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

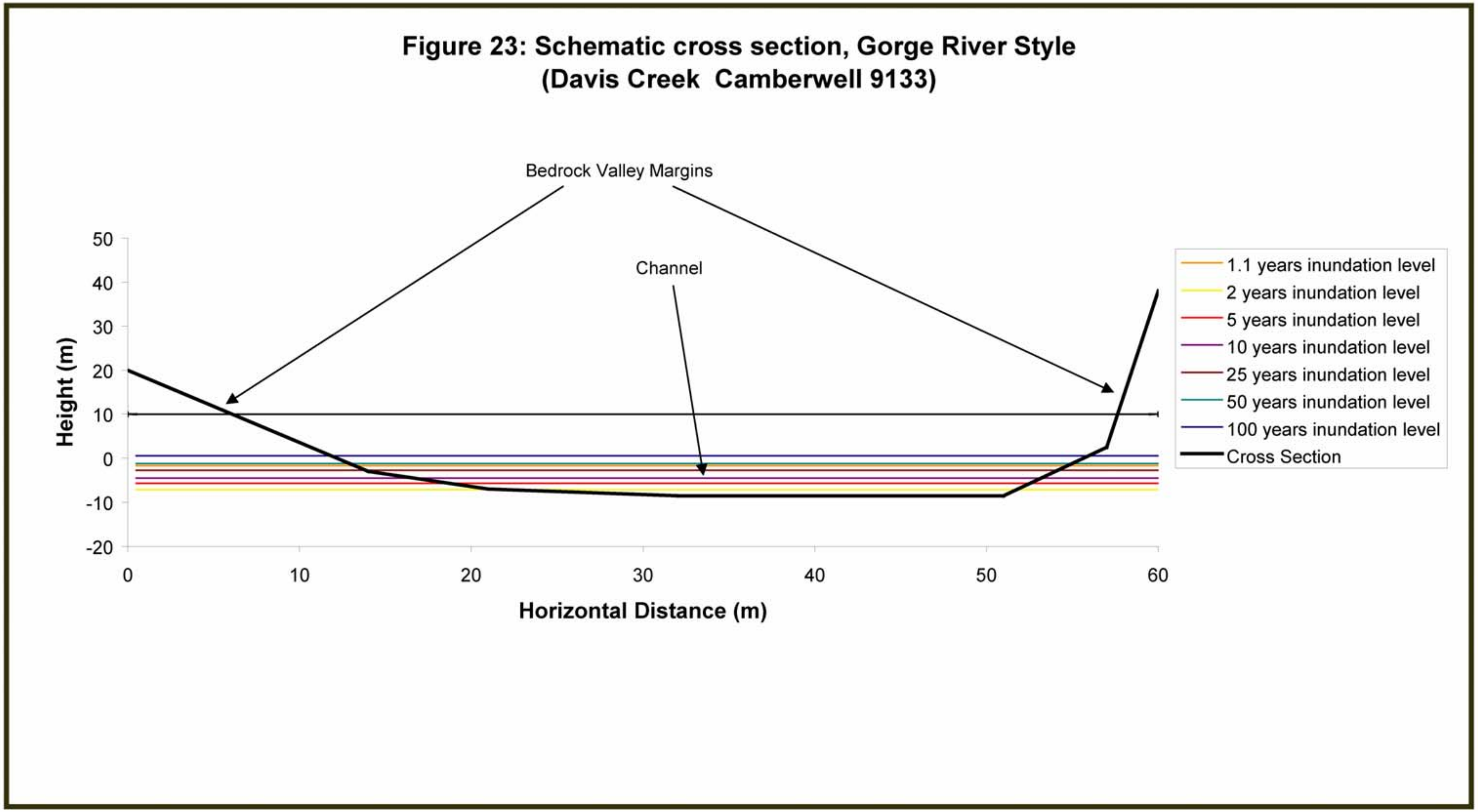


Figure 23: Schematic cross section, Gorge River Style
(Davis Creek Camberwell 9133)
Bedrock Valley Margins
Channel
Height (m)
Horizontal Distance (m)
1.1 years inundation level
2 years inundation level
5 years inundation level
10 years inundation level
25 years inundation level
50 years inundation level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

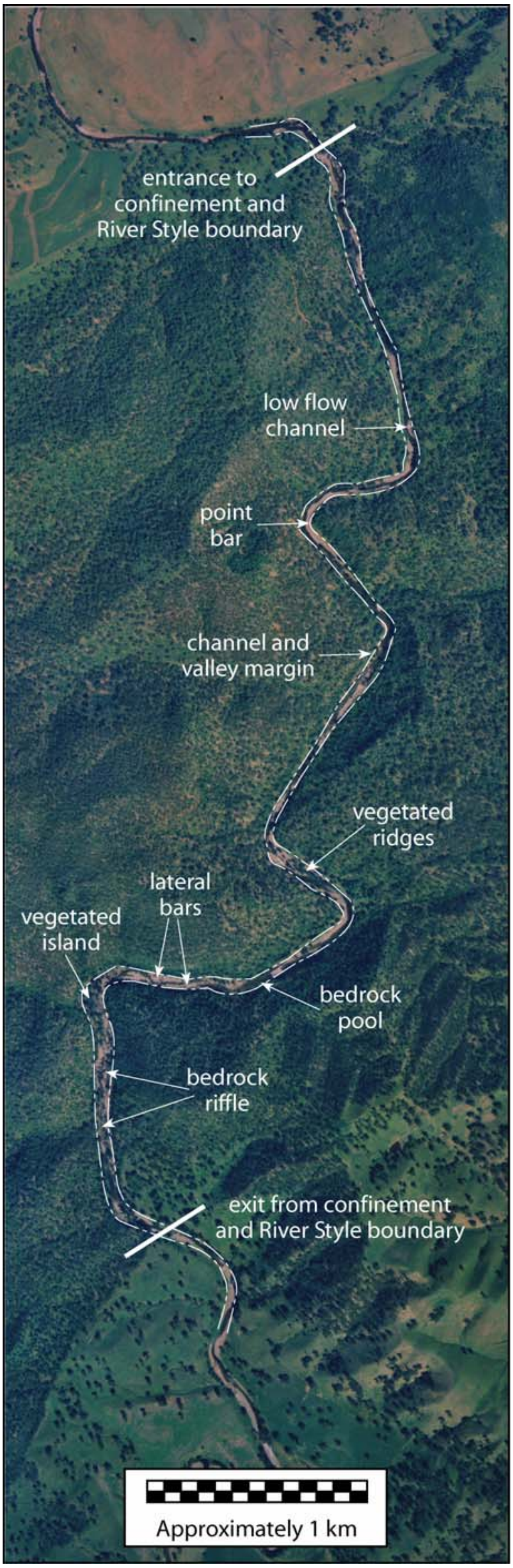


Figure 24: Aerial View of a Gorge River Style reach, Pages River

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.

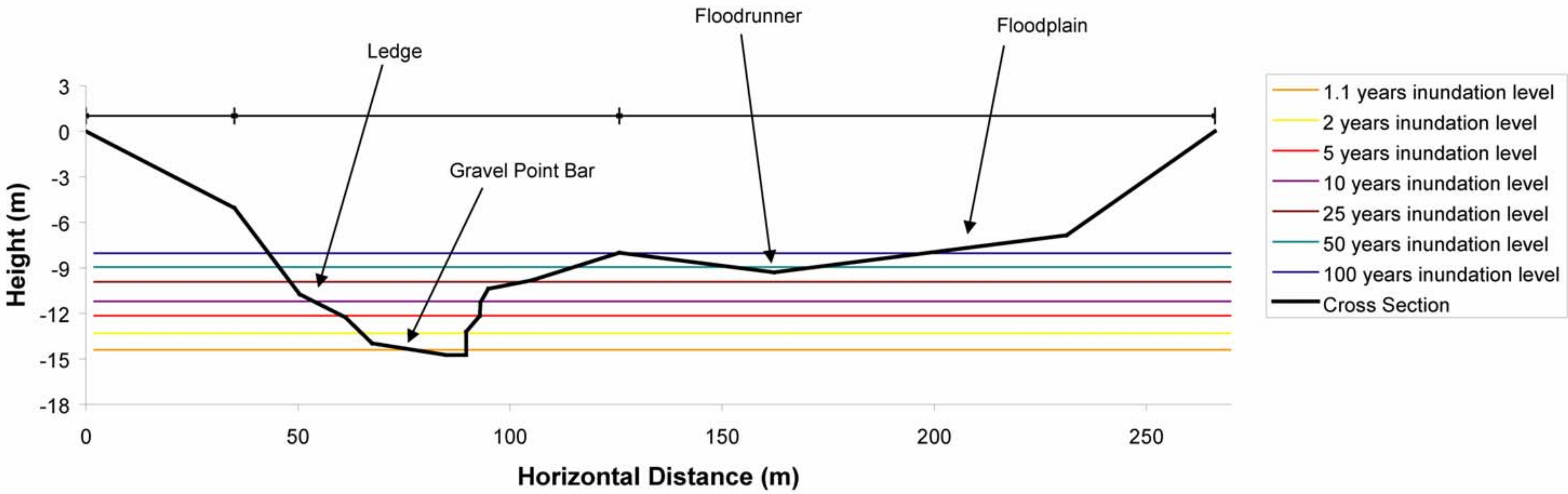
Even though high stream power can be generated in this river style, it has reasonable lateral stability due to the confinement imposed by the bedrock valley margin,. Areas where the valley widens and larger floodplain pockets exist, are susceptible to channel degradation and widening in response to the 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)



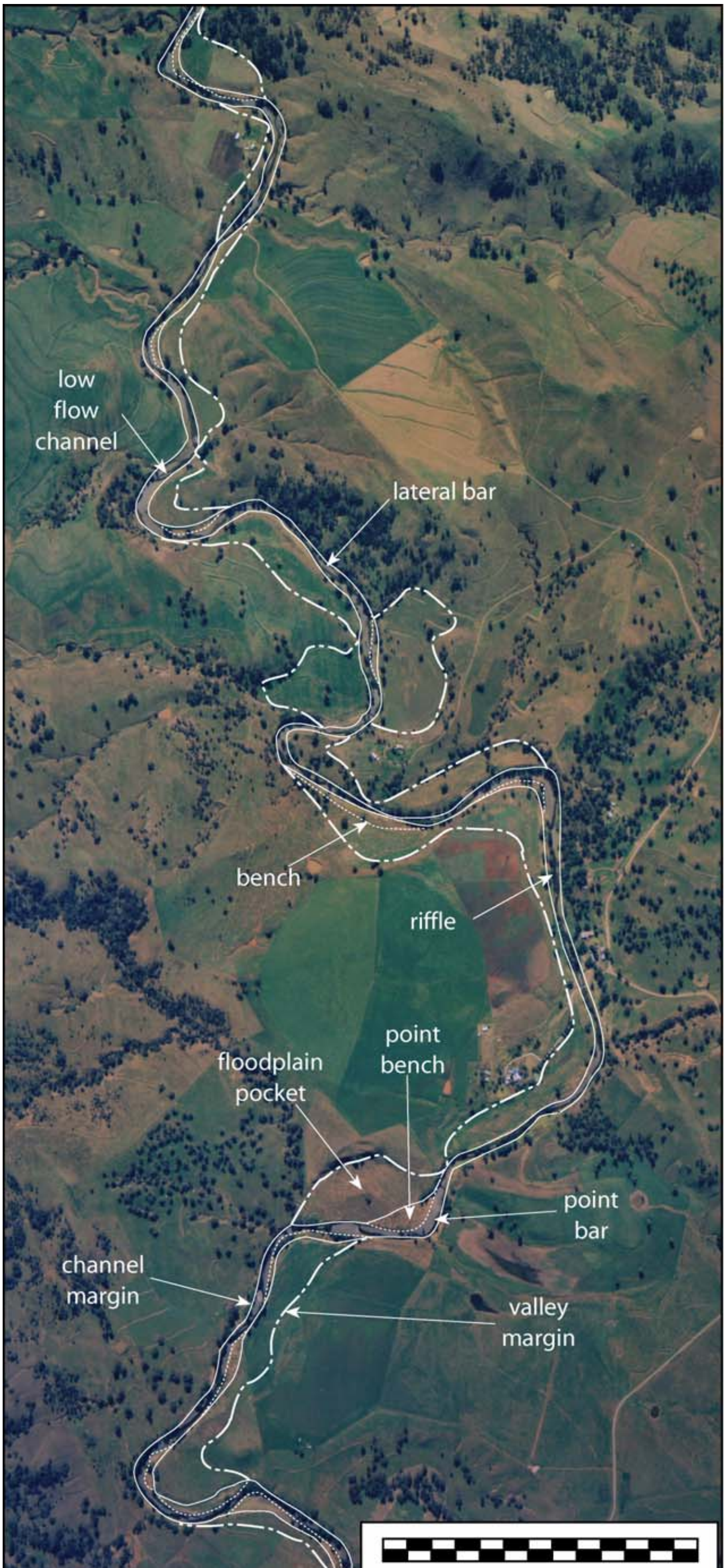


Figure 26: Aerial View of a Bedrock Controlled Discontinuous Floodplain River Style reach, Isis River

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.

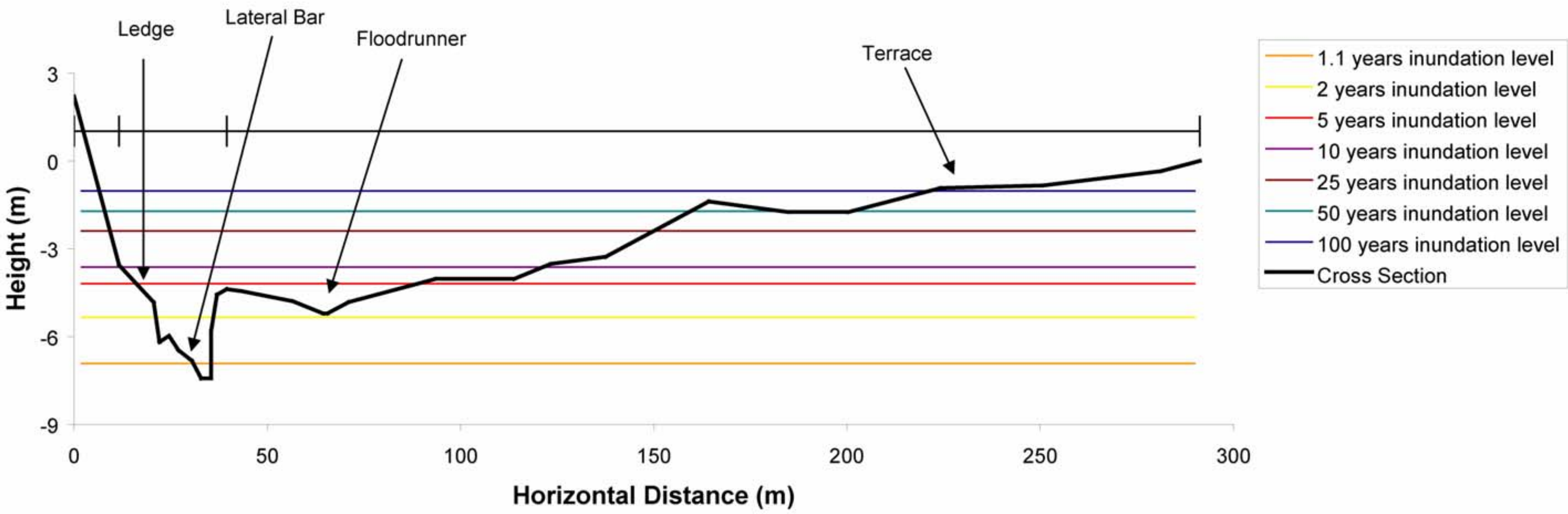
CONTROLS	
Upstream catchment area (km^2)	Catchment area varies across the catchment, but are relatively low compared to other River Styles. Upstream areas range from 98 km^2 along the Pages River to 126 km^2 along Dart Brook. Average catchment area = 91.193 km^2
Landscape unit and within-Catchment position	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)



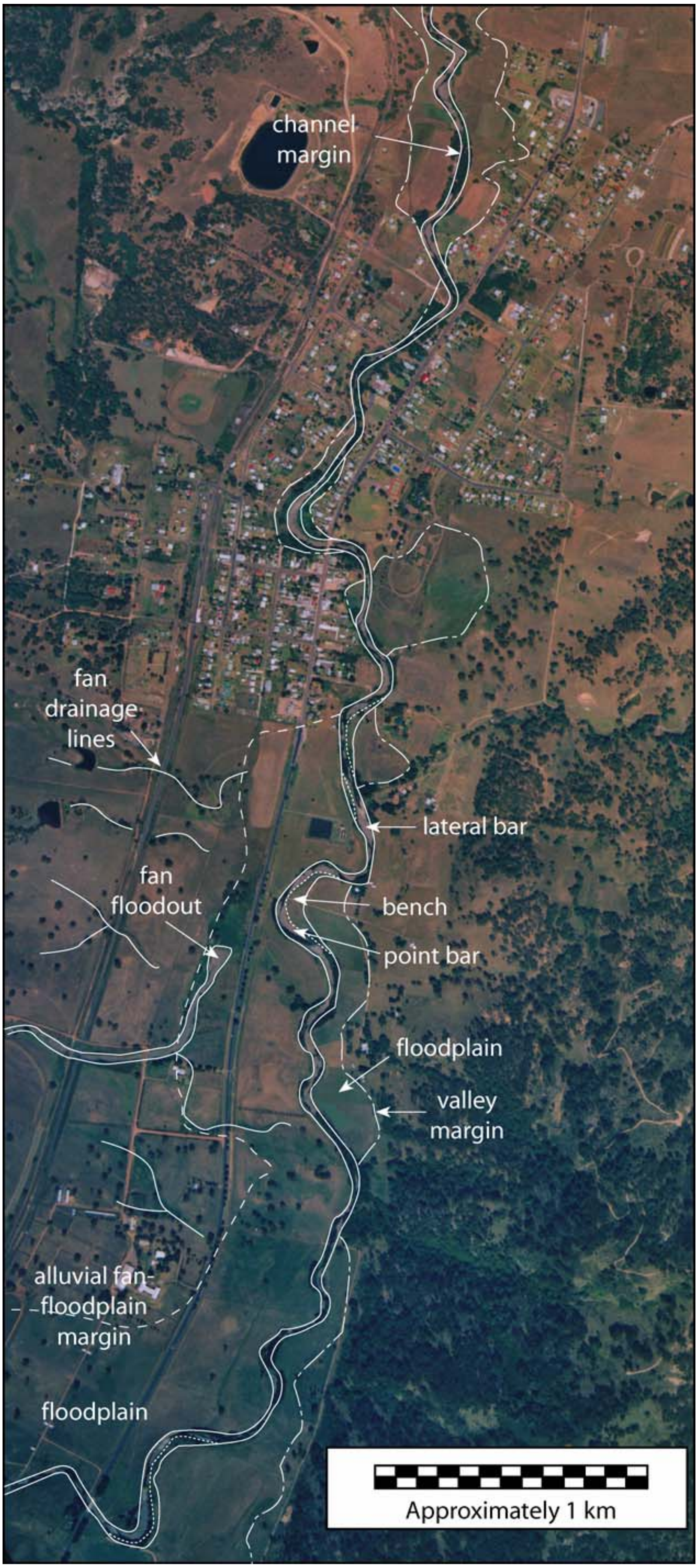


Figure 29: Aerial view of a Meandering Planform Controlled Discontinuous Floodplain River Style reach, Pages River

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.

<table>
<tr><td rowspan="2">Geomorphic units
(Geometry, sedimentology)</td><td>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.</td></tr>
<tr><td><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.</td></tr>
<tr><td rowspan="2">Vegetation associations</td><td><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.</td></tr>
<tr><td><u>Floodplain geomorphic units</u>
Dominated by pasture, localised willows, rye grass and sedge. Occasional eucalypt.</td></tr>
</table>

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

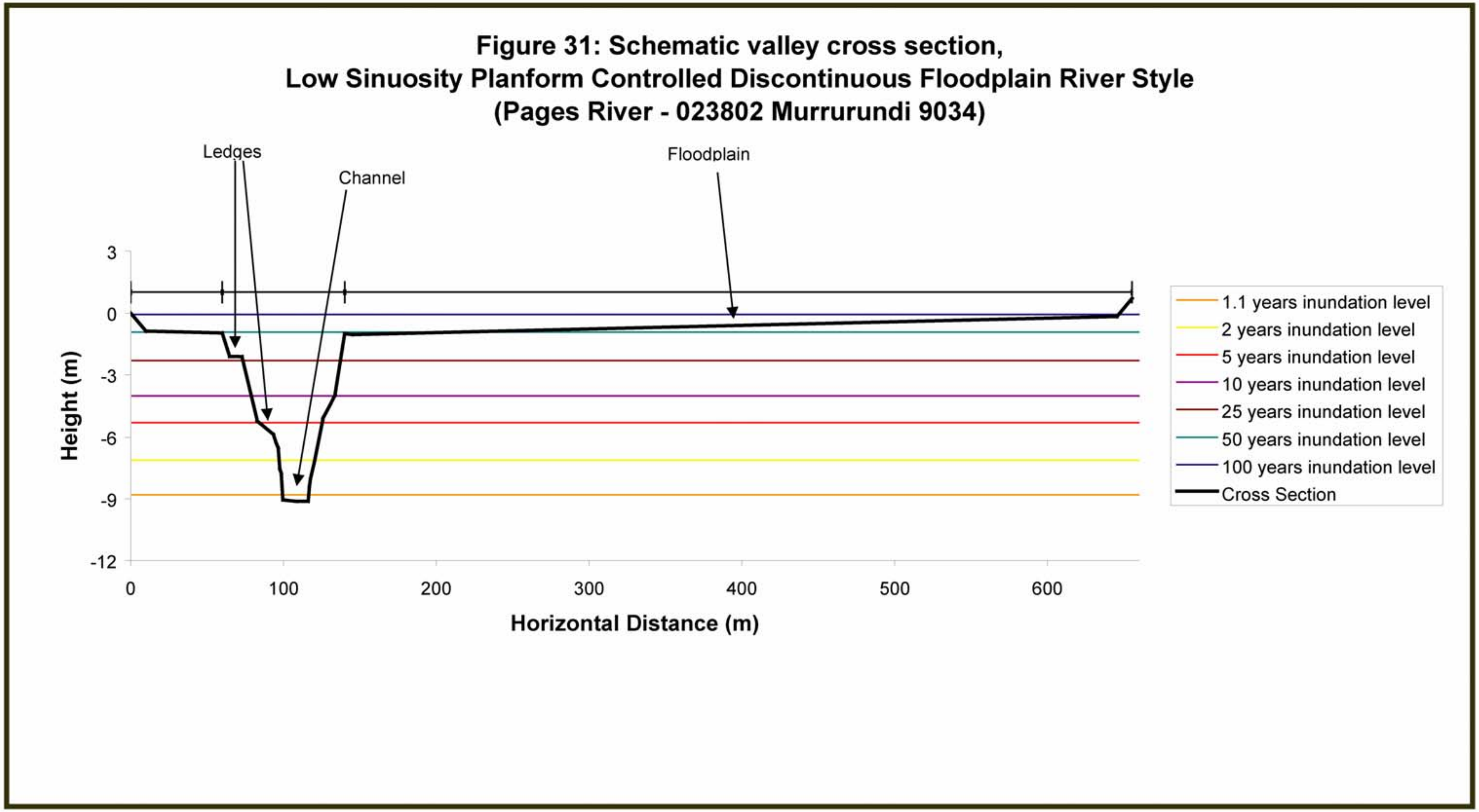


Figure 31: Schematic valley cross section,
Low Sinuosity Planform Controlled Discontinuous Floodplain River Style
(Pages River - 023802 Murrurundi 9034)
Ledges
Channel
Floodplain
Height (m)
3
0
-3
-6
-9
-12
0
100
200
300
400
500
600
Horizontal Distance (m)
1.1 years inundation level
2 years inundation level
5 years inundation level
10 years inundation level
25 years inundation level
50 years inundation level
100 years inundation level
Cross Section

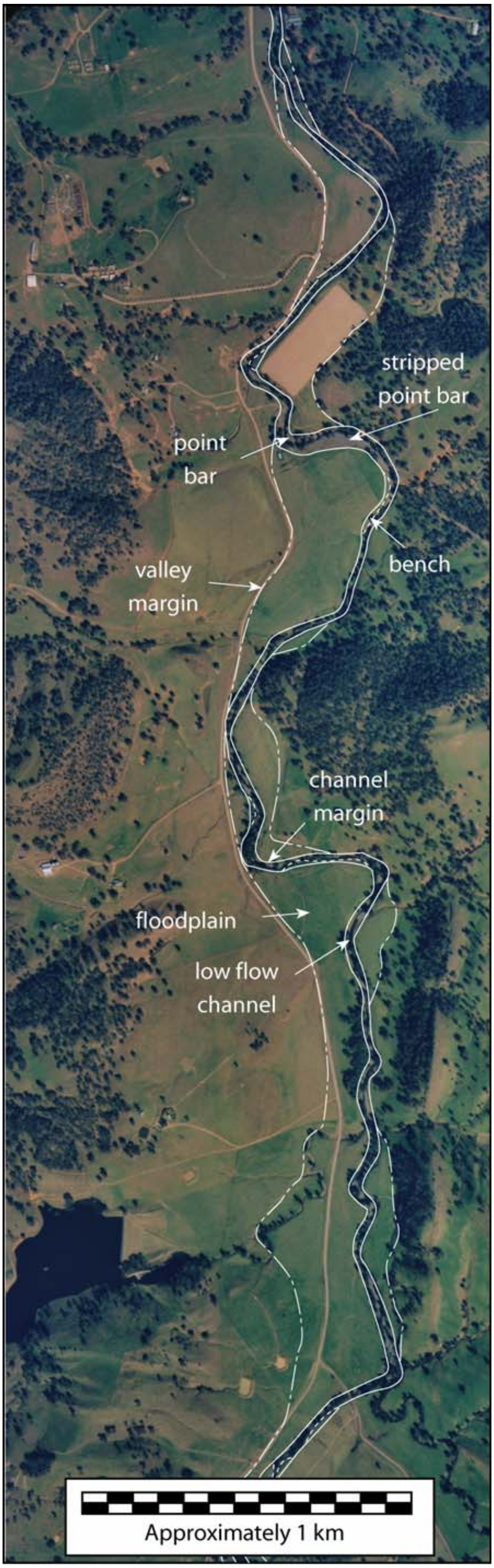


Figure 32: Aerial View of a Low Sinuosity Planform Controlled Discontinuous Floodplain River Style reach, Hunter River

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.

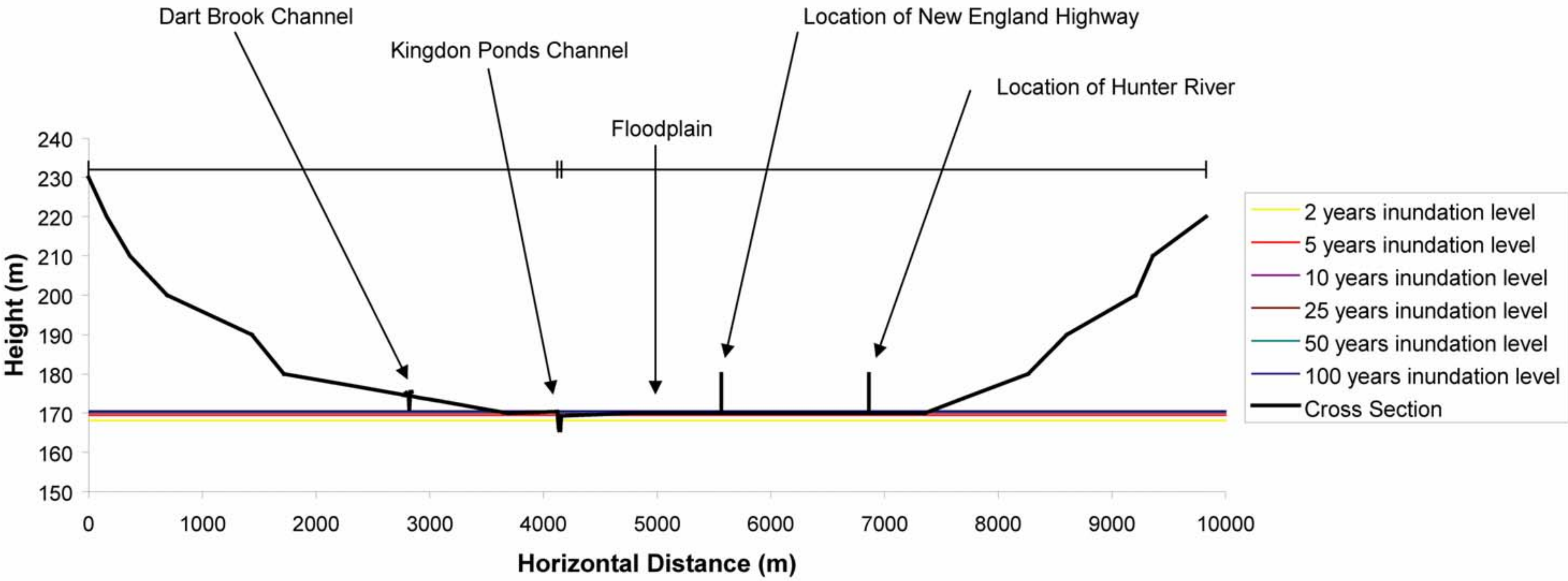
CONTROLS

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 valley cross section data generated from the topographic map, Aberdeen 1:25,000 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.)

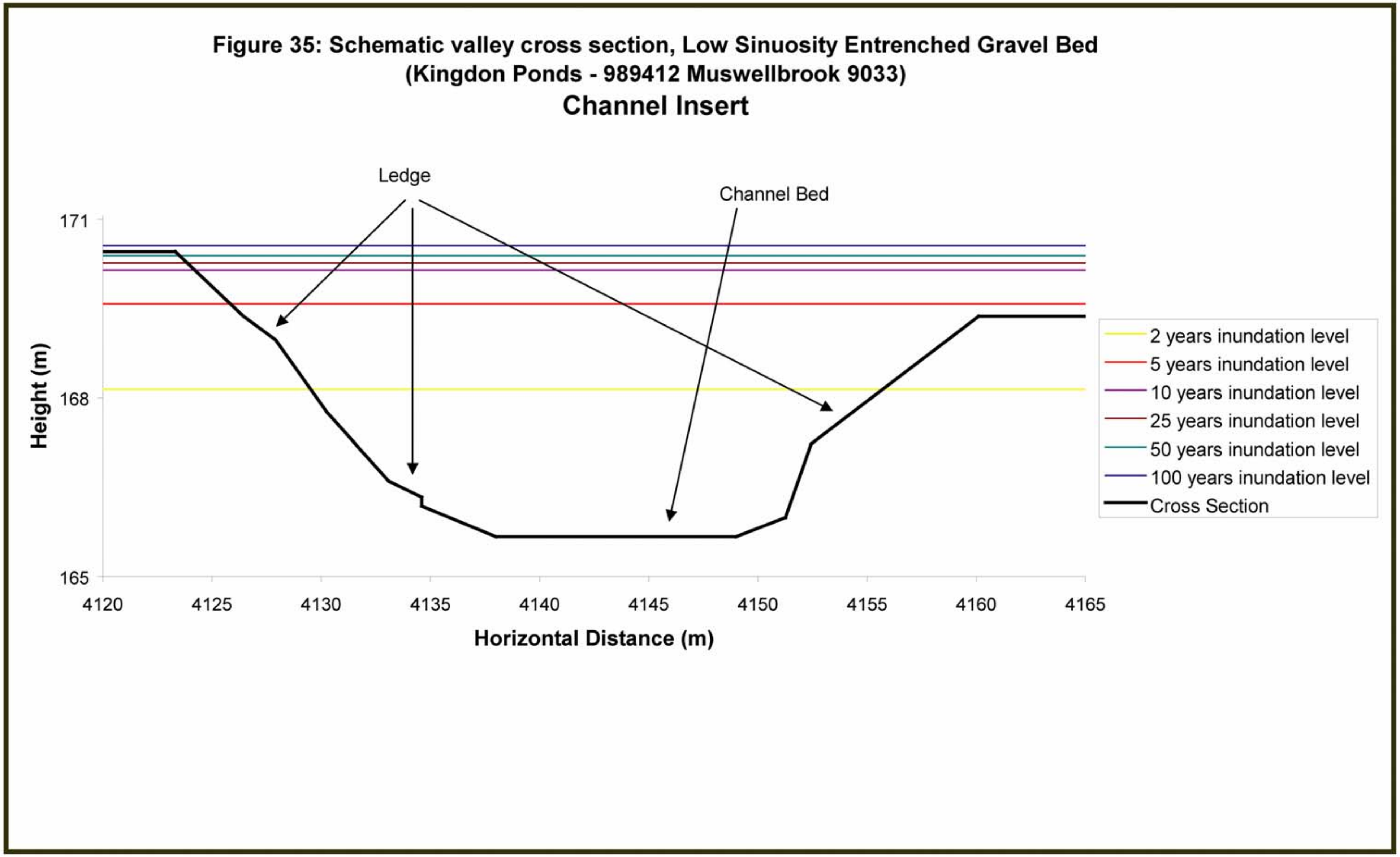


Figure 35: Schematic valley cross section, Low Sinuosity Entrenched Gravel Bed
(Kingdon Ponds - 989412 Muswellbrook 9033)
Channel Insert
Ledge
Channel Bed
171
168
165
Height (m)
4120
4125
4130
4135
4140
4145
4150
4155
4160
4165
Horizontal Distance (m)
2 years inundation level
5 years inundation level
10 years inundation level
25 years inundation level
50 years inundation level
100 years inundation level
Cross Section

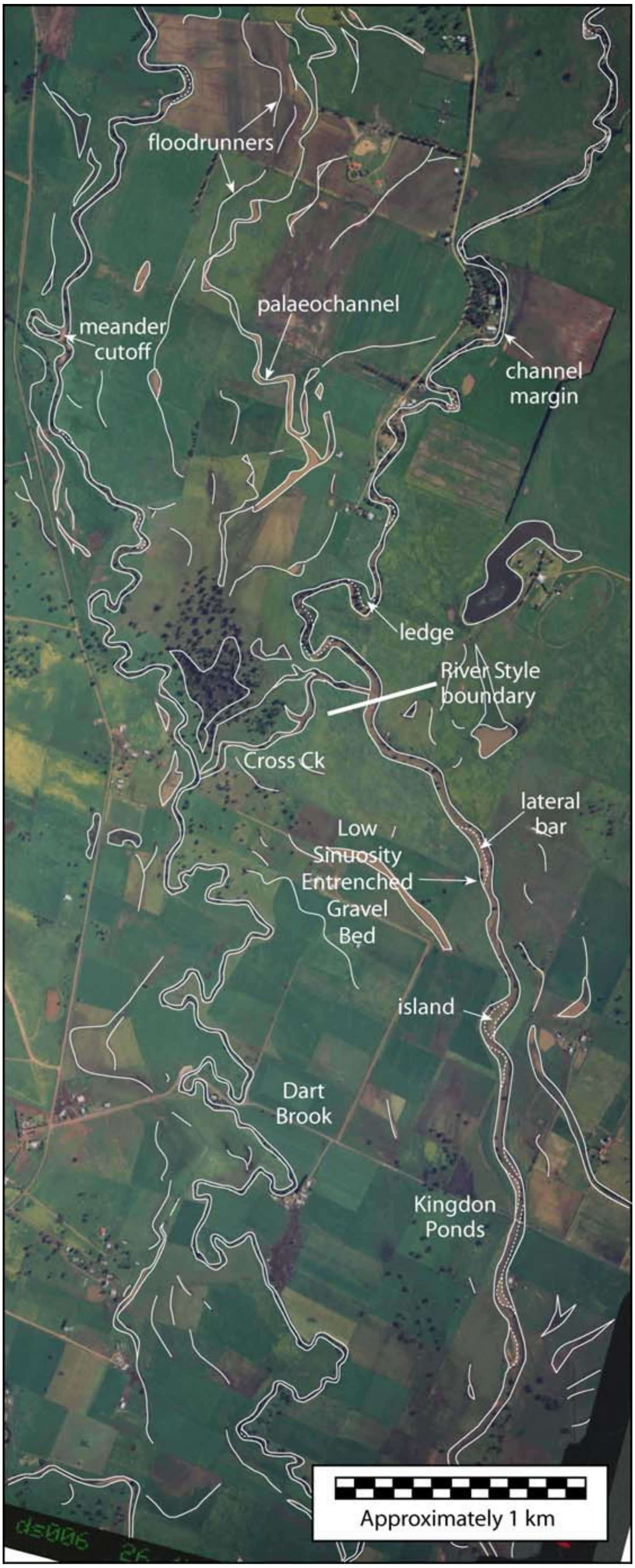


Figure 36: Aerial View of a Low Sinuosity Entrenched Gravel Bed and Meandering Entrenched Gravel Bed River Style reach, lower ends of Dart Brook and Kingdon Ponds

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.

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 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).
	<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.
Vegetation associations	**<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.
	<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.

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

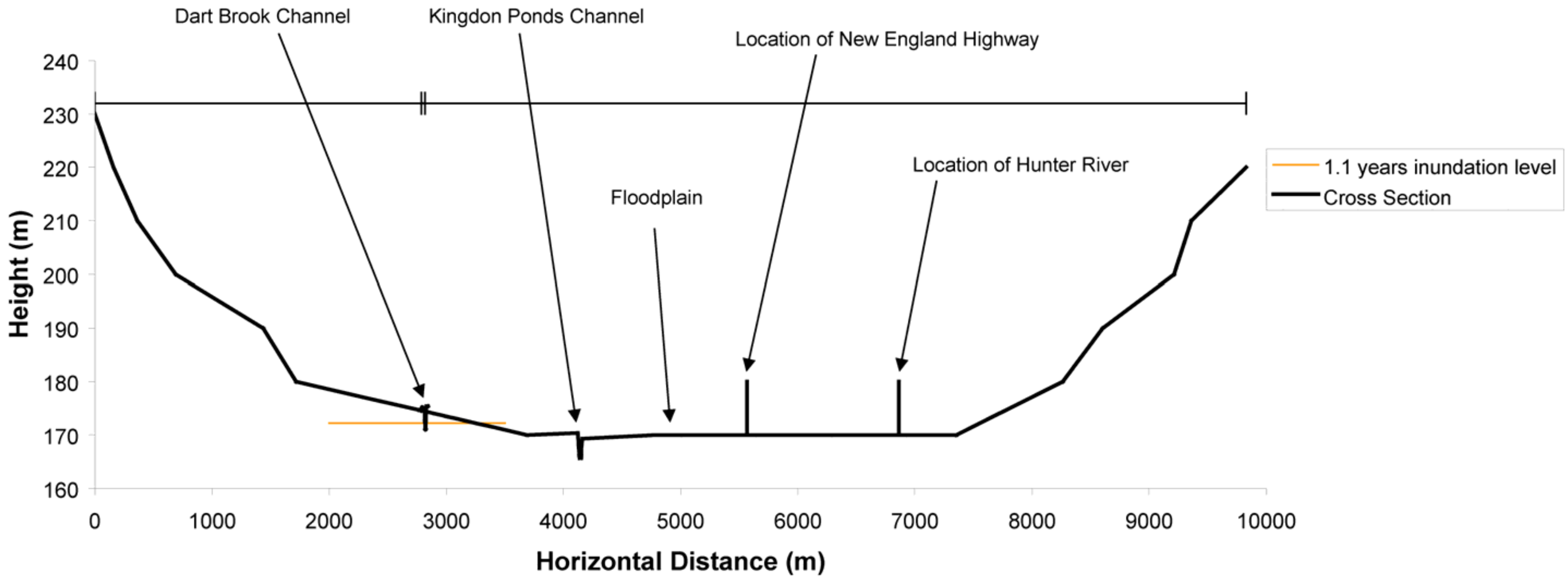
Due to the wide, flat, low gradient floodplains, overbank flow is dispersed over a large area. In more moderate events the water recharges the floodplain and, close to the channel, small levees vertically accrete. Where flows scour depressions, as floodwaters short circuit the floodplain, floodrunners 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	

Meandering Entrenched Gravel Bed (Dart Brook – 976413 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)	40.60	Unable to Model					
Energy Slope	0.00105						
Critical Flow (m^3/s)	3.96						
Water Level is (m)	172.24						
Critical Surface Width (m)	6.00						
Unit Stream Power (Watts/m^2 or N/m^2/s)	6.80						

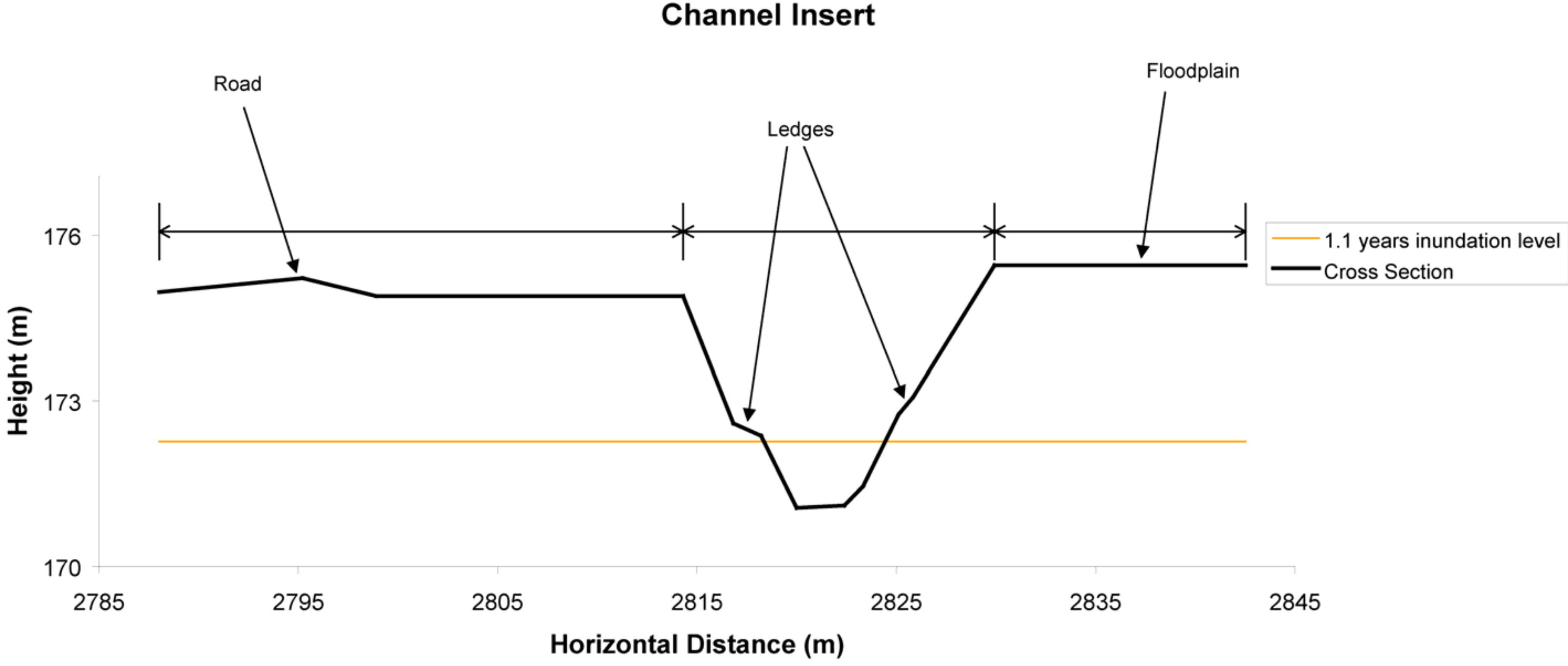
Figure 38: Schematic valley cross section, Meandering Entrenched Gravel Bed (Dart Brook 976413 Muswellbrook 9033)



(This plot is a composite of channel survey data of Dart Brook and Kingdon Ponds collected on site and valley cross section data generated from the topographic map, Aberdeen 1:25,000 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)



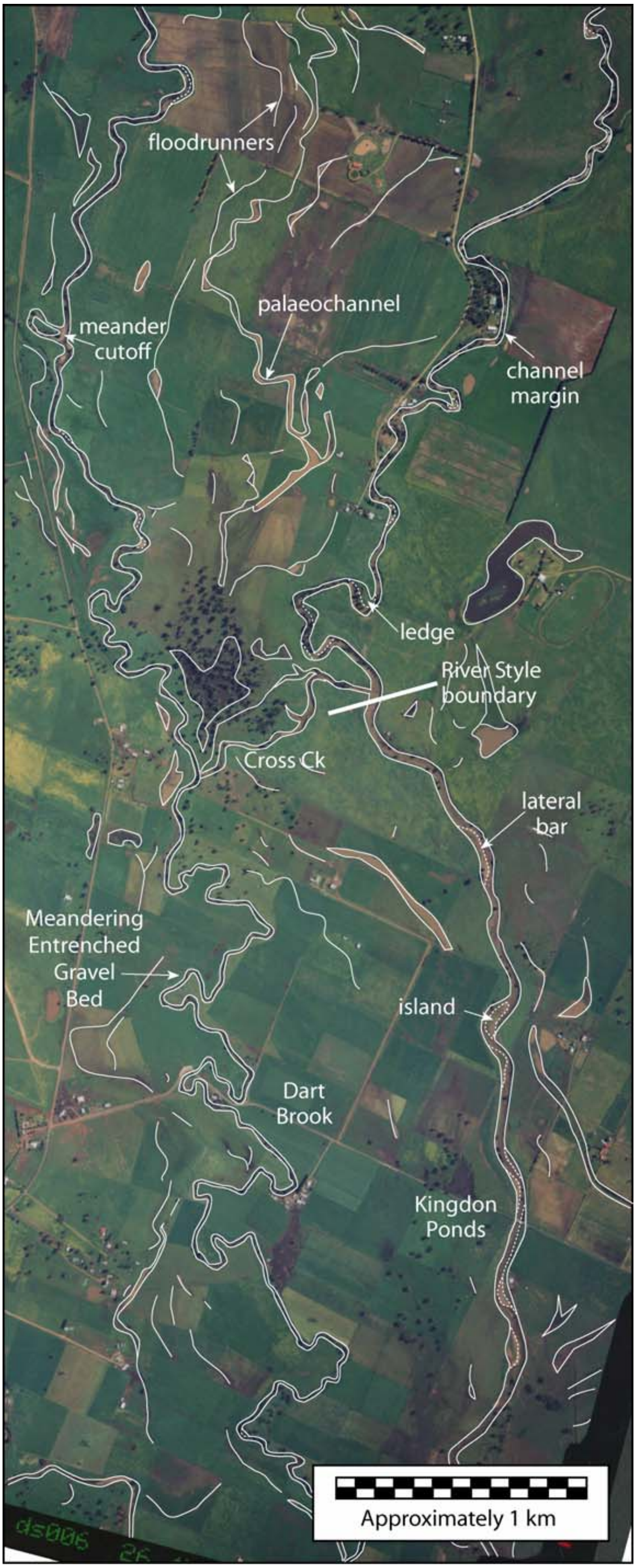


Figure 40: Aerial View of a Meandering Entrenched Gravel Bed and Low Sinuosity Entrenched Gravel Bed River Style reach, lower ends of Dart Brook and Kingdon Ponds

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.

<table>
<tr><td rowspan="2">Geomorphic units
(Geometry, sedimentology)</td><td>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.</td></tr>
<tr><td>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.</td></tr>
<tr><td rowspan="2">Vegetation associations</td><td>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.</td></tr>
<tr><td>Floodplain geomorphic units
Improved pastures dominates the floodplain, with some native eucalypts still persisting. Willows are abundant in the riparian zone.</td></tr>
</table>

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)

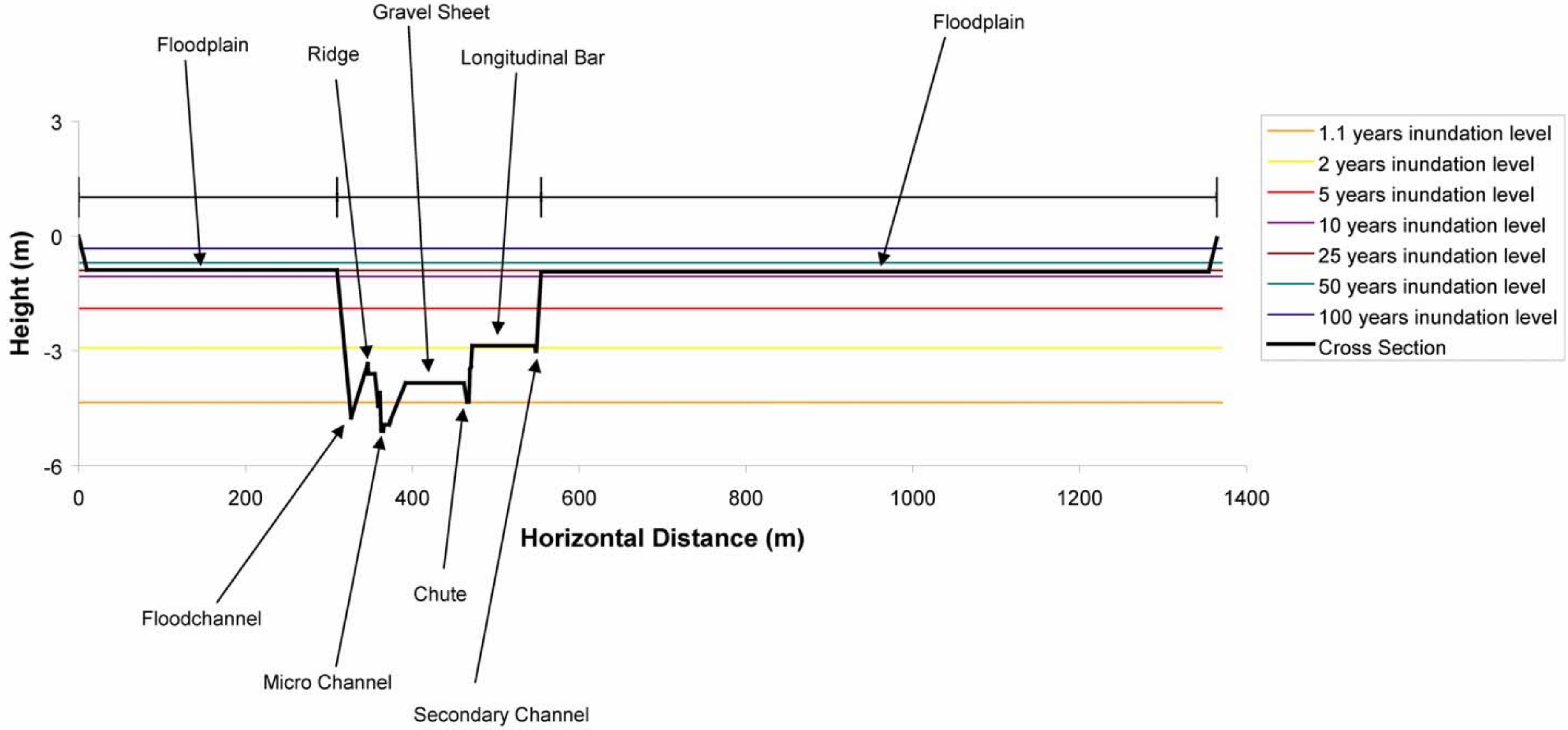


Figure 43: Aerial View of a Low Sinuosity Gravel Bed River Style reach, Pages River

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.

Geomorphic units (Geometry, sedimentology)	**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.
	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.
Vegetation associations	**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.
	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.

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	(see table below)

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

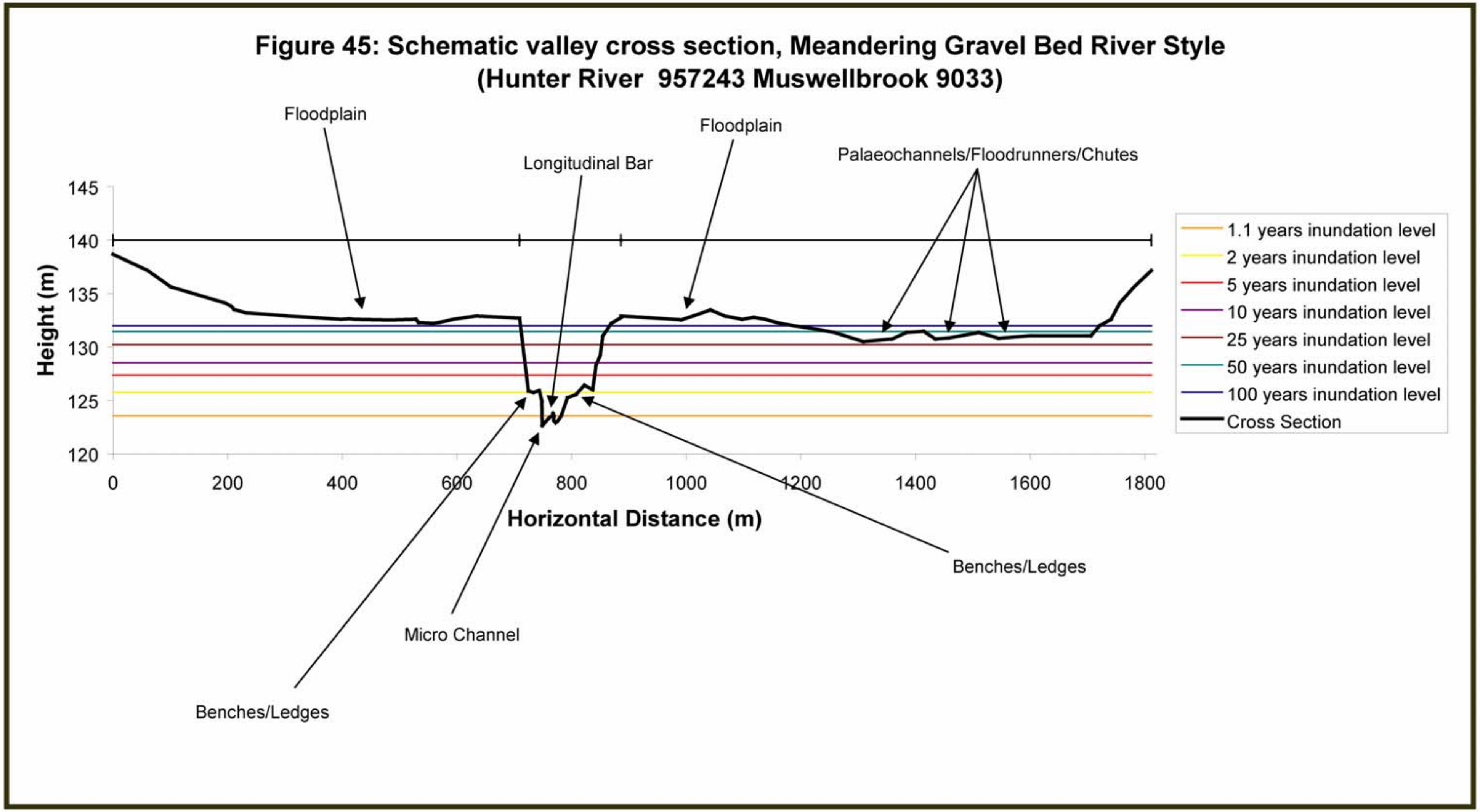


Figure 45: Schematic valley cross section, Meandering Gravel Bed River Style
(Hunter River 957243 Muswellbrook 9033)
Floodplain
Floodplain
Longitudinal Bar
Palaeochannels/Floodrunners/Chutes
145
140
135
130
125
120
Height (m)
0
200
400
600
800
1000
1200
1400
1600
1800
Horizontal Distance (m)
1.1 years 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

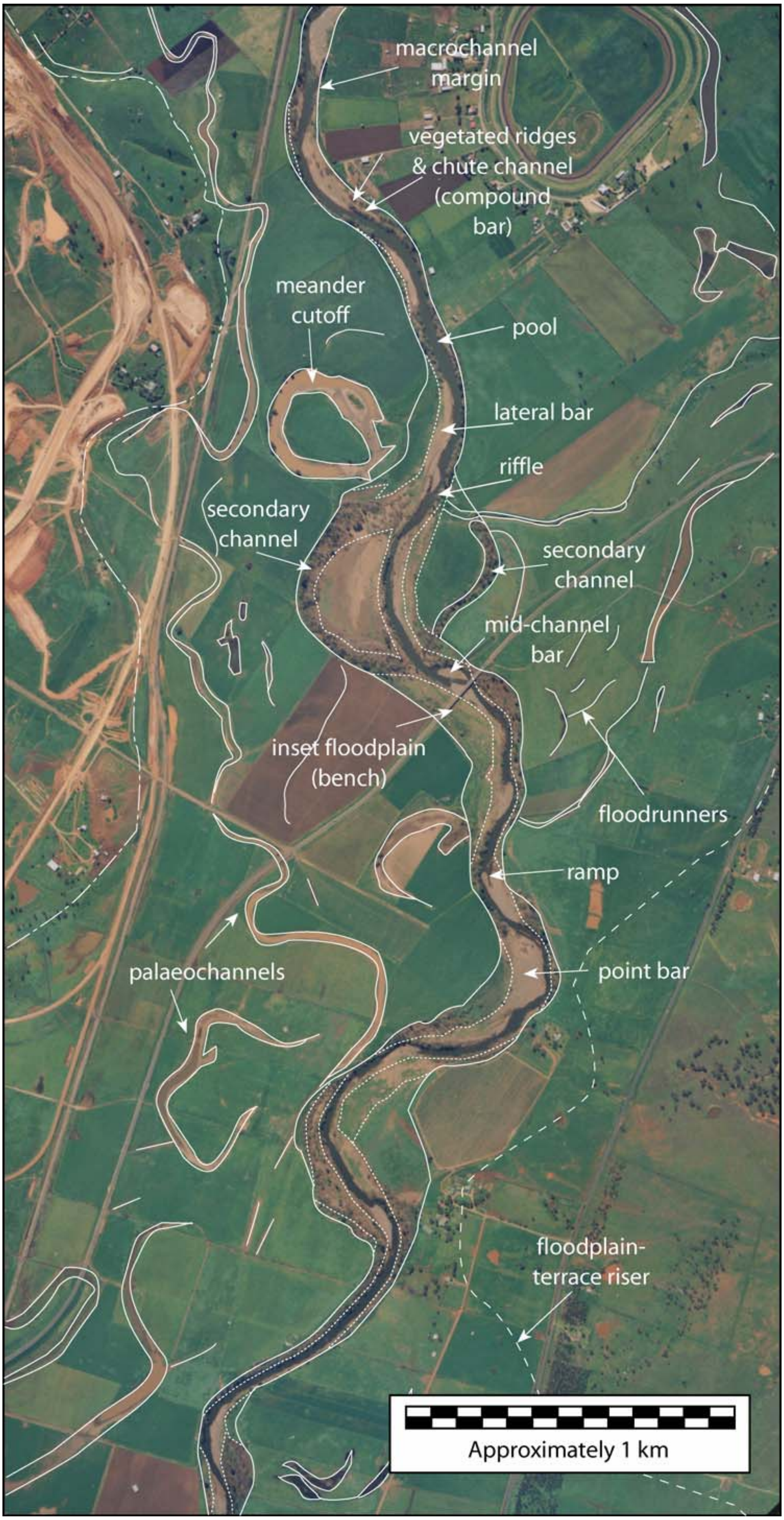


Figure 46: Aerial View of a Meandering Gravel Bed River Style reach, Hunter River

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.

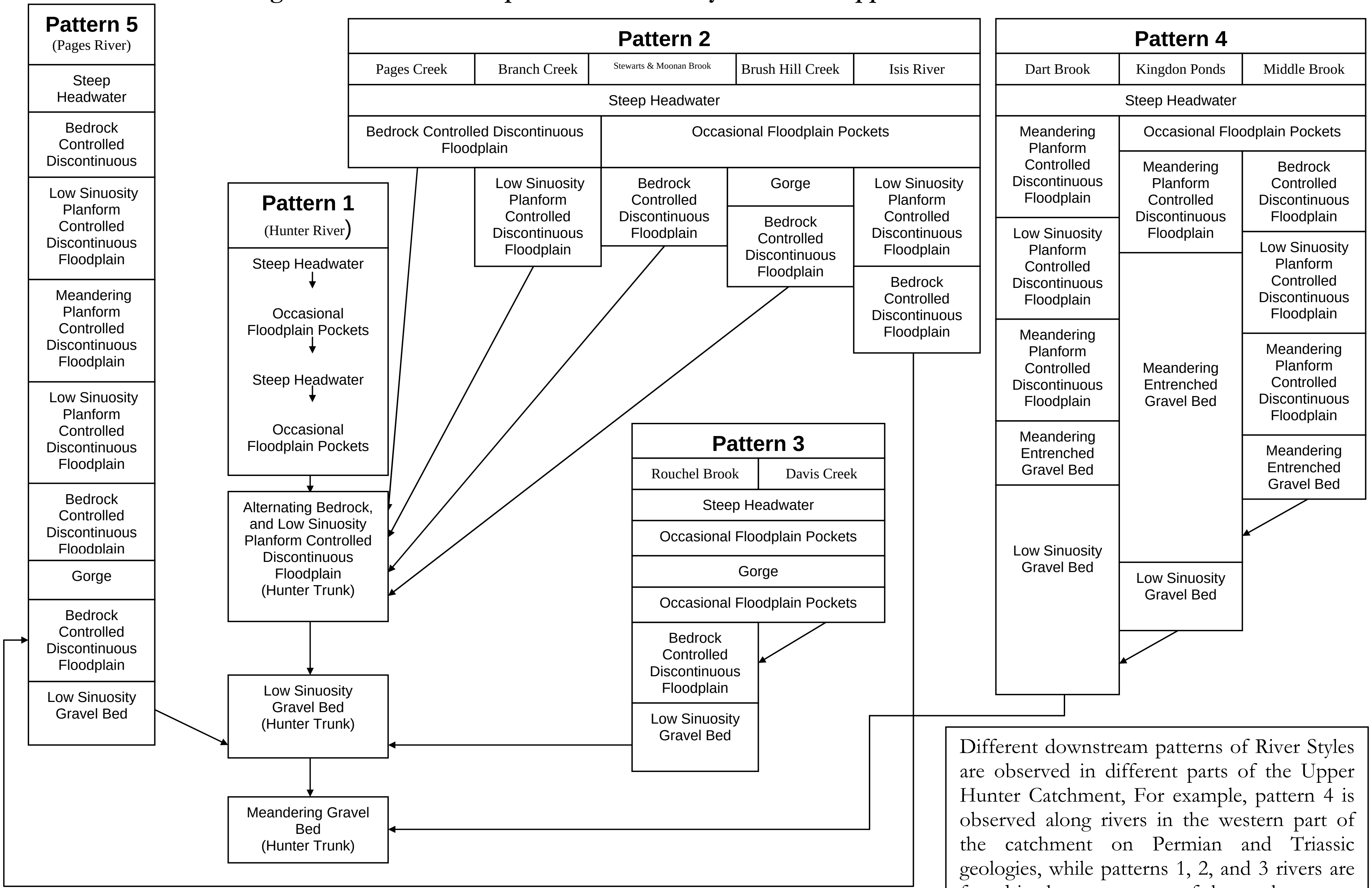
The **meandering gravel bed** River Style is located in wide alluvial valley settings (valley width <1000 m) with the channel meandering down the centre of the valley. Reaches of this River Style occur on the lower sections of the Upper Hunter River, where catchment areas are large average 4018 km^2). 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.

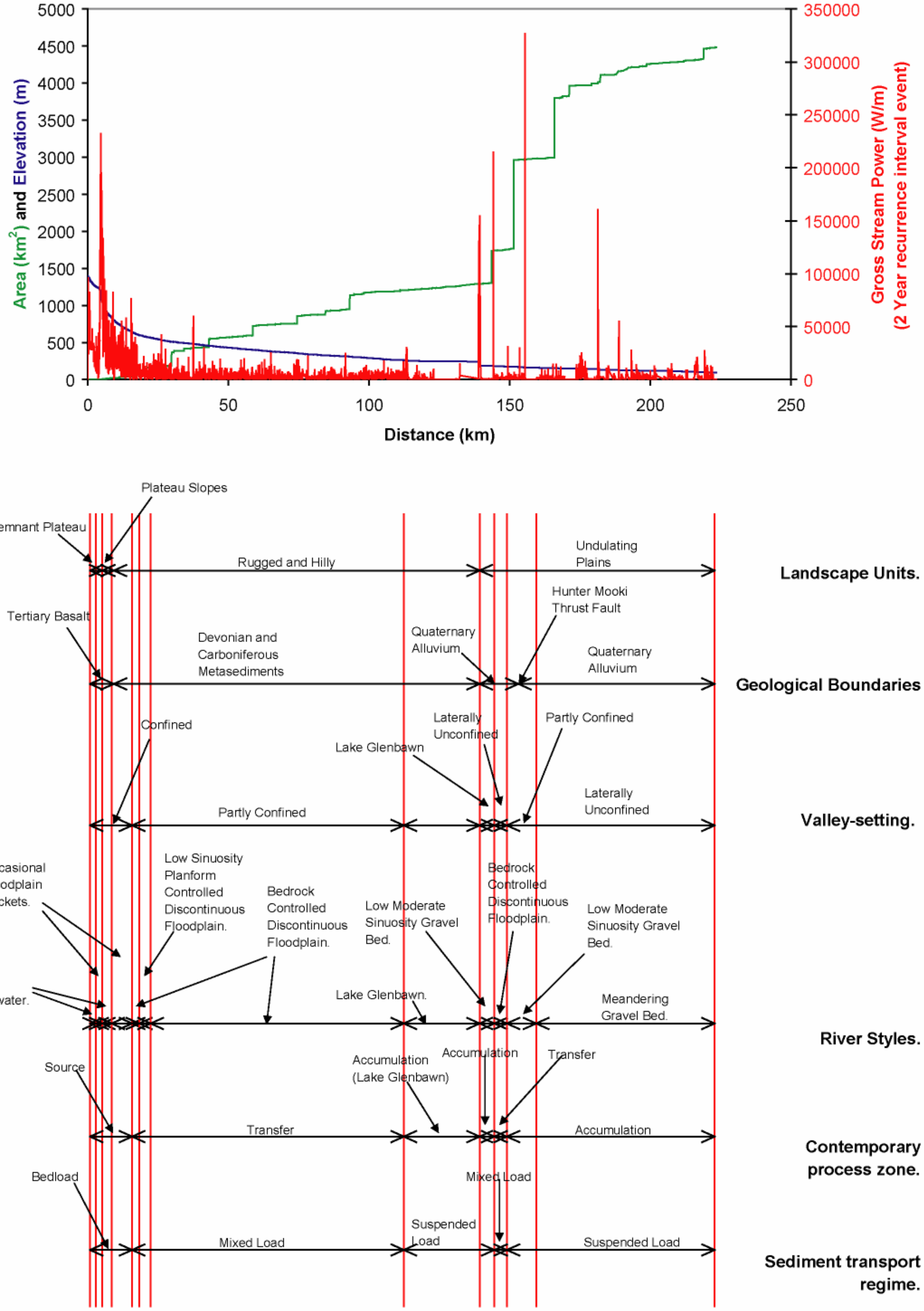
Pattern 1 rivers (Hunter River)
The Hunter River trunk stream begins on the remnant plateau, has a break in slope at the edge of the remnant plateau, and continues across the plateau slopes, the rugged and hilly landscape unit of Devonian and Carboniferous meta-sediments, and onto the undulating plain.

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).

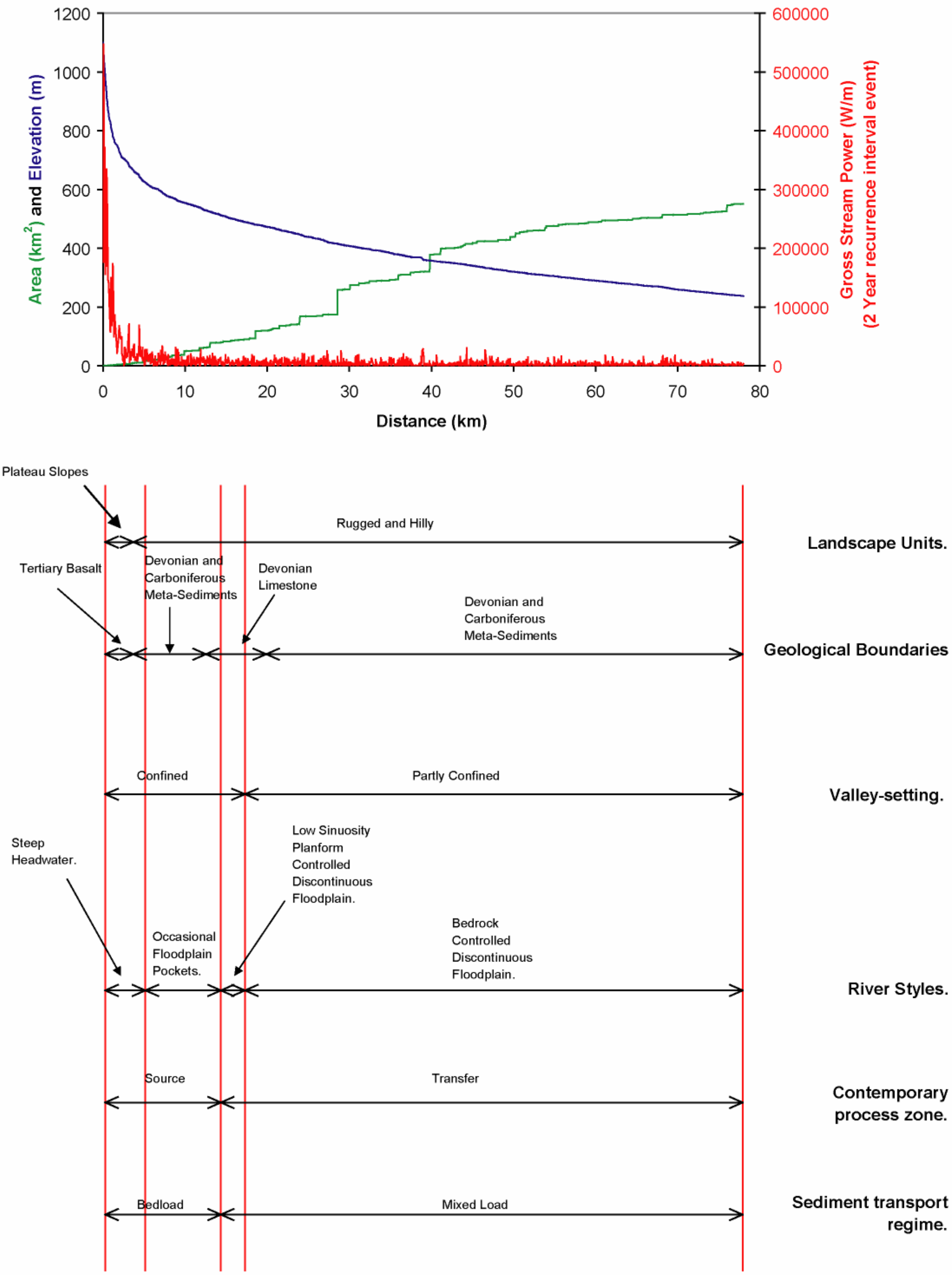
As the river flows beyond the valleys with basalt ridges the landscape is lower in altitude but rugged and hilly. Pattern 2 rivers in the Rugged and Hilly landscape unit are either Bedrock-Controlled Discontinuous Floodplain or Low Sinuosity Planform Controlled Discontinuous Floodplain River Styles. 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)



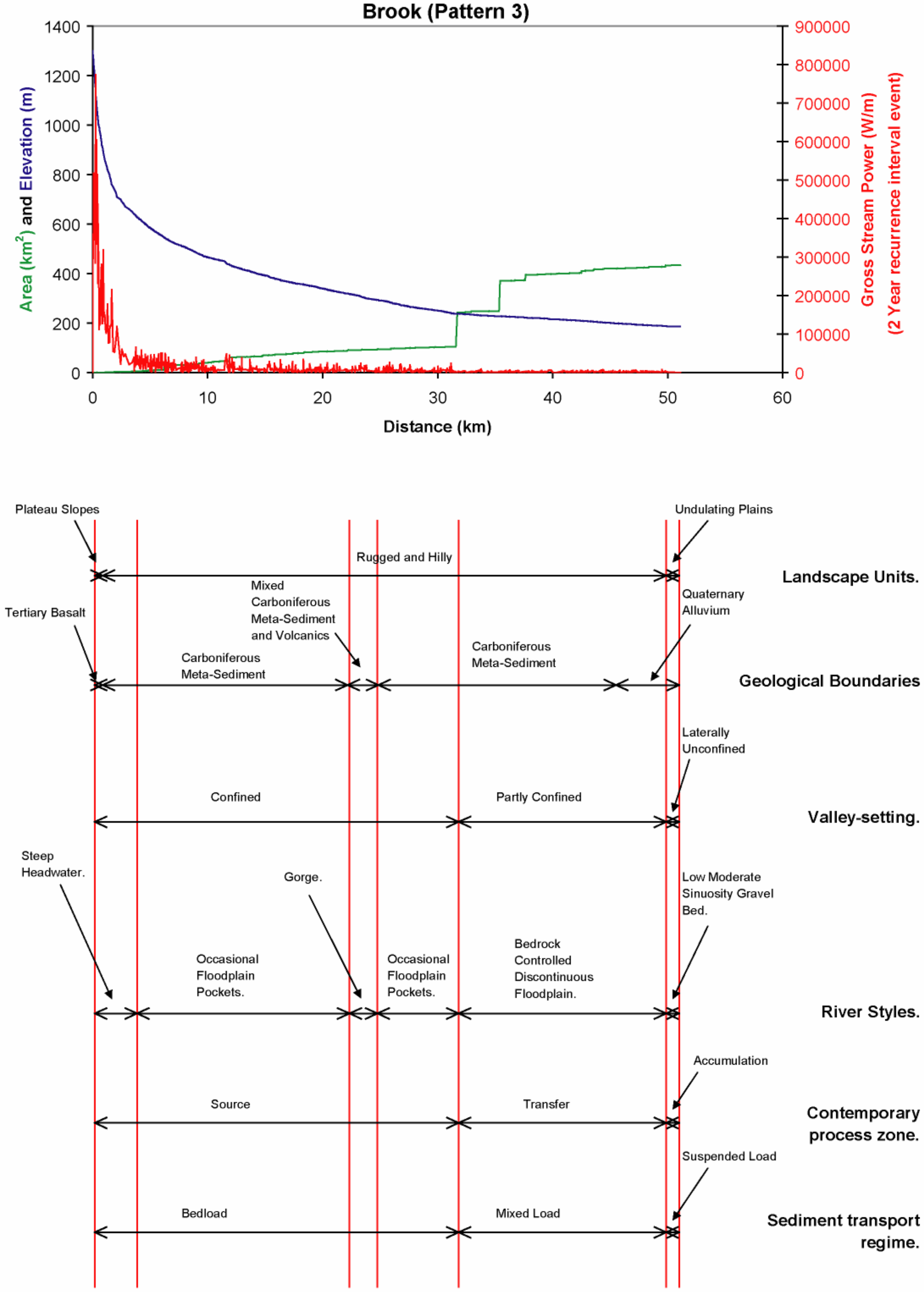
Pattern 3 rivers (Davis Creek, Rouchel Brook)
Subcatchments that begin in the Plateau Slopes landscape unit, continue across the Rugged and Hilly landscape unit with the majority of there length in confined valleys, and join the Hunter River at the downstream end of the rugged and hilly landscape unit.

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.

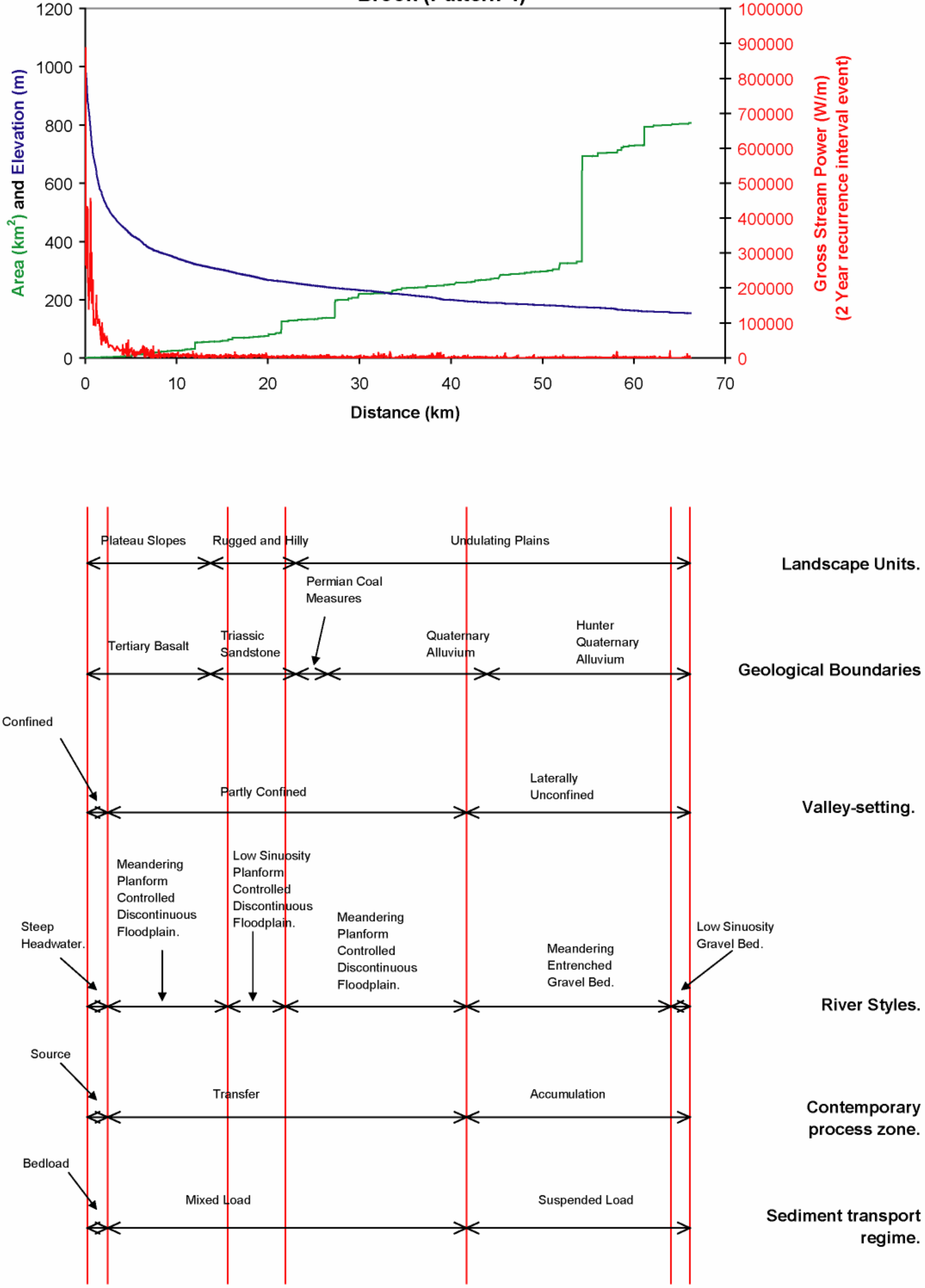
Because of their proximity it is a reasonable assumption that when Dart Brook, Middle Brook, and Kingdon Ponds are in flood the Hunter is also in flood. This means that when large formative flows are present in Dart Brook, Middle Brook, and Kingdon Ponds it is highly likely that the Hunter floodplain 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.

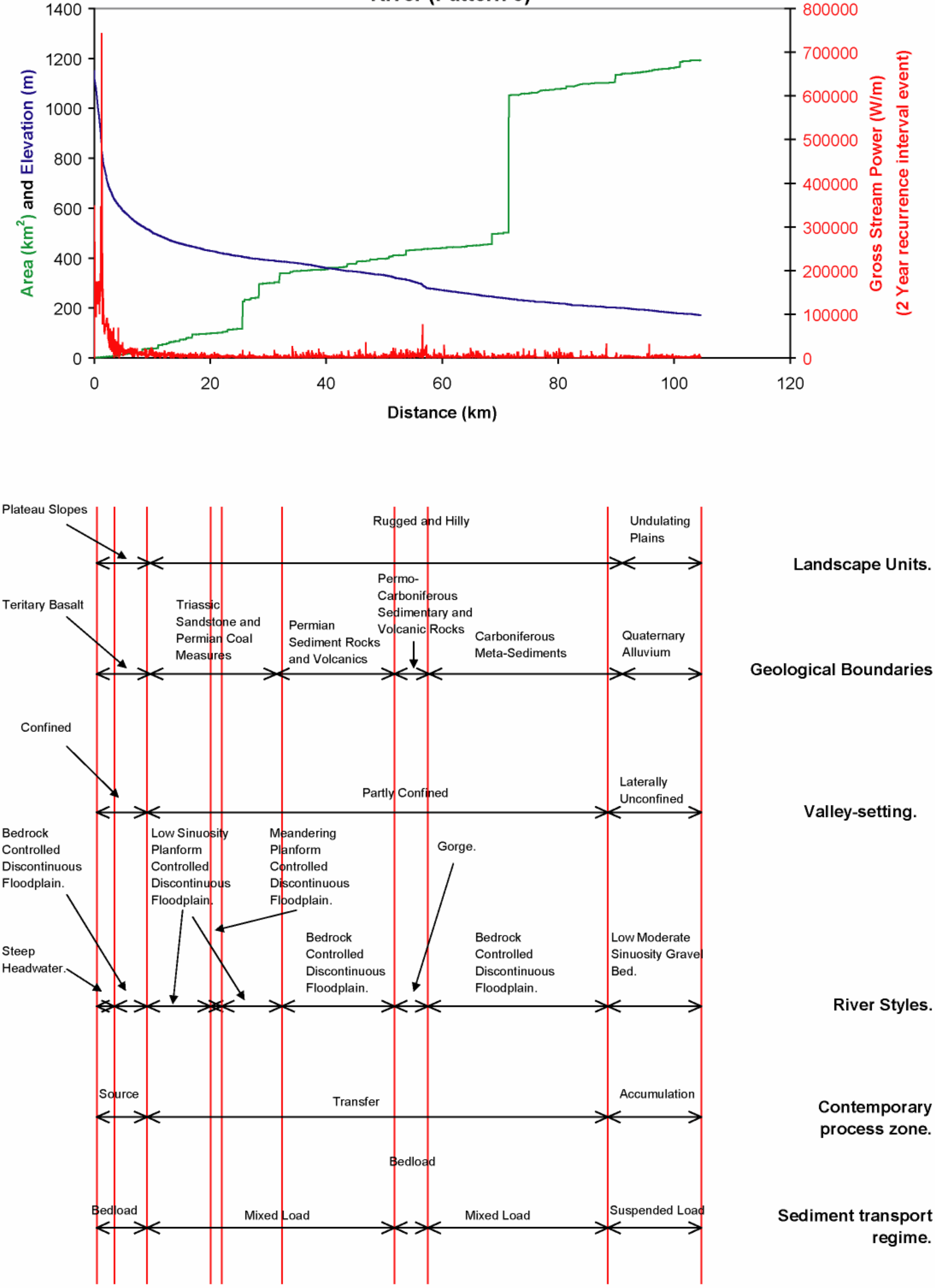
Pages River falls into pattern 5, it is unique because the Pages River rises to the west of the Hunter-Mooki fault and crosses to the east. No other river in the Upper Hunter catchment does the same. Even though it is a unique downstream pattern it is basically a collage of sections of other patterns. 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.

REFERENCES

Anon (1999). *The Geological Evolution of New South Wales – A Brief Review*. Department of Mineral Resources of New South Wales.

Beckett, J. Doyle, R. and Herlihy, I. (1997) A brief history of coal mining in the Upper Hunter River Valley, in, Boyd, R.L. and Allan, K. (eds). 31st Newcastle Symposium on Advances in the study of the Sydney Basin, April 18-20, Newcastle, Australia.

Bridge, M.H. (1958) Coal mining at Muswellbrook, *Scone and Upper Hunter Historical Society Journal*, 2 327-332.

Brierley, G.J., Fryirs, K., Outhet, D. and Massey, C. (2002) Application of the River Styles framework as a basis for river management in New South Wales, Australia. *Applied Geography* 22, 91-122.

Conaghan, P.J., Jones, J.G., McDonnell, K.L., and Royce, K., (1982). A Dynamic Fluvial Model for the Sydney Basin. *Journal of the Geological Society of Australia* 29, 55-70.

Cunningham, P. (1826) Two years in New South Wales, Libraries Board of South Australia, 1966.

Dangar, H (1828) *Index and Directory to the Map of the Country Bordering upon the River Hunter*, Joseph Cross, London, 1828.

DLWC (2000): *Hunter, Karuah and Manning Catchments State of the Rivers and Estuaries Report – 2000*. NSW Department of Land and Water Conservation, Sydney.

Erskine, W. (1984) Downstream impacts of Glenbawn Dam on the upper Hunter River, N.S.W., *19th Institute of Australian Geographers Conference*. Water Resources Commission of N.S.W., Sydney.

Erskine, W., Geary, P.M. and Outhet, D.N. (1983) *Management of Sand and Gravel Extraction in the Hunter River, NSW Water* Resources Commission of NSW, Sydney.

Galloway, R.W. (1963) Geomorphology of the Hunter Valley, in Story, R., Galloway, R.W., van de Graaff, R.H.M. and Tweedie, A.D. *General report on the Lands of the Hunter Valley,* CSIRO, Melbourne 1963, 91-101.

Glen, R.A., and Beckett, J., (1989). Thin-Skinned Tectonics in the Hunter Coalfield of the New South Wales. *Australian Journal of Earth Sciences* 36, 589-593.

Jones, J.G., Conaghan, P.J., McDonnell, K.L., Flood, R.H., and Shaw, S.E., (1984). Papuan Basin Analogue and a Foreland basin Model for the Bowen – Sydney Basin. In: *Phanerozoic Earth History of Australia*. (Editor J.J. Veevers), pp 243-262.

Laurie, Montgomerie and Pettit Pty Ltd (1979) *Benefits of Large Water Storages in NSW: a review prepared for Water Resources Commission, New South Wales*. Water Resources Commission, New South Wales, Sydney, 112-118.

Monteith, N.H. (1953) The contribution of historical factors to the present erosion condition of the Upper Hunter River, Journal of the Soil Conservation Service NSW, 9, 85-91.

Moriarty, E.O. (1870) *Floods in the Hunter: Progress Report*, Thomas Richards, Government Printer.

New South Wales Coastal Rivers Floodplain Management Studies Hunter Valley, March 1981, Sinclair and Knight & Partners Pty Ltd Consulting Engineers.

Newcastle and the Hunter Region 2000-2001 (2000), Hunter Valley Research Foundation, M. Engel and Mcdonald, R. (eds)

O'Sullivan, P.B., Coyle, D.A., Gleadow A.J.W., and Kohn, B.P., (1996). Late Mesozoic to Early Cenozoic Thermotectonic History of the Sydney Basin and the Eastern Lachlan Fold Belt, Australia. Mesozoic Geology of the Eastern Australia Plate Conference. *Geological Society of Australia, Extended Abstracts* No.43, pp 424-432.

Peake, T. (2003) *Hunter Bushland Resource Kit, Hunter,* Catchment Management Trust, Southward Press, Sydney.

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Wood, W.A. (1972) Dawn in the valley: the story of settlement in the Hunter River Valley to 1833, Wentworth Books, Sydney.