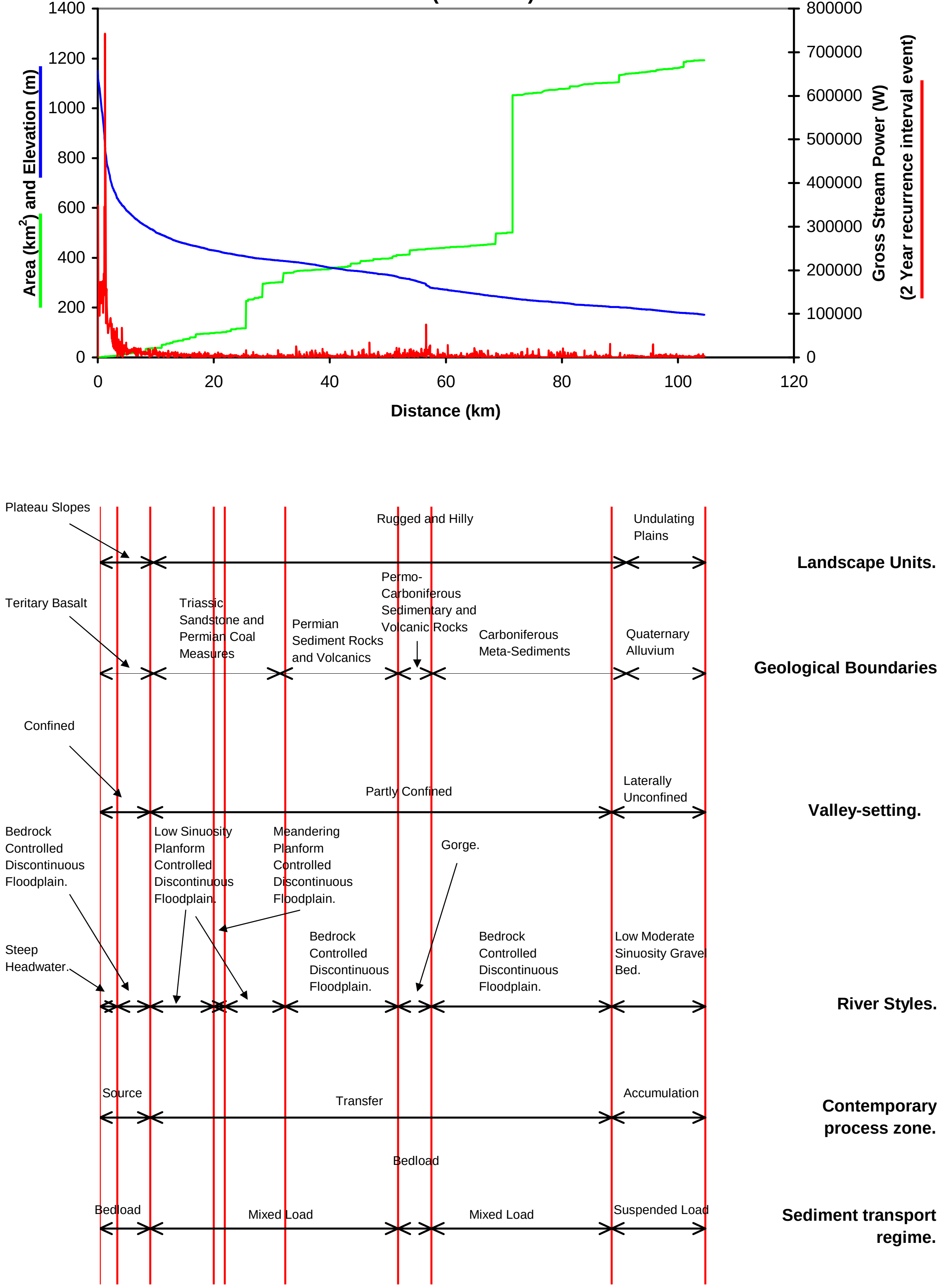
Pages River falls into pattern 5, it is unique because the Pages River rises to the west of the Hunter-Mooki fault and crosses to the east. No other river in the Upper Hunter catchment does the same. Even though it is a unique downstream pattern it is basically a collage of sections of other patterns. The Pages River starts in the Plateau Slopes landscape unit where the headwaters are eroding into the basalt slopes of a remnant plateau. The steep slopes, confined valleys and low catchment areas produce the Steep Headwater River Style.

The Pages River then pass into the Rugged and Hilly landscape unit where the valleys are less steep, wider, and partly confined. This greater valley width and increased catchment area produces the three partly confined River Styles, Bedrock Controlled Discontinuous Floodplain, Low Sinuosity Planform Controlled Discontinuous Floodplain, and Meandering Planform Controlled Discontinuous Floodplains.

The Pages River then crosses the Hunter-Mooki Fault and traverses hard Permo-Carboniferous sedimentary and volcanic rocks. The hardness of these rock produce a gorge river reach. Downstream of the Gorge River Style the river flows through the Rugged and Hilly landscape unit of Devonian and Carboniferous meta-sediments and a partly confined valley with Bedrock Controlled Discontinuous Floodplain Rive Style occurs. Pattern 4 is basically the same as patterns 1 and 2 in the Rugged and Hilly landscape unit.

The last 15 km, or so, of the Pages River is a Low Sinuosity Gravel Bed River Style. This reach occurs on the Undulating Plains landscape unit. The valleys widen and stream power is reduced so that relatively wide floodplains develop.

Figure 53: Controls on downstream patterns of River Styles along the Pages River (Pattern 5)



4. SECTION 4
IMPLICATIONS OF THIS WORK: USING THE RIVER STYLES FRAMEWORK AS A PHYSICAL TEMPLATE FOR ASSESSING CATCHMENT-SCALE BIOPHYSICAL LINKAGES AND IMPLEMENTING RIVER REHABILITATION STRATEGIES IN THE UPPER HUNTER CATCHMENT

4.1 Practical uptake and extension of findings from application of the River Styles framework in the Upper Hunter Catchment: Some comments on adoption

In a dramatic process that marks the transition beyond the era of command-and-control, engineering-dominated programs for river management, community participation now drives the river rehabilitation process across Australia. The days of techno-fix are over, and community-driven programs now present the key to success in environmental management practice. In developing such initiatives, fundamental shifts in land and water management practice, and our aesthetic/cultural values, are required if we are to reverse the process of environmental deterioration across much of the continent. Moves towards sustainability require that we reappraise our perspectives, attitudes and actions in fulfilling a collective commitment to 'duty of care' principles. Ultimately, we are ALL affected by the health of aquatic ecosystems, and the life systems they support.

Building on this premise, effective communication of scientific principles is integral in the design and implementation of successful on-the-ground strategies. Moves towards a collective sense of engagement and ownership within a participatory approach to environmental management require that major consideration be given to the processes of information management, and related issues of data collection, storage, delivery (presentation) and use. Application of the River Styles work provides core scientific baseline data that can assist this process, framing what can realistically be achieved in environmental terms. Effective engagement with adaptive management principles is also required to sustain the commitment to maintenance programs, 'tweaking the system' as we learn and reframing our objectives as required.

Consultation processes should accompany each step in the application of the River Styles framework in any catchment. Collaboration with industry, personnel in state agencies, river managers and various stakeholders is a core component of the adoption process. This sustained commitment to knowledge transfer and reinforcement markedly enhances the prospects for capacity building and ownership of information that accompanies the development of a catchment-based river rehabilitation plan. In the Upper Hunter catchment, industry- and community-based workshops and field days provided opportunities for collective learning through knowledge sharing, as well as familiarising stakeholders with the diversity of river forms and processes in the catchment.

4.2 Maximising the potential of the River Styles framework: Using a geomorphic template as an integrative platform for an ecosystem approach to natural resources management

In a sense, the River Styles framework provides catchment-specific baseline information upon which broad-based management initiatives can be ***integrated***, providing a coherent platform for programs that address concerns for ***landscape futures***. Geomorphic components of landscapes (e.g. topography, lithology, sediment stores, vegetation cover, runoff relationships, etc.), their catchment-specific connections, and their sensitivity to human disturbance (and associated patterns, rates and consequences of change) present key information that guides and constrains management activities.

Sustainable river management outcomes cannot be achieved *independent from* consideration of geomorphic insights which document the diversity, patterns and changing nature of river character and behaviour across a catchment. Rather, geomorphic insights can provide a template upon which information can be organised and structured in an efficient and meaningful manner, enabling us to identify and address gaps in our primary data and understanding.

The River Styles framework synthesises local and reach-scale data into catchment-wide analyses, providing a geomorphic catchment context with which to integrate an array of biophysical data, thereby presenting a coherent physical template for management activities. The physical template developed through application of this framework in the Upper Hunter catchment will be used as a platform to add further layers of information as part of inter-disciplinary research and cross-issue planning programs (see Brierley et al., 2002). Such developments mark practical steps towards realistic thinking and application of ecosystem-based approaches to natural resources management. In some ways, the River Styles framework may be viewed as the basal landscape context for such endeavours. Use of this template ensures that planners consistently take into account geomorphic behaviour and controls on that behaviour, within-catchment linkages of biophysical processes, and the evolutionary character and rate of change to river morphology.

Perhaps the core area in which principles from geomorphology have received notable uptake over the past decade or so has been in the field of ***biodiversity management***. Key themes in this work have been the re-emergence of cross-disciplinary fields such as geo-ecology and landscape ecology, renewing emphasis on landscape linkages/connections (Tockner et al., 2002). Future environmental management programs must address concerns for the linkage of aquatic and terrestrial ecosystems, developing new approaches to restoration ecology that manage for ecological health/diversity and measures of aquatic ecosystem functionality. This requires that we build on successes of environmental management programs that have targeted single species, whether birds, fish, plants, frogs, macroinvertebrates or whatever, and seek to develop programs that operate at the ecosystem level.

Across much of the world, human endeavours have increasingly homogenised ecosystems and landscapes, modifying our sense of representativeness and connectedness. By presenting a framework that 'works with' the inherent diversity of landscape forms and processes in differing settings, the physical template developed through application of the River Styles framework enables an appropriate sense of 'naturalness' to be established. Working from this template, adopted management measures are sympathetic to local environmental needs and values. In some cases the physical structure of ecosystems is naturally simple, and these systems should be managed as such. Similarly, in many instances we cannot 'restore' river systems, so our goals must be framed in terms of the 'best that is achievable', working towards 'created' complex adaptive (adjusting) ecosystems. Piecemeal strategies invite disaster. Recognising the fragmented, modular nature of many ecosystems and landscapes today, remaining semi-natural ecosystems must be enhanced, whenever possible, building out from scarce ‘natural’, ‘near-pristine’ or ‘good condition’ remnants. Conservation areas need to be identified and managed in terms of their ‘uniqueness’ and ‘rarity’ value, through river health, heritage, and wild and scenic rivers programs.

At the landscape scale, ***vegetation management programs*** provide key starting points for biodiversity management, and associated concerns for flow, sediment and nutrient/contaminant programs. Effective targeting of replanting programs, tied to agroforestry developments, land management practices on farms, riparian vegetation and weed management programs, etc. provide tangible steps towards healthier catchments. Endeavours to attain, wherever appropriate, a continuous riparian corridor, with native vegetation dominant, are primary initial goals. Whenever practicable, fencing-off programs that minimise damage associated with stock access should be implemented, tied directly to weed management programs. The longitudinal and lateral connectivity of biophysical linkages that are sustained, enhanced or re-established through such programs should be framed in a manner that is appropriate for the type of river, its within-catchment position, and associated upstream-downstream linkages.

Flow management programs should aim to maintain, whenever possible, the vagaries of the natural hydrological cycle, including natural river and wetland functions and processes. Appropriate mixes of environmental and channel maintenance flows should be framed in context of the catchment-specific needs that reflect the biophysical linkages evident in the landscape of concern. Targeted flow management strategies for ecological needs (e.g. maintenance of low flow stage refugia) must be tightly integrated with programs that address ***water quality***, ***salinity*** and ***contaminant/nutrient*** management programs. The River Styles template not only provides background information on the differing needs of individual river types, but more importantly demonstrates and explains how these reaches are linked in a catchment context.

The pattern and rate of geomorphic changes induced by human disturbance also has profound implications for the structural integrity of rivers, underpinning our efforts at ***sediment*** management along river courses. For example, river rehabilitation programs that are framed in context of geomorphic recovery notions must recognise limitations imposed by the catchment-scale sediment budget and associated patterns of sediment stores. Such insights determine the viability of programs that endeavour to release sediments from some reaches and trap them elsewhere. In many parts of Australia, and indeed throughout the upper Hunter catchment, the effectiveness of such programs will be determined primarily in terms of alluvial sediment budget relationships, as slope sources are largely disconnected from valley floors or within-catchment sediment transfer linkage relationships are very inefficient. Indeed, such issues are fundamental to water quality (turbidity) and nutrient/contaminant management programs.

As moves towards more holistic ecosystem-based approaches to natural resources management are embraced, increased emphasis will be placed on the need to develop and apply core components of adaptive management principles, reframing our approach to the implementation and maintenance of ***monitoring and auditing programs***. To date, our record in testing the effectiveness of environmental management programs has been poorly structured, sparsely implemented, and scarcely reported. Any moves towards post-project appraisals must be built upon pre-project data, requiring that commitment to such initiatives be acted upon immediately; ideally they would have been instigated some time ago. Significant questions must be addressed about the selection of *representative* monitoring sites, and what should be measured at these sites. In river terms, programs that monitor river health have placed virtual disregard for the geomorphic structure and function of river courses and associated notions of geomorphic river condition. Indeed, it is hard to build programs around such notions when appropriate information bases on geomorphic river character, behaviour and condition do not yet exist!

Ultimately, our success in landscape- or ecosystem-scale programs in natural resources management will be determined, in large part, by the effectiveness with which we integrate these various components in coherent, holistically framed management activities.

4.3 Future management implications in the upper Hunter Catchment: Using River Styles analyses in the Hunter Blueprint implementation process

Holistic river management decisions require an appropriate information base on geomorphic river character, behaviour, condition and recovery potential throughout a catchment. Without these sorts of baseline information, piecemeal, site-specific works will continue to be undertaken independent from catchment-scale processes and linkages. In these circumstances, the likelihood of river rehabilitation success is compromised. Endeavours to rehabilitate riverine landscapes must be framed in terms of clearly articulated, validated and realistic goals, placing the reach under consideration in its broader catchment context. This requires sufficient knowledge of the physical character and behaviour of the system, the operation of biophysical fluxes, and the changing nature of biophysical interactions and linkages under differing forms of disturbance regime (integrating natural and human disturbance events).

Inevitably, management goals reflect human values and perceptions. Ultimately, the rehabilitation process must be framed in ecological terms, striving to improve the ecological condition (or health) of the river system. The best way to achieve these goals is to enhance natural recovery processes that are inherent to the system under investigation.

Rehabilitation strategies must work with the natural diversity of river forms and processes. Rivers naturally adjust and change. Any rehabilitation strategy that fails to accommodate the natural process functioning of rivers is more likely to require recurrent and costly remedial work. By assessing river character and behaviour, insights can be gained as to the natural diversity and functioning of rivers, ensuring that river rehabilitation strategies work with (and enhance) these natural processes.

This report has focussed solely on the character, behaviour and patterns of rivers in the Upper Hunter Catchment using Stage One of the River Styles Framework. This baseline assessment provides the foundations for analysis of river condition (based on assessments of river evolution) and river recovery potential (based on the trajectory of change, and catchment-scale fluxes, limiting factors and degrading pressures). With this coherent information package, river management strategies can be prioritised and effective river conservation and rehabilitation strategies implemented. These additional layers of information will be assessed by personnel in the Hunter Regional Office of DIPNR as part of the Hunter Blueprint implementation process. This will provide a strategic foundation upon which to identify areas of the catchment that are vulnerable or sensitive to geomorphic change. New management practices can then be focussed, realistic and achievable.

In the Upper Hunter catchment, significant capacity for river adjustment is largely limited to laterally-unconfined River Styles. Geomorphic adjustments include incision, lateral expansion and wholesale channel shifts (e.g. cutoff formation and straightening). These adjustments are particularly evident along the Low sinuosity gravel bed River Style. Localised capacity for adjustment occurs along Partly-confined rivers. The bedrock-controlled variant displays localised adjustment via channel expansion of some bends. Along planform-controlled variants, similar geomorphic responses have occurred along with channel planform changes (e.g. avulsion, cutoffs). Analysis of the nature and extent of geomorphic changes aids our interpretation of where change is likely to continue in the future and what the off-site impacts of change will be. Within this context, river planners can develop management practices that will have a positive flow on effect downstream. This sort of information is vital in development of river management plans that strategically target certain areas in the Upper Hunter catchment, ensuring that river management plans build upon a strong knowledge base, thereby providing a basis for determination of realistic rehabilitation targets and adoption of an appropriate prioritisation process. This information will be critical in attaining the goals of the Blueprint.

4.4 Future research in the upper Hunter Catchment: Using geomorphology as a physical template

In future research initiatives developed as part of the ARC Linkage Project, the information gathered as part of Stage One application of the River Styles framework will provide the core information base atop which to assess the movement of sediment and nutrients throughout the catchment, determine how rivers have changed in the past, assess weed sources and native vegetation associations, and for defining the lifecycle ranges for various fish species. Primary findings and future research in the catchment, as part of the ARC Linkage Project are as follows:

- A large proportion of river courses in the Upper Hunter Catchment flow within confined or partly-confined valleys. While these rivers effectively flush materials contributed to them, the majority of the upper catchment is decoupled (disconnected) from watercourses by long-term sediment stores such as terraces, piedmont zones, fans, and discontinuous watercourse (termed buffers). In addition, sediment is trapped along river courses behind barriers such as dams. Sediments that smother other landforms (termed blankets) also disconnect vital ecological functions such as nutrient cycling and water movement. As a consequence, the sedimentary flux operates within a remarkably small ‘effective catchment area’. Under these conditions, there is a significant lag effect between upstream sediment release and sediment delivery to the study reach as these buffers, barriers and blankets delay (or impede) the conveyance of water and sediments. This finding indicates that disturbance responses in much of the upper catchment are mediated or absorbed by the landscape, such that they exert only a marginal short-term effect on the study reach. Ongoing work is quantifying these relationships and examine the consequences for various other biophysical fluxes (e.g. bedload and suspended load movement, flood regime implications, nutrient fluxes, transfer of seeds, movement of fish etc.). Such insights present a predictive basis with which to build future scenarios and foresight likely future river condition in different parts of the catchment.
- Given the limited geomorphic capacity for adjustment of rivers across much of the Upper Hunter Catchment, geomorphic responses of rivers to human disturbance have been very localised, with only a few instances where dramatic changes have occurred. Future work will examine how different rivers in the upper catchment have evolved throughout the Holocene and in particular how rivers have changed since European settlement. This will provide the basis for examining the specific causes of the sensitivity of rivers to change and implications for river recovery within the catchment.
- The potential for geoecological recovery of the study reach is potentially compromised by the limited availability of bedload calibre materials contributed from the upper catchment (at least from readily accessible storage zones). However, the increased connectivity of the system following European settlement has facilitated more peaked flows with greater availability of suspended load materials. Human disturbance has markedly accelerated rates of slope wash and rill erosion in the Hunter catchment, resulting in some of the highest modelled rates of available sediment in the country. In addition to this slope-derived material, suspended loads have been accentuated by bank erosion that has resulted in channel expansion (i.e. reworked floodplains) and incision of previously discontinuous watercourses. Through this latter process, the connectivity of tributary systems to the trunk stream has likely increased. Reduced hydraulic roughness within the larger capacity channels has ensured that water and suspended load materials are conveyed more rapidly to the study reach and beyond. This accounts for the increased rates of dredging that have been required in Newcastle Harbour. Our preliminary

findings from this project indicate that the limited degree of catchment-scale connectivity (i.e. the small effective catchment area indicated above) has ensured that only a very small proportion of materials that have been eroded in the period since European settlement are actually available to the river system directly. This hypothesis will be tested in future work.

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