CHAPTER FIVE
STAGE TWO : THE EVOLUTION AND GEOMORPHIC CONDITION OF RIVERS IN BEGA CATCHMENT

5.1 Introduction and outline of this chapter

Stage Two of the River Styles framework has three steps as noted in **Figure 5.1**.

Figure 5.1 Steps in Stage 2 of the River Styles framework

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

The following products are presented in separate sections for Bega catchment:

Stage Two, Step One

- Table noting the capacity for adjustment of each River Style in the catchment.

Stage Two, Step Two

- Planform and cross-sectional evolutionary sequences for each River Style noting where irreversible geomorphic change has occurred (i.e. where a change in River Style has occurred).

Stage Two, Step Three

- Tables of pertinent questions with which to assess the geomorphic condition of each reach of each River Style in the catchment, framed in terms of the relevant geoindicators within each degree of freedom.
- Tables noting the 'ticks and crosses' for each reach of each River Style in the catchment, framed in terms of the three degrees of freedom.
- Tables explaining how each degree of freedom has adjusted along good, moderate and poor condition reaches of each River Style. Photographs accompany these tables.

- A catchment-wide map showing the distribution of good, moderate and poor condition reaches.

5.2 Stage Two, Step One: The capacity for adjustment of River Styles in Bega catchment

5.2.1 Assess the ability of each degree of freedom to adjust for each River Style

For each River Style in Bega catchment the question was asked: In what ways can this type of river adjust within its valley-setting under the prevailing set of flow and sediment characteristics? This question was framed around the three degrees of freedom that are used to assess the capacity for river adjustment namely, channel attributes, channel planform and bed character. This analysis provides an indication as to the sensitivity of each River Style to change.

Table 5.1 notes the capacity for adjustment for each River Style in Bega catchment. This provides a surrogate for assessment of sensitivity to change. All Confined and Partly-confined River Styles have limited capacity for adjustment and are therefore considered resilient to change. The Intact valley fill and Floodout River Styles are also resilient to change because the absence or discontinuity of channels limits the ability to rework sediments. However, once incised, the Channelised fill River Style develops, resulting in rivers with significant capacity to adjust. Hence, these rivers are considered highly sensitive to change. Because of its coarse boulder texture, the Low sinuosity boulder bed River Style is also considered resilient to change. The alluvial rivers with continuous channels (i.e. the Channelised fill and Low sinuosity sand bed River Styles) have the greatest capacity for adjustment. These 'sensitive' reaches have experienced significant geomorphic change in period since European settlement.

The capacity for adjustment along the River Styles in the Confined valley setting is limited (see **Table 5.1**). For the Steep headwater and Gorge River Styles, adjustments are limited to reorganisation of bed materials. Along the Confined valley with occasional floodplain pockets River Style, the three degrees of freedom can locally adjust. For example, channel width can only adjust where occasional floodplain pockets occur. Depending on valley configuration, among other factors, floodplains may be reworked or even stripped at high flow stages. A predictable pattern of grain sizes occurs on islands and in pools. Disruption to these patterns reflects alterations to the sediment regime of the reach and deterioration of its geomorphic condition.

Table 5.1 Capacity for adjustment of River Styles in Bega catchment framed in terms of the three degrees of freedom

River Style	Channel attributes	Channel planform	Bed character	Capacity for adjustment
Confined valley setting				
Steep headwater				**Low**
Gorge				**Low**
Occasional floodplain pockets				**Low**
Partly-confined valley setting				
Bedrock-controlled discontinuous floodplain				**Moderate**
Laterally-unconfined valley setting				
Intact valley fill				**Low**
Floodout				**Low**
Low sinuosity boulder bed				**Low**
Channelised fill				**High**
Low sinuosity sand bed				**High**

	Minimal or no adjustment potential
	Localised adjustment potential
	Significant adjustment potential

Other River Styles with limited capacity to adjust include those with absent or discontinuous channels or coarse bedload materials that are not readily reworked. The former types of rivers have intact valley fill surfaces that are relatively resilient to change. The capacity for adjustment is restricted to localised redistribution of materials over swampy surfaces. The Intact valley fill and Floodout River Styles fall into this category in Bega catchment. Along the Low sinuosity boulder bed River Style, localised adjustments in channel planform occur over a fan-like surface. This is accompanied by local bed material reorganisation.

In the Partly-confined valley setting, the capacity for adjustment increases. Along the Partly-confined valley with bedrock controlled discontinuous floodplain River Style, all three degrees of freedom have the capacity to adjust. Channel size and shape may change, the alignment or planform of the channel can shift within the sinuous valley, and reorganisation of bed materials can occur as material is transferred along the channel bed.

Rivers with significant capacity to adjust are found in the laterally-unconfined valley setting with continuous channels. In Bega catchment, the Channelised fill River Style is found at the base of the escarpment and the Low sinuosity sand bed River Style is observed along the lowland plain. Both are formed in wide, alluvial valleys. The Channelised fill River Style is characterised by a wide, deep, low-sinuosity trench with a suite of bar, swamp and inset geomorphic units. The incised trench is aligned down the centre of the valley, with continuous, perched floodplains on either side. The Channelised fill River Style has significant potential to adjust its channel geometry, planform and bed character given the relatively loose alluvial materials through which the channel flows (see **Table 5.1**). The Low sinuosity sand bed River Style is characterised by a wide, shallow macrochannel with a range of benches, islands and sand bars. Significant material reorganisation occurs within this macrochannel. On the floodplain, floodchannels are occupied in large flood events and are a potential area of channel adjustment. Hence, this River Style has significant potential to adjust its channel geometry, planform and bed character.

5.2.2 Determine which geoindicators within each degree of freedom are relevant for each River Style and construct a table noting the 'relevant geoindicators' that will be used to identify a natural reference condition and assess the geomorphic condition of reaches

Following procedures outlined in Brierley and Fryirs (2005), each geoindicator used to determine the geomorphic condition of a reach is assessed to determine whether it is 'relevant' for the River Style under investigation. Only those geoindicators that provide direct insight into how a river adjusts are used to assess geomorphic condition. **Table 5.2** outlines 'relevant geoindicators' for each River Style in Bega catchment. These parameters are later assessed in more detail to identify a reference condition and assess the geomorphic condition of reaches of each River Style.

Table 5.2: The relevance of geoindicators used to measure the geomorphic condition of different River Styles in Bega catchment

Geoindicator / River Style	Steep Headwater	Gorge	Confined valley with occ. fplain pockets	Partly-confined valley with bedrock-cont discont. fp.	Intact valley fill	Floodout	Channelised fill	Low sinuosity boulder bed	Low sinuosity sand bed
Channel attributes									
Size	NO	NO	NO	YES	NO	NO	YES	NO	YES
Shape	NO	NO	YES	YES	NO	NO	YES	YES	YES
Bank morphology	NO	NO	YES	YES	NO	NO	YES	NO	YES
Instream vegetation structure	YES	YES	YES	YES	YES	YES	YES	YES	YES
Wood loading	YES	YES	YES	YES	NO	NO	NO	YES	YES
Channel planform									
Number of channels	NO	NO	NO	NO	NO	NO	NO	YES	YES
Sinuosity of channels	NO	NO	NO	NO	NO	NO	NO	NO	YES
Lateral stability	NO	NO	NO	YES	NO	NO	YES	NO	YES
Geomorphic unit assemblage	YES	YES	YES	YES	YES	YES	YES	YES	YES
Riparian vegetation	YES	YES	YES	YES	YES	YES	YES	YES	YES
Bed character									
Grain size and sorting	YES	YES	YES	YES	YES	YES	YES	YES	YES
Bed stability	NO	NO	NO	YES	YES	YES	YES	YES	YES
Hydraulic diversity	YES	YES	YES	YES	NO	NO	YES	YES	YES
Sediment regime	YES	YES	YES	YES	YES	YES	YES	YES	YES

5.3 Stage Two, Step Two: The evolution of River Styles in Bega catchment

5.3.1 Identify a timeframe over which environmental conditions in the catchment/region have been relatively uniform

The Holocene has been a phase of 'relative stability' in southeastern Australia (Young et al., 1987). While localised flood-induced responses are inevitable, there is no evidence along coastal valleys of NSW to suggest that synchronous or systematic landscape changes occurred during the Late Pleistocene-Holocene interval (e.g. Prosser and Winchester, 1996; Tooth and Nanson, 1995). The most dramatic and systematic changes occurred following European settlement post-1788.

Putting aside the impacts of aboriginal landuse and fire (Hughes and Sullivan, 1981; Wasson, 1994), assessment of the geomorphic structure and function of rivers prior to European settlement (i.e. 1788) provides an idealised platform upon which to analyse the nature and extent of subsequent river changes. In Bega catchment it has been possible to identify pre-disturbance river character and behaviour given the short period of time (just over 200 years) since European settlement. Hence, the evolutionary sequences in Bega catchment have been assessed over the last 200 years, extending into the Holocene where possible. This timeframe of reference incorporates the post-European settlement disturbance phase and any subsequent recovery phases.

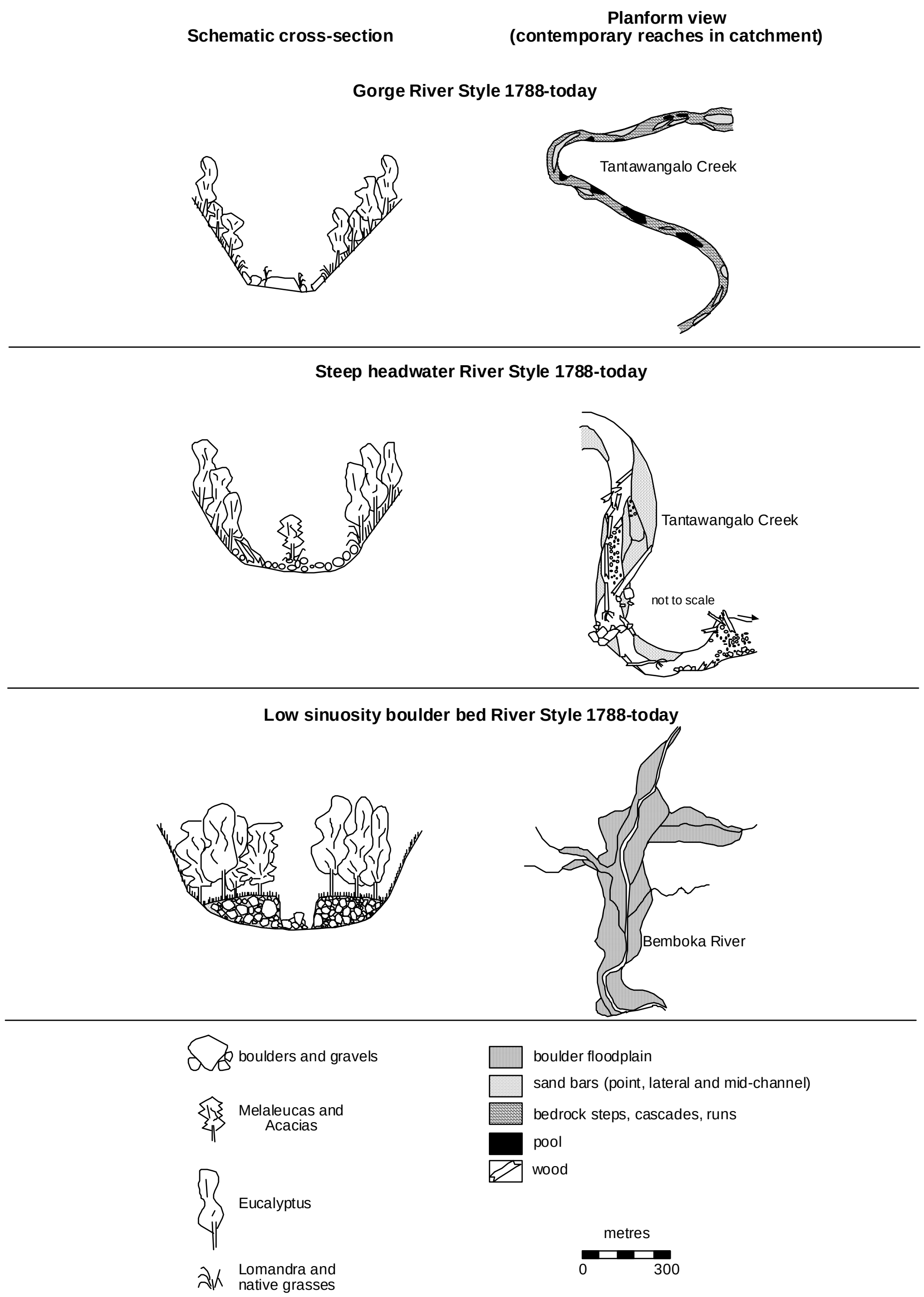
5.3.2 The evolution of River Styles in Bega catchment

Significant research into river evolution had been undertaken in key reaches of Bega catchment that cover the full spectrum of River Styles found in the catchment (e.g. Brierley and Fryirs, 1998, 1999; Brierley et al., 1999; Brooks and Brierley, 1997, 2000; Fryirs, 2002, 2003; Fryirs and Brierley, 1998a, b, c, 1999, 2000). The evolutionary pathways presented in **Figures 5.2 – 5.8** highlight the pre-European settlement disturbance character and behaviour, and changes that have occurred since European settlement. These evolutionary sequences have been constructed along representative reaches of each River Style, and ergodic reasoning has been used to place other contemporary reaches of the same River Style on the sequence. Portion plans from the 1850's and 1860's, field sedimentology, C_{14} dating, historical photographs and multiple series of air photographs have been used to construct the evolutionary sequences.

5.3.2.1 Evolution of the Steep headwater, Gorge and Low sinuosity boulder bed River Styles

Evolutionary sequences along the Steep headwater, Gorge and Low sinuosity boulder bed River Styles were undertaken respectively in upper Tantawangalo above the escarpment, the Tantawangalo escarpment zone and at the base of the escarpment along Bemboka River (**Figure 5.2**). Given their bedrock-controlled or boulder material mix, these rivers have little capacity to adjust their morphology. Also, given their location in upper parts of the catchment, and the rugged nature of adjacent terrain, direct and indirect human impacts have been much less than elsewhere. The only changes that were detected along these reaches were adjustments to bed material reorganisation during and following flood events associated with the influx and reworking of bedload calibre materials.

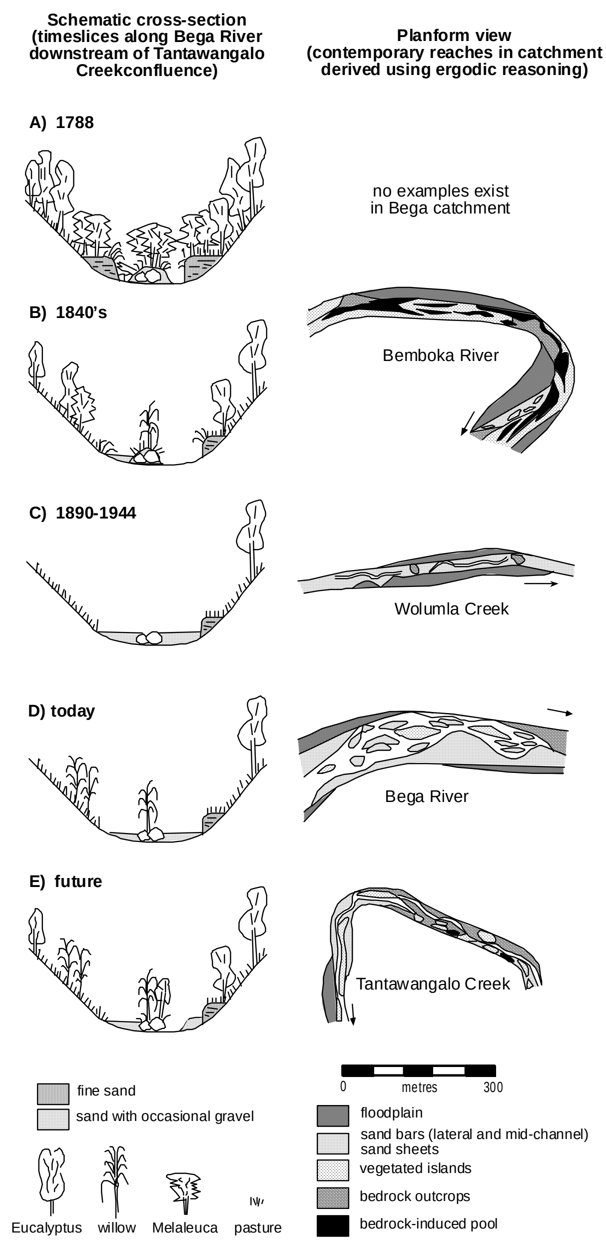
Figure 5.2 Evolution of the Gorge, Steep headwater and Low sinuosity boulder bed River Styles in Bega catchment



5.3.2.2 Evolution of the Confined valley with occasional floodplain pockets River Style

Evolutionary assessments of the Confined valley with occasional floodplain pockets River Style were made along the Lower Bega River reach. In the pre-European settlement period this reach had a relatively narrow channel. Bed morphology was likely locally variable dependent on the degree of bedrock outcropping, the configuration of islands and the loading of wood (**Figure 5.3 A**). High channel and floodplain roughness resulted in the retention of fine sands atop the floodplain. The channel was likely characterised by a series of bedrock induced pools, runs and glides separated by bar and island complexes. The floodplain was likely characterised by an open forest association with localised scour around vegetation induced in overbank events.

Figure 5.3 Evolution of the Confined valley with occasional floodplain pockets River Style



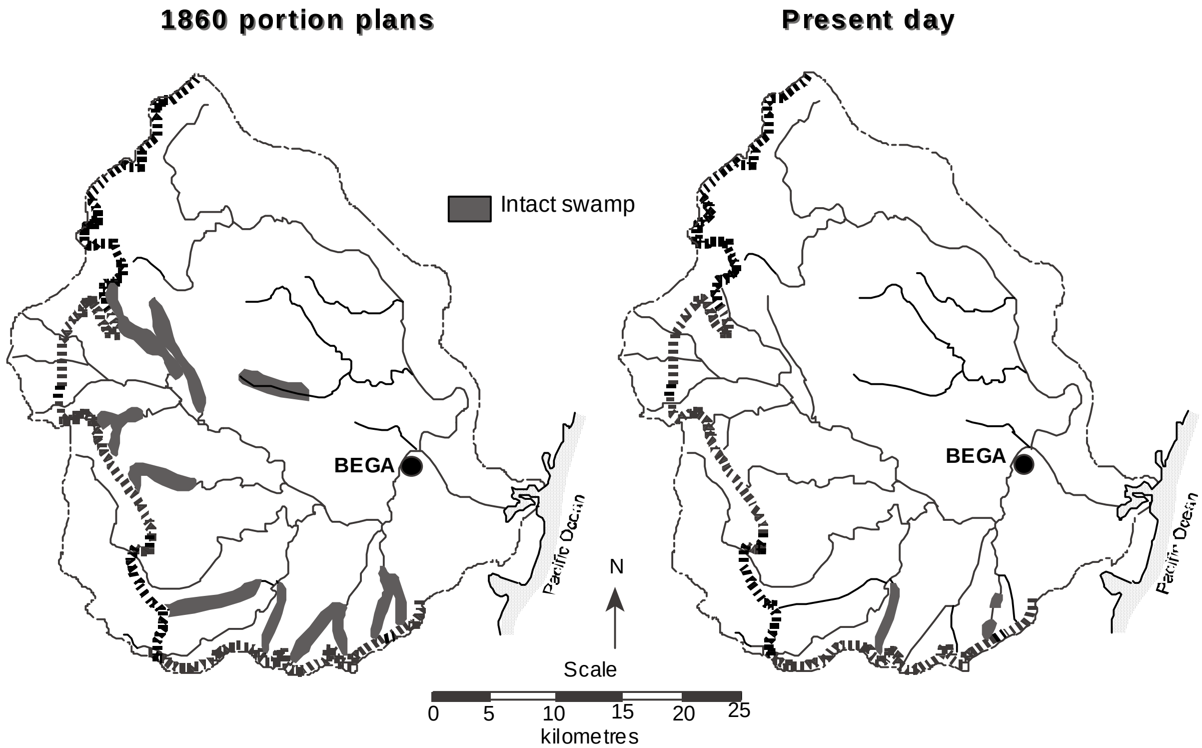
Within a few decades of European settlement, this reach had expanded laterally and floodplain reworking had occurred (**Figure 5.3 B**). This was a direct result of initial anthropogenic disturbance to riparian vegetation and later occurred in response to increased sediment supply from upstream. While the river maintained an imposed bedrock channel, local widening occurred adjacent to the occasional pockets of floodplain. The channel bed became increasingly homogeneous as pools began to infill and the channel bed was covered with sand. By 1944, pools were completely infilled, and runs and glides were covered with large volumes of bedload material. The low flow channel was poorly defined, flowing atop large sand sheets and around bedrock outcrops (**Figure 5.3 C**). An analogous reach occurs along Wolumla Creek.

Today, there is evidence that sediment input to this reach is decreasing as the tail of the sediment slug passes (Fryirs and Brierley, 2001). Exotic vegetation, largely willows, has colonised some sand bars. Large volumes of sand still occur along this reach (**Figure 5.3 D**). With time, pool scour and re-emergence is likely to occur. Bedrock runs and glides will progressively be uncovered and sand sheets will be re-vegetated forming within-channel islands (**Figure 5.3 E**). Channel dimensions will re-adjust with the formation of localised benches along the channel margin. An analogous reach occurs along Tantawangalo Creek.

5.3.2.3 Evolution of the Partly-confined valley with bedrock-controlled discontinuous floodplain and Floodout River Styles

Two evolutionary pathways were derived for the Partly-confined valley with bedrock controlled discontinuous floodplain River Style in Bega catchment, dependent on whether a Floodout was present prior to European settlement. In most subcatchments that drain directly from the escarpment, where Channelised fill/Intact valley fill River Styles occur at the base of the escarpment, floodouts extended along the mid-catchment reaches of river courses. The extent of Intact valley fill and Floodout River Styles prior to European settlement, as identified from 1860's portion plans, is depicted in **Figure 5.4**. Detailed analyses for the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style were completed along Wolumla Creek (see Brierley and Fryirs, 1998) and for the Floodout River Style along Frogs Hollow Creek where the last remaining floodout in Bega catchment occurs.

Figure 5.4 Extent of Intact valley fill and Floodout River Styles in Bega catchment at the time of European settlement and today



In their pre-disturbance state, floodout surfaces were dominated by *Melaleuca ericifolia* and tussock grass. Valley floor surfaces comprise suspended load mud, with occasional sand deposits in floodouts immediately downstream from discontinuous gullies (see Brierley and Fryirs, 1998) (**Figure 5.5 A, B**). Within a few decades of European settlement, most of these reaches had developed continuous channels. Channel incision was a direct result of anthropogenic disturbance of swamp surfaces, vegetation removal, and influxes of sediment from the Channelised fill River Style upstream (**Figure 5.5 C**). These reaches adopted an imposed sinuous channel within a meandering valley alignment. As the channel became continuous and widened, significant volumes of sediment were released (**Figure 5.5 D**; Brierley and Fryirs, 1998). At this point in the evolutionary sequence, the character and behaviour of the Partly-confined valley with bedrock-controlled floodplain River Style reaches across the catchment are analogous (i.e. reaches in these settings have near-consistent river morphology regardless of whether a floodout was present at the time of European settlement). This is evidenced by contemporary reaches along Sandy Creek and South Wolumla Creek (**Figure 5.5 D and 5.6 C**). The low flow channel is poorly defined and braids atop large sand sheets. No pools are evident. Given the poor cover of riparian vegetation and lack of instream roughness, the reach has limited capacity to retain fine grained sediments. Devegetated banks and erodible bank materials accelerate channel expansion and the rate of lateral channel movement. Convex banks are characterised by point bars and discontinuous pockets of floodplain.

Figure 5.5 Evolution of the Floodout and Partly-confined valley with bedrock-controlled discontinuous floodplain Styles

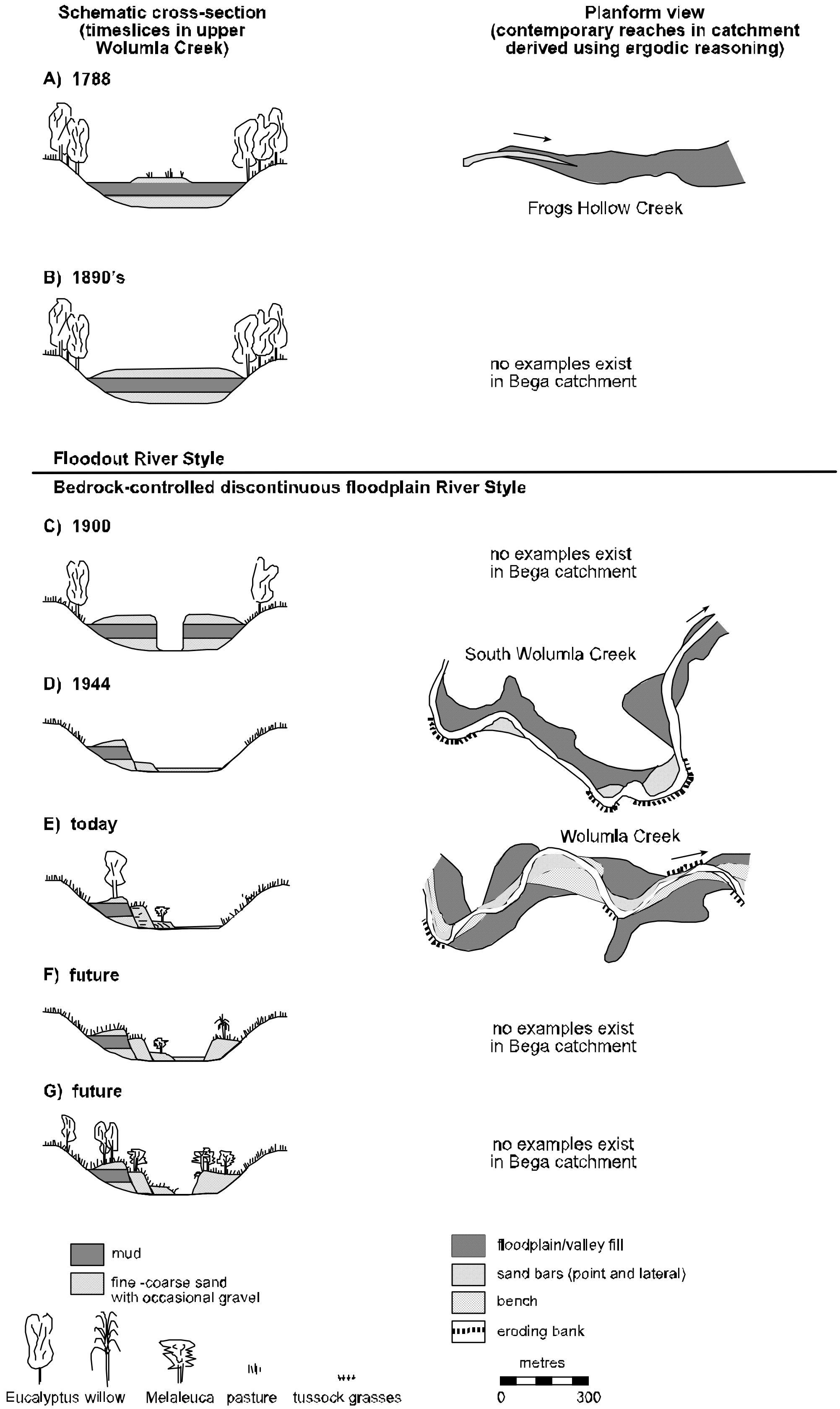
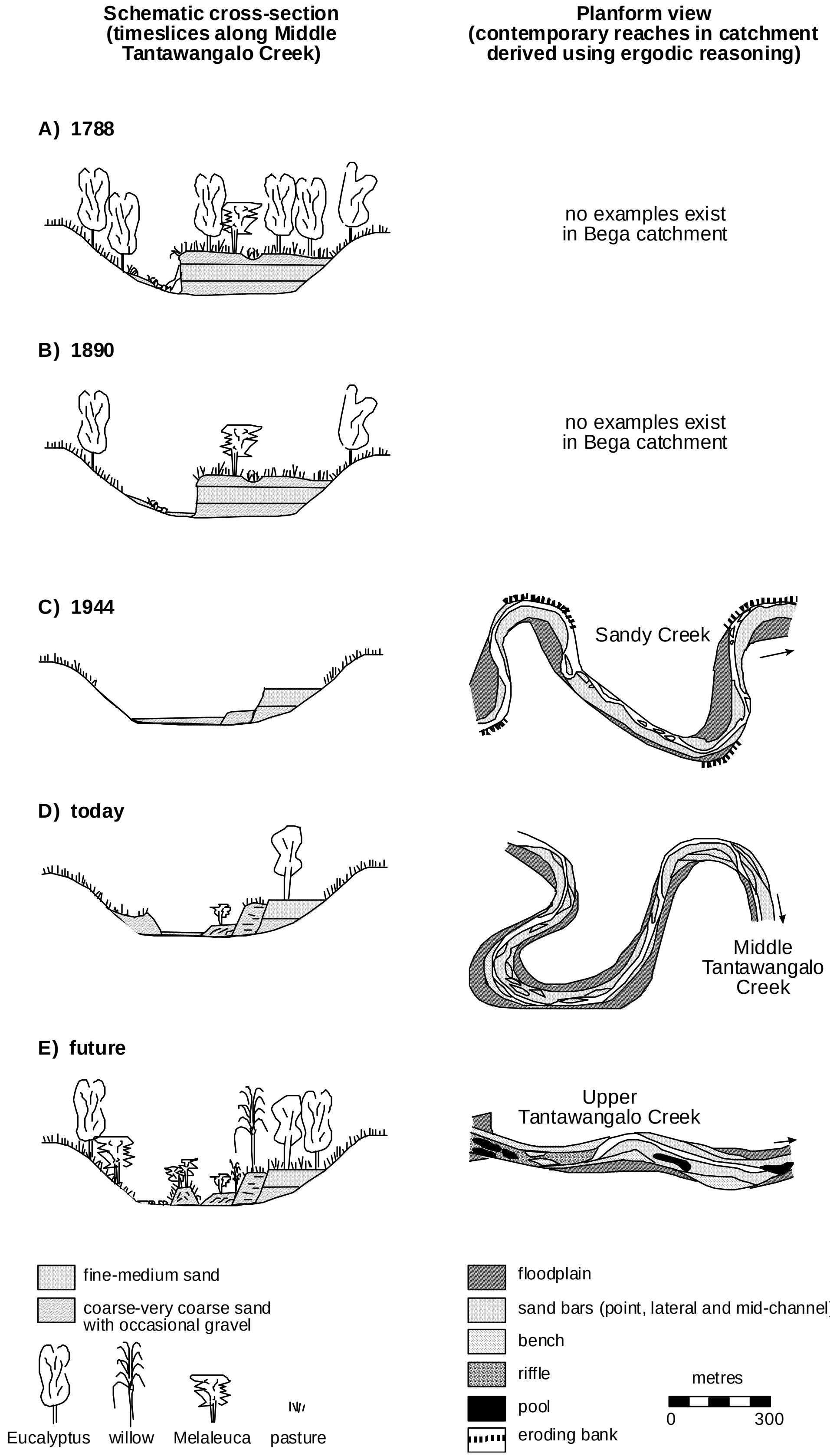


Figure 5.6 Evolution of the Partly-confined valley with bedrock-controlled discontinuous floodplain Style



Over time, the low flow channel becomes better defined. A contemporary example of this stage occurs along Wolumla Creek (**Figure 5.5 E**). Sediment inputs and outputs eventually become roughly balanced, with point bar and point bench storage on the inside of bends and maintenance of sediment throughput along the channel bed. As the channel becomes narrower and deeper, it adopts a more sinuous course. Point bars and point benches store significant volumes of material, as do within-channel ridges which form as a result of vegetation colonisation. Pools re-emerge as sediment is flushed through the reach. A contemporary example of this stage occurs along Tantawangalo Creek (**Figure 5.6 D**).

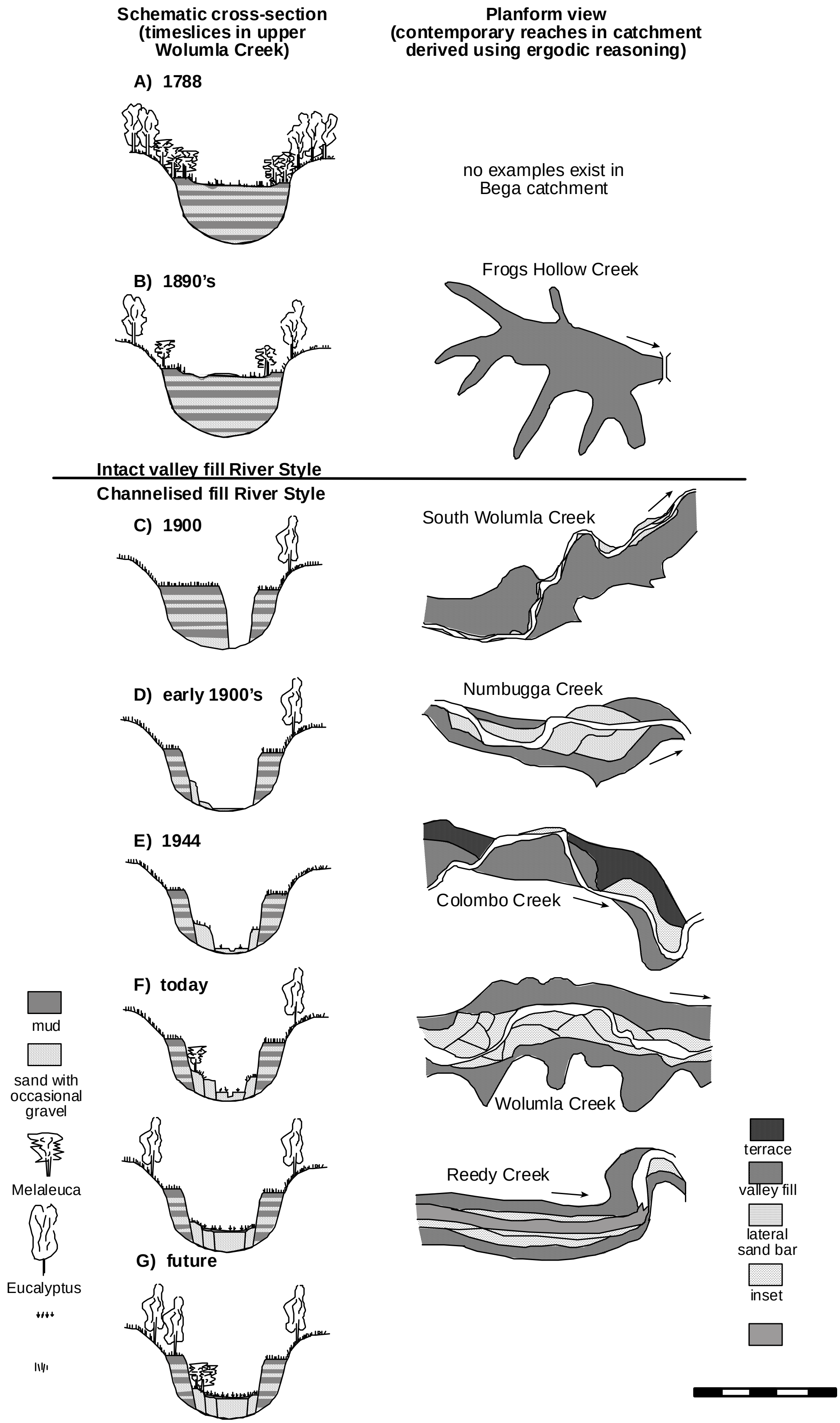
In those subcatchments that drain from the uplands, or where the Partly-confined valley with bedrock-controlled floodplain River Style occurs further down the catchment, floodouts did not occur prior to Eurpoean settlement. Analysis of the evolution of this type of river was conducted along lower Tantawangalo Creek (**Figure 5.6**). Prior to European settlement, this reach was characterised by a narrow, deep channel with significant hydraulic diversity induced by wood and a heterogeneous assemblage of geomorphic units including pools, riffles, bar complexes, islands, etc (**Figure 5.6 A**). Following removal of riparian vegetation and desnagging, channels expanded and these reaches became increasingly homogenous (**Figure 5.6 B**). With large inputs of bedload material, sand sheets covered the channel bed infilling pools and smothering riffles (**Figure 5.6 C**).

5.3.2.4 Evolution of the Intact valley fill and Channelised fill River Styles

The stratigraphy of valley fills in Wolumla subcatchment reflects recurrent phases of cutting and filling over the last 6,000 years (Fryirs and Brierley, 1998 a). However, the present incisional phase is considered to be the largest and most extensive of any that has occurred over this timeframe (Fryirs and Brierley, 1998 a). Hence in Wolumla subcatchment, and along most other base of escarpment valleys, irreversible geomorphic change has been recorded over the last 200 years (nb., this reflects a management perspective, as cut and fill activity is a natural process, the rate and extent of which have been altered (accelerated) since European settlement).

At the time of European settlement, most base of escarpment valleys contained the Intact valley fill River Style (Brierley et al., 1999) (**Figure 5.4**). This River Style was characterised by unincised swamps with discontinuous drainage lines (**Figure 5.7 A**). The valley floor comprised mud and sand with a distinct vegetation pattern dominated by *Melaleuca ericifolia* (Fryirs and Brierley, 1998 a). Only two analogous Intact valley fill River Style reaches remain in Bega catchment, along Frogs Hollow and Towridgee Creeks (**Figure 4.20**, **Figure 5.7 B**).

Figure 5.7 Evolution of the Intact valley fill and Channelised fill River Styles



Stratigraphic and historical portion plans indicate that an analogous feature occurred along Wolumla Creek in the late 1860's. On the portion plans, 'Wolumla Big Flat' is noted (Fryirs and Brierley, 1998 a). As a direct result of anthropogenic disturbance to swamp surfaces, headcuts retreated through the valley fill of upper Wolumla Creek by 1900 (Fryirs and Brierley, 1998 a) (**Figure 5.7 C**). A fundamental shift in the behavioural regime of this river occurred, transforming the reach into a Channelised fill River Style. Incision was quickly followed by channel expansion, producing a channel that was locally more than 10 m deep and 100 m wide (**Figure 5.7 D**). This wide, deep channel comprised continuous sand sheets with occasional inset features, a poorly defined low flow channel and limited riparian vegetation. Given low channel roughness, there was limited capacity to retain fine grained materials within the channel. A contemporary version of this phase is evident in upper Numbugga catchment (see **Figure 5.7 D**).

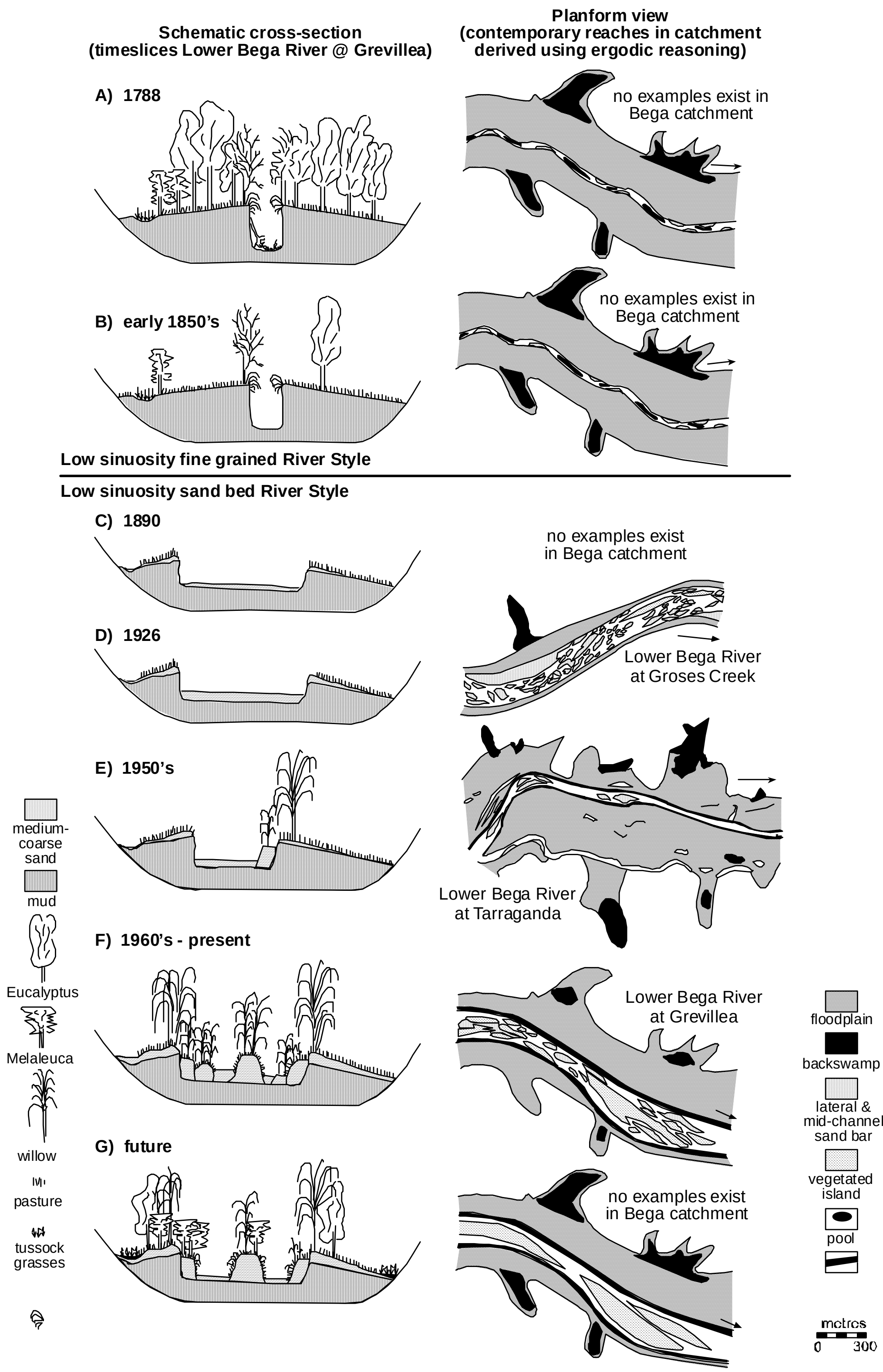
Air photographs from 1944 indicate that the incised trench along Wolumla Creek was beginning to infill (**Figure 5.7 E**). In some places, over 3 m of material has accumulated on the channel bed while inset features have continued to build along channel margins. These act to reduce channel width and depth, and modify channel alignment. Subsequent air photograph runs in 1962, 1971, 1989 and 1994 show little change in geomorphic structure. This reach is now characterised by increased heterogeneity in its geomorphic unit assemblage (**Figure 5.7 F**). Channel infilling and narrowing continue to occur, producing a compound channel with a vegetated inset floodplain. Initially, a well-defined low flow channel develops. With time, the low flow channel will become locally swampy and mud will be retained on the channel bed. This is analogous to processes occurring today along Reedy Creek (**Figure 5.7 G**). There are signs that the channel bed is becoming discontinuous. Eventually this will instigate redevelopment of an intact swamp within the incised trench, reintroducing heterogeneity in bed material character and greater water retention, thereby maintaining the duration of base flows.

5.3.2.5 Evolution of the Low sinuosity sand bed River Style

The evolutionary development of the lowland plain rivers foccussed on the reach around Bega township at 'Grevillea', as documented by Brooks and Brierley (1997, 2000).

Portion plans dating from the 1850s and palaeochannel indicators (i.e. Casuarina lined channel margins) show that the pre-European settlement lowland plain of the Bega and Brogo Rivers was characterised by a deep, narrow channel with a series of pools and riffles (**Figure 5.8 A**; Brooks and Brierley, 1997, 2000). This was a mixed load system in which fine grained suspended load material was deposited on the floodplain during overbank events. The loading of wood was likely high, and riparian vegetation was dominated by *Casuarina cunninghami* and *Lomandra spp*. The floodplain consisted of an open woodland association, with backswamps dominated by *Melaleuca spp*. Given the relatively low channel capacity, transfer of water and organic matter to the floodplain was readily maintained. A low sinuosity fine grained River Style occurred along this lower end of the catchment.

Figure 5.8 Evolution of the Low sinuosity sand bed River Style



The lower course of the Bega River expanded from around 40 m wide to 140 m wide within a few decades of European settlement (**Figure 5.8 C**), essentially as a consequence of the removal of riparian vegetation. Photographs from the 1890s show a wide, shallow channel with a homogeneous sand sheet that is free of vegetation. The river has been transformed from a mixed load to a bedload dominated system. Pools have been infilled, and up to 2 m of sand has accumulated on floodplains previously dominated by silt (Brooks and Brierley, 1997). An irreversible change to a Low sinuosity sand bed River Style had occurred.

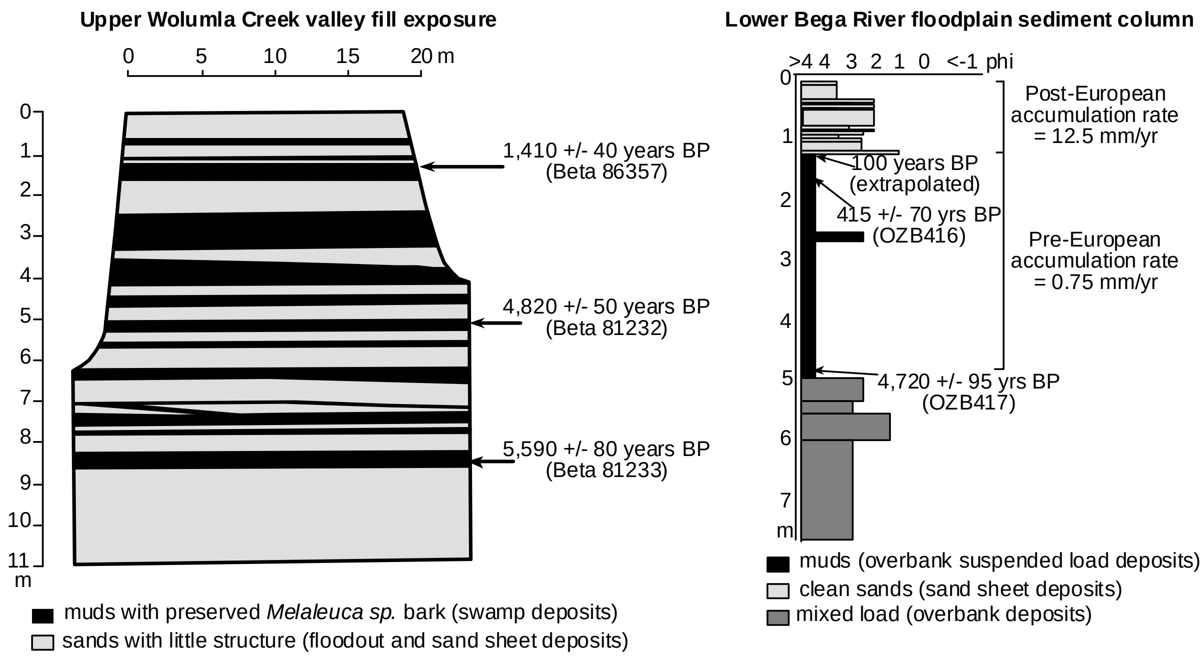
Detailed field investigations indicate that relatively little change to river structure occurred along the lower Bega River between 1920-1960 (Brooks and Brierley, 2000) (**Figure 5.8 D**). However, since the 1960s, willows and other forms of vegetation (native colonisers and exotics) have choked the channel. This has produced a complex pattern of channel-marginal benches, bars and islands. Channel contraction and the reworking of instream sediments (i.e. the formation of islands) have returned some structural heterogeneity to the channel (**Figure 5.8 F**).

Over time the geomorphic function of the lowland plain has changed. In its pre-disturbance state, this reach acted as a transfer zone (*sensu* Schumm, 1977), with limited rates of sediment flux. As the channel expanded, significant volumes of sediment were released. Subsequently, however, the lowland plain has stored large volumes of material derived from the upstream sediment slug (Fryirs and Brierley, 1998 b). As the tail of the sediment slug passes, it is considered likely that the lowland course of Bega River will be characterised by numerous narrow, deep channels in something akin to an anabranching pattern (**Figure 5.8 G**). As channels deepen, sand sheet inundation on the floodplain will be alleviated and the habitat potential and transfer of flow, organics and fine grained sediment to backswamps will be improved.

5.3.2.6 Summary findings about the evolution of rivers in Bega catchment

Various broad scale findings emerged from the catchment-wide appraisal of river evolution. Firstly, the preservation potential of alluvial sediments in Bega catchment has been relatively short (in geological terms). In only a few subcatchments were Pleistocene (assumed) or older materials locally preserved in terraces, fans and along the lowland plain (Nott et al., 1991). Other than the thick alluvial sequences noted along the lowland plain (Brooks and Brierley, 1997; Nott et al., 1991), the majority of sediments in the catchment are dated as Holocene in age. Valley fills and discontinuous floodplains at the base of the escarpment are <6,000 years old and <10,000 years old respectively (see Fryirs, 2002). With the exhaustion of these sediment stores, rates of geomorphic recovery that reflect re-filling of enlarged channels could be in the order of thousands of years (**Figure 5.9**).

Figure 5.9 The age of alluvial valley fill and floodplain sequences in upper Wolumla Creek and lower Bega River respectively (source: Fryirs and Brierley, 1998a; Brooks and Brierley, 1997).

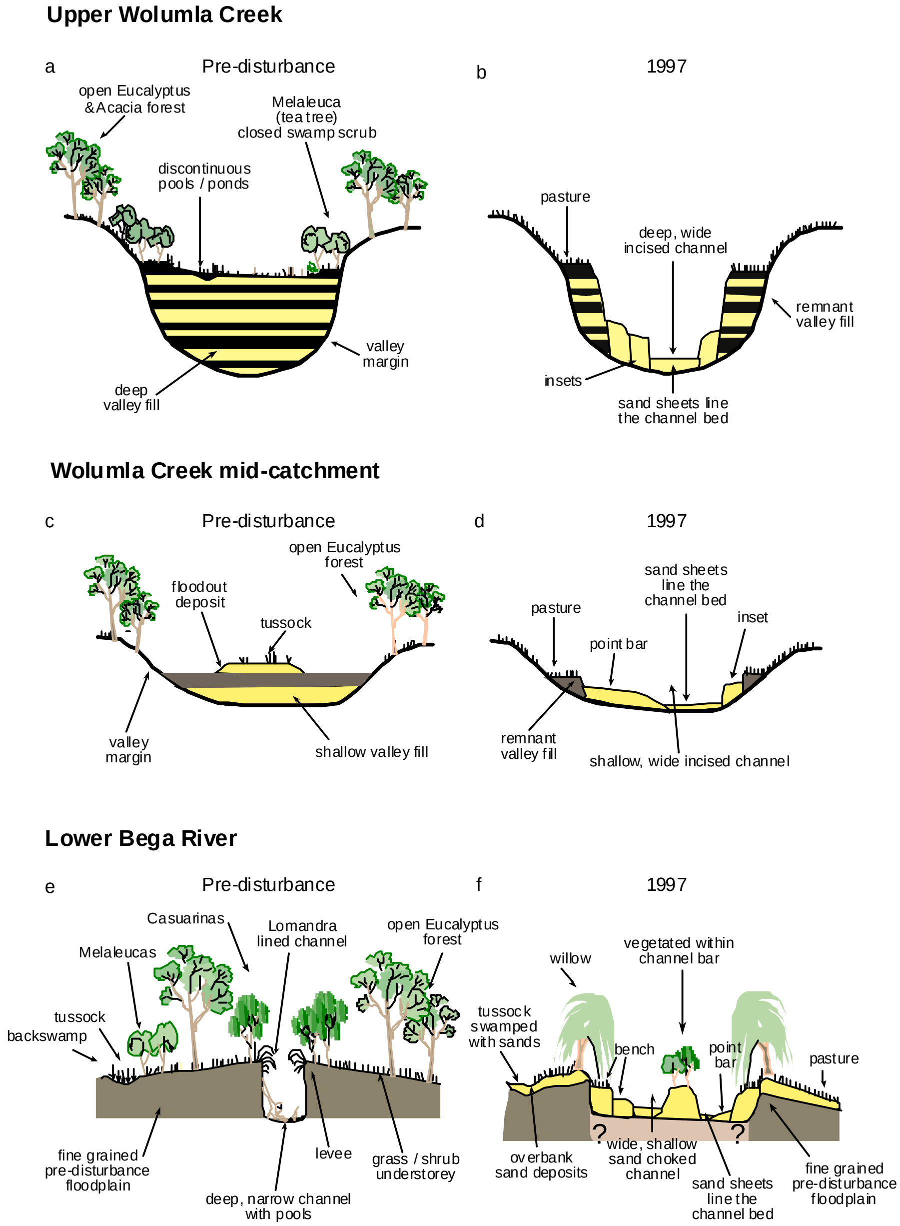


Secondly, significant diversity of geomorphic response to disturbance was noted for different River Styles, yet land use changes associated with European settlement were profound in all reaches other than those in the escarpment and uplands. While the type of direct human disturbance varied across the catchment (e.g. removal of riparian vegetation and wood along continuous watercourses, and drainage of swamps), reaches that are sensitive to disturbance have been irreversibly altered in virtually all instances. In reaches of those River Styles that are considered to be resilient to disturbance (e.g. Partly-confined valley with bedrock-controlled discontinuous floodplain River Style and Low sinuosity boulder bed River Style), changes evidenced are considered to be reversible.

Thirdly, the evolutionary sequences indicate that most river changes occurred within a few decades of European settlement. It has been estimated that over 40 % of all Holocene alluvial sediments have been removed, resulting in exhaustion of alluvial sediment stores across much of the catchment (Fryirs and Brierley, 2001). It has taken 100-150 years for signs of geomorphic river recovery to begin to appear in this system. The lags between disturbance and degradation were short and sharp, while the recovery process will be long and gradual. Catastrophic geomorphic adjustments along certain River Styles, particularly along the Channelised fill and Low sinuosity sand bed rivers, triggered a severe phase of degradation and off-site responses that have not been recorded at any other time in the Holocene (Brooks and Brierley, 1997; Fryirs, 2002; Fryirs and Brierley, 1998 a).

Fourthly, profound changes to catchment-wide longitudinal, lateral and vertical connections of geomorphic processes in the period pre- and post-European settlement have been recorded (see Brierley et al., 1999 for details). Prior to European settlement, longitudinal disconnection predominated with the prevalence of discontinuous watercourses and large alluvial sediment stores. The decoupled nature of the system ensured that geomorphic changes to flow and sediment regimes were damped throughout the catchment. Cumulative effects of geomorphic changes in one part of the catchment were not conveyed to the lowland plain (**Figure 5.10**).

Figure 5.10 Summary of evolutionary changes and cumulative impacts on the geomorphic structure of rivers in Bega catchment



Following European settlement, incision into discontinuous water courses increased the longitudinal connectivity of water and sediment transfer. These responses drove geomorphic change throughout the catchment with Confined and Partly-confined rivers acting as efficient conveyors of sediment and the lowland plain experiencing the cumulative impacts of disturbance.

At the time of European settlement, most tributary subcatchments comprised intact swamps at the base of the escarpment, extending to floodouts in middle reaches. These areas acted as large sediment sinks, effectively disconnecting downstream sediment cascades. Drainage lines in the rest of the catchment acted as transfer zones, flushing fine-grained materials to the estuary and offshore. By the 1890s, the lowland plain acted as a large sediment source zone, with channel expansion occurring as a direct result of riparian and floodplain vegetation removal. This lead to a decrease in the volume of material stored in the floodplain sink and an increase in the volume of material stored in the channel zone. At this time, the swamps at the base of the escarpment remained intact, and continued to act as accumulation zones.

By around 1900, deep incised trenches had formed in the swamps at the base of the escarpment, transforming these reaches into large sediment sources. This compounded change along the lowland plain. Sediments released from these swamps were progressively and effectively transferred through confined and partly-confined reaches in mid-catchment and deposited on the lowland plain. Some of this material was restored as sand sheets atop the floodplain sink, while the majority remained in the channel zone and is available for reworking. By 1926 the lowland plain channel had been transformed from a 40 m wide channel to around 150 m wide (Brooks and Brierley, 1997). The cascading effect of sediment release and transfer was strongly connected throughout the catchment.

Since 1944, the lowland plain has reverted to an accumulation zone that stores large volumes of material in the channel zone as a sediment slug. In the upper parts of the catchment, sediment has started to refill the incised trenches at the base of the escarpment, and several metres of sand have accumulated on the channel bed. Hence, these reaches have reverted to sediment accumulation zones. This results in weak linkages in the sediment cascade. However, the morphology and sedimentology of recent infilling by bedload deposits in these reaches differs notably from the swamp/floodout sequences that characterised the pre-disturbance valley fill. The post-1944 phase has been dominated by river recovery processes.

5.3.3 The (ir)reversibility of river changes in Bega catchment: Identifying natural reference conditions against which to assess the geomorphic condition of rivers

In this section, procedures developed to assess geomorphic river condition by Fryirs (2003) and Brierley and Fryirs (2005) are applied throughout Bega catchment. The evolutionary sequences of each River Style are used to determine if irreversible geomorphic change has occurred and to identify reference reaches (**Figure 3.8**).

Reference reaches are of the same River Style and operate under the same boundary conditions as the reach being examined. Given the degree of disturbance experienced by many rivers in Bega catchment, the pre-European settlement state is not always an appropriate reference against which to assess geomorphic condition and recovery potential because the boundary conditions have changed. Hence, three broad types of reference condition were identified in Bega catchment.

1. *Reaches where direct or indirect human disturbance has occurred resulting in irreversible geomorphic change.*

Irreversible geomorphic change was noted along the sensitive reaches of the lowland plain and base of the escarpment. Localised irreversible change also occurred where floodouts once occurred. Along the lowland plain, a transition from a Low sinuosity fine grained River Style in the late 1850s to a Low sinuosity sand bed River Style had occurred by 1890 (see **Figure 5.8**). At the base of the escarpment, eight of the ten reaches of the Intact valley fill River Style in the 1890s were transformed to a Channelised fill River Style by the 1900s (see **Figure 5.7**). In assessing contemporary geomorphic river condition for these incised valley fills, there is little to be gained in making direct comparisons with the 'intact' phase of their evolution. Hence, assessment of geomorphic condition is framed in relation to other variants of the 'cut' phase of activity for this type of river. In relation to the evolutionary sequence shown in **Figure 5.7**, this equates to Stage H. This 'future' extrapolation outlines a reference condition in which infilling of the incised trench is underway, instigating swamp development on valley floors. A future perspective is required because equivalent responses have yet to be attained in patterns of river adjustment recorded for this type of river in Bega catchment. In other words, no reach in the catchment has yet to fully adjust to the new set of boundary conditions, using the criteria presented in **Table 5.8**.

Immediately downstream of these swamps, Floodout reaches were transformed into Partly-confined valley with bedrock-controlled discontinuous floodplain River Styles (as found along Pattern 1 river courses, see Chapter 4 and **Figure 4.20**).

Mindful of the irreversible changes to the geomorphic structure of these river courses, appraisal of the contemporary geomorphic condition of reaches along the lowland plain and at the base of the escarpment/mid-catchment cannot be framed in terms of their pre-1900 condition. Hence, the geomorphic condition of these reaches is assessed relative to a reference reach of the contemporary River Style. Unfortunately, no reaches in the catchment can be used to define this reference condition. Hence, the evolutionary sequences are used to identify or predict the expected natural condition under the prevailing catchment boundary conditions for each of these River Styles. These circumstances are met by using **Stage G** of the evolutionary sequence for the Low sinuosity sand bed River Style (**Figure 5.8**). **Stage E** of the evolutionary sequence (**Figure 5.6**) was used to provide the reference condition for the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style. **Stage H** of the evolutionary sequence (**Figure 5.7**) was used to provide the natural reference condition for the Channelised fill River Style.

2. *Reaches where human disturbance has occurred, but geomorphic changes to river character and behaviour remain reversible.*

The Partly-confined valley with bedrock-controlled discontinuous floodplain and Confined valley with occasional floodplain pockets River Styles are resilient to change given their bedrock imposed character. **Figures 5.6** and **5.3** show that while geomorphic changes along these river courses have been significant, the changes that have occurred fall within the capacity for adjustment of the River Style (see Brierley and Fryirs, 2005). In other words, while the catchment boundary conditions under which these reaches operate have been fundamentally altered through removal of vegetation and changes to the sediment regime, a wholesale shift in the morphology of the river has not been recorded. Although the catchment boundary conditions under which these reaches operate have been fundamentally altered and the rate of sediment transfer has changed, geomorphic changes are considered to be reversible. Reference conditions for these types of river are available in the catchment. These reaches are used as benchmarks against which the geomorphic condition of other reaches is assessed. Reaches that demonstrate the expected character and behaviour that fit the selection criteria in **Tables 5.6** and **5.5** have been identified along Upper Tantawangalo Creek (**Stage E**, **Figure 5.6**) and along Bemboka River (**Stage B**, **Figure 5.3**).

3. *Remnant reaches that have been minimally disturbed by humans, such that geomorphic changes to river character and behaviour remain reversible.*

Gorge and Steep headwater River Styles are the only rivers in Bega catchment that operate under relatively undisturbed boundary conditions. These River Styles are located in the escarpment zone and uplands areas of the catchment and are largely contained within the South-East Forests National Park. In these reaches, the flow and sediment regimes, and vegetation associations, remain largely unchanged from pre-European settlement times. **Figure 5.2** shows that geomorphic changes have been negligible over the last 150 years and hence these rivers still operate within the capacity for adjustment of the original River Style.

The Intact valley fill, Floodout and Low sinuosity boulder bed River Styles also retain evidence from pre-disturbance river conditions in the catchment. As discussed previously, many river courses contained intact valley fills and swamps at the time of European settlement. Similarly, fan-like boulder rivers extended from the base of the escarpment along Bemboka River. These rivers have experienced limited alteration to their geomorphic structure and function, operating as they did prior to European settlement. Hence, a pre-disturbance reference condition is also appropriate for these reaches (**Figure 5.2**).

5.4 Stage Two, Step Three: Interpret and explain the geomorphic condition of rivers in Bega catchment

5.4.1 Construct tables that ask questions about the 'desirability' criteria used to assess river character and behaviour of each reach based and 'relevant geoindicators' for each River Style

Using the table of relevant geoindicators for each River Style (**Table 5.2**), a series of desirability questions has been developed for each River Style in Bega catchment. Each table asks specific questions about the 'appropriateness' of each geoindicator for each River Style. Given the (ir)relevance of each geoindicator to different River Styles, specific tables are presented for each River Style (**Tables 5.3-5.10**). These tables are used to determine the geomorphic condition of each reach of each River Style.

Building on procedures outlined in Brierley and Fryirs (2005), the geoindicators measured for each River Style in Bega catchment, and the selection criteria for assessing good condition reaches in Bega catchment, are outlined in **Tables 5.3 – 5.10**. The explanation and interpretation of the geomorphic condition of each reach in the catchment is documented in **Tables 5.13 – 5.25**. These tables provide a benchmark against which to interpret whether river recovery has taken place, marking an improvement in river condition.

Table 5.3 Measures used to assess good condition reaches of the Steep headwater River Style in Bega catchment (Confined valley-setting)

Degrees of freedom and relevant geoindicators	Questions to ask for each reach of the River Style	Questions that must be answered YES
Channel attributes • Instream vegetation structure • wood loading	• Is there a large volume of wood and/or potential for wood recruitment? (woody debris is common as the core of islands and bars and induces step-pool complexes) • Is the instream vegetation structure appropriate?	1 out of 2
Channel planform • Assemblage of geomorphic units • Riparian vegetation	• Is the assemblage, pattern and condition of instream geomorphic units appropriate for the River Style? Are key units present? (i.e. does the reach have lateral and mid-channel bars, runs, cascades, islands, glides, pools with no signs of deterioration such as infilled pools and sand sheet deposition? • Is vegetation continuity and composition of the riparian zone near-natural for the River Style with few exotics?	1 out of 2
Bed character • Grain size and sorting • Hydraulic diversity • Sediment regime	• Is the grain size, sorting and organisation of materials in different geomorphic units appropriate for the River Style? (i.e. are sands in bars, gravels in runs and glides, organics and fine-grained materails in pools and bedrock cascades?) • Is there a wide range of roughness characteristics and hydraulic diversity along the reach? • Is the sediment storage/transport function of the reach appropriate for the River Style and its catchment position (these reaches should act as sediment source or transfer zones)	2 out of 3

Table 5.4 Measures used to assess good condition reaches of the Gorge River Style in Bega catchment (Confined valley-setting)

Degrees of freedom and relevant geoindicators	Questions to ask for each reach of the River Style	Questions that must be answered YES
Channel attributes • Instream vegetation structure • wood loading	• Is the instream vegetation structure appropriate? • Is there occasional wood and/or potential for wood recruitment? (wood is common as the forcing agent in step-pool sequences)	1 out of 2
Channel planform • Assemblage of geomorphic units • Riparian vegetation	• Is the assemblage, pattern and condition of instream geomorphic units appropriate for the River Style? Are key units present? (i.e. does the reach have bedrock induced pools and runs separated by waterfalls with no signs of deterioration such as infilled pools and sand sheet deposition) • Is vegetation continuity and composition of the riparian zone near-natural for the River Style with few exotics?	1 out of 2
Bed character • Grain size and sorting • Hydraulic diversity • Sediment regime	• Is the grain size, sorting and organisation of materials in different geomorphic units appropriate for the River Style? (i.e. is the reach dominated by bedrock and large boulders?) • Is there a wide range of roughness characteristics and hydraulic diversity along the reach? • Is the sediment storage/transport function of the reach appropriate for the River Style and its catchment position (i.e. is it a sediment transfer zone?)	2 out of 3

Table 5.5 Measures used to assess good condition reaches of the Confined valley with occasional floodplain pockets River Style in Bega catchment

Degrees of freedom and relevant geoindicators	**Questions to ask for each reach of the River Style**	**Questions that must be answered YES**
Channel attributes • Shape • Bank morphology • Instream vegetation structure • wood loading	• Is channel shape appropriate along the reach (i.e. are banks irregular along bedrock-controlled sections and stepped where floodplains occur?) • Are banks eroding in the right places and at the right rate? (i.e. with no signs of channel expansion?) • Is there wood around islands and/or potential for wood recruitment? (wood often induces island development and acts as a forcing agent for pool-run development) • Is the instream vegetation structure appropriate?	3 out of 4
Channel planform • Assemblage of geomorphic units • Riparian vegetation	• Is the assemblage, pattern and condition of instream and floodplain geomorphic units appropriate for the River Style? Are key units present? (i.e. does the reach have bedrock induced pools and runs with well vegetated islands and bedrock outcrops with no signs of deterioration such as infilled pools or extensive sand sheets covering the channel bed)? • Is vegetation continuity and composition of the riparian zone near-natural for the River Style with few exotics?	1 out of 2
Bed character • Grain size and sorting • Hydraulic diversity • Sediment regime	• Is the grain size, sorting and organisation of materials in different geomorphic units appropriate for the River Style? (i.e. does the reach have a mix of exposed bedrock outcrops and bedrock pools, sandy islands, fine grained materials in pools and on islands, and occasional gravels in runs?) • Is there a wide range of roughness characteristics and hydraulic diversity along the reach? • Is the sediment storage/transport function of the reach appropriate for the River Style and its catchment position (i.e. do these reaches act as sediment throughput zones with localised sediment storage in islands?)	2 out of 3

Table 5.6 Measures used to assess good condition reaches of the Partly-confined valley with bedrock controlled discontinuous floodplain River Style in Bega catchment

Degrees of freedom and relevant geoindicators	**Questions to ask for each reach of the River Style**	**Questions that must be answered YES**
Channel attributes • Size • Shape • Bank morphology • Instream vegetation structure • wood loading	• Is channel size appropriate given the catchment area, the prevailing sediment regime and the vegetation character? Is the channel functionally connected to the floodplain pockets? (i.e. is the channel overwidened, overdeepened or does it have an appropriate width:depth?) • Is channel shape appropriate along the reach (i.e. does it have symmetrical or compound inflection points and asymmetrical bends)? • Are banks eroding in the right places and at the right rate? (concave bank erosion is a natural process along these rivers) • Is there wood in the channel and/or potential for wood recruitment? (these reaches often have wood induced pools on bends) • Is the instream vegetation structure appropriate?	4 out of 5
Channel planform • Lateral channel stability • Assemblage of geomorphic units • Riparian vegetation	• Is the channel positioned correctly on the valley floor and the lateral stability of the channel appropriate given the texture and slope of the reach? (signs of instability include channel expansion and accelerated rates of concave bank erosion?) • Is the assemblage, pattern and condition of instream and floodplain geomorphic units appropriate for the River Style? Are key units present? (i.e. are there instream point benches, point bars, pools, riffles and island complexes, and floodplain floodrunners with no signs of deterioration such as floodplain stripping and/or sand sheet deposition?) • Is the continuity and composition of the riparian zone near-natural for the River Style with few exotics?	2 out of 3
Bed character • Grain size and sorting • Bed stability • Hydraulic diversity • Sediment regime	• Is the grain size, sorting and organisation of materials in different geomorphic units appropriate for the River Style? (i.e. is there a mix of sands in point bars and islands, occasional gravels and organics in the pools and fine sands on the floodplain?) • Is bed stability appropriate? (Signs of bed instability or disturbance will include incision along inflection points between bends and formation of an homogenous bed morphology) • Are roughness characteristics and the pattern of hydraulic diversity along the reach appropriate for the River Style? • Is the sediment storage/transport function of the reach appropriate for the River Style and its catchment position (i.e. is it a sediment transfer zone where inputs and outputs of sediment are balanced over time via movement of material from point bar to point bar?)	3 out of 4

Table 5.7 Measures used to assess good condition reaches of the Intact valley fill and Floodout River Styles in Bega catchment (Laterally-unconfined valley-setting with discontinuous channel)

Degrees of freedom and relevant geoindicators	Questions to ask for each reach of the River Style	Questions that must be answered YES
Channel attributes • Instream vegetation structure	• Is swamp and aquatic vegetation composition and/or coverage on the valley fill surface appropriate?	1 out of 1
Channel planform • Assemblage of geomorphic units • Riparian vegetation	• Is the assemblage and pattern of geomorphic units appropriate for the River Style? Are key units present? (i.e. are there swamps, sand lobes and occasional ponds with no signs of deterioration such as sand sheets covering the entire valley floor or development of discontinuous channels in the swamp?) • Is vegetation continuity along the swamp margins near-natural for the River Style with few exotics?	1 out of 2
Bed character • Grain size and sorting • Bed stability • Sediment regime	• Is the grain size and sorting of the floodout/valley fill material appropriate for the River Style? (i.e. are there muds in the swamps and ponds and sands in floodout lobes?) • Is valley fill stability appropriate? (Signs of instability or disturbance may include incision, headcut retreat, or enlargement of ponds) • Is the sediment storage/transport function of the reach appropriate for the River Style and its catchment position (i.e. is it a sediment accumulation zone?)	2 out of 3

Table 5.8 Measures used to assess good condition reaches of the Channelised fill River Style in Bega catchment (Laterally-unconfined valley-setting with continuous channel)

Degrees of freedom and relevant geoindicators	Questions to ask for each reach of the River Style	Questions that must be answered YES
Channel attributes • Size • Shape • Bank morphology • Instream vegetation structure	• Is channel size appropriate given the catchment area, the prevailing sediment regime and the vegetation character? (i.e. is the channel overwidened, overdeepened or does it have an appropriate width:depth?) • Is channel shape appropriate along the reach? (i.e. is the channel compound in shape with a series of inset surfaces within a symmetrical trench?) • Are banks eroding in the right places and at the right rate? (signs of deterioration include vertical or undercut banks along the length of the reach) • Is the instream vegetation structure appropriate? (i.e. is aquatic vegetation colonising the bed of the incised channel?)	3 out of 4
Channel planform • Lateral channel stability • Assemblage of geomorphic units • Riparian vegetation	• Is the lateral stability of the channel appropriate given the texture and slope of the reach? (signs of deterioration include channel expansion and low flow channel reworking of bed materials) • Is the assemblage, pattern and condition of instream and floodplain geomorphic units appropriate for the River Style? Are key units present? (i.e. does the reach have a series of insets and a swampy channel bed with no signs of reworking such as dissection, stripping or undercutting etc.) • Is the continuity and composition of the riparian zone near-natural for the River Style with few exotics?	2 out of 3
Bed character • Grain size and sorting • Bed stability • Hydraulic diversity • Sediment regime	• Is the grain size, sorting and organisation of materials in different geomorphic units appropriate for the River Style? (i.e. are sands stored in insets, and mud and organic matter stored on the channel bed?) • Is bed stability appropriate? (signs of bed instability or disturbance will include incision into sands or to bedrock) • Is the sediment storage/transport function of the reach appropriate for the River Style and its catchment position? (i.e. is it acting as a sediment accumulation zone?) • Are roughness characteristics and the pattern of hydraulic diversity along the reach appropriate for the River Style? (i.e. does the reach have a swampy channel bed with a series of inset bench features?)	3 out of 4

Table 5.9 Measures used to assess good condition reaches of the Low sinuosity boulder bed River Style in Bega catchment (Laterally-unconfined valley-setting with continuous channel)

Degrees of freedom and relevant geoindicators	Questions to ask for each reach of the River Style	Questions that must be answered YES
Channel attributes • Shape • Instream vegetation structure • wood loading	• Is channel shape appropriate along the reach? (i.e. is it irregular?) • Is there wood in the channel and/or potential for wood recruitment? (these reaches often have wood induced pools at the core of islands and spanning low flow stringers) • Is the instream vegetation structure appropriate on islands?	2 out of 3
Channel planform • Number of channels • Assemblage of geomorphic units • Riparian vegetation	• Does the reach have the right number of channels positioned correctly on the valley floor? (a multitude of low flow stringers should flow around boulder islands) • Is the assemblage, pattern and condition of instream and floodplain geomorphic units appropriate for the River Style? Are key units present? (i.e. does the reach have a mosaic of boulder islands, cascades, steps, runs and bedrock-induced pools and are there signs of tributary shifting over the surface of the floodplain?) • Is the continuity and composition of the riparian zone near-natural for the River Style with few exotics?	2 out of 3
Bed character • Grain size and sortingorting • Bed stability • Hydraulic diversity • Sediment regime	• Is the grain size, sorting and organisation of materials in different geomorphic units appropriate for the River Style? (i.e. boulders in islands and the floodplain and bedrock induced pools and cascades) • Is bed stability appropriate? (Signs of bed instability or disturbance will include incision into boulder materials and reworking of materials on the channel bed) • Is there high hydraulic roughness and diversity along the reach? • Is the sediment storage/transport function of the reach appropriate for the River Style and its catchment position (i.e. is it a sediment transfer zone?)	3 out of 4

Table 5.10 Measures used to assess good condition reaches of the Low sinuosity sand bed River Style in Bega catchment (Laterally-unconfined valley-setting with continuous channel)

Degrees of freedom and relevant geoindicators	Questions to ask for each reach of the River Style	Questions that must be answered YES
Channel attributes • Size • Shape • Bank morphology • Instream vegetation structure • wood loading	• Is channel size appropriate given the catchment area, the prevailing sediment regime and the vegetation character such that the channel and floodplain are functionally connected? (i.e. is the channel overwidened, overdeepened, or does it have an appropriate width:depth?) • Is channel shape appropriate along the reach? (i.e. compound or irregular) • Are banks eroding in the right places and at the right rate? • Is there wood in the channel and/or potential for wood recruitment? (wood induced pools may be evident) • Is the instream vegetation structure appropriate?	4 out of 5
Channel planform • Number of channels • Sinuosity of channels • Lateral channel stability • Assemblage of geomorphic units • Riparian vegetation	• Does the reach have the right number of channels positioned correctly on the valley floor? (Signs of change may include the formation of avulsive networks or floodchannels on the floodplain) • Is the sinuosity of the channel appropriate given the texture and slope of the reach? • Is the lateral stability of the channel appropriate given the texture and slope of the reach? (signs of degradation include channel expansion and low flow channel reworking of bed materials) • Is the assemblage, pattern and condition of instream and floodplain geomorphic units appropriate for the River Style? Are key units present? (i.e. does the reach have islands, benches, levees, backswamps?) • Is the continuity and composition of the riparian zone near-natural for the River Style with few exotics?	4 out of 5
Bed character • Grain size and sorting • Bed stability • Hydraulic diversity • Sediment regime	• Is the grain size, sorting and organisation of materials in different geomorphic units appropriate for the River Style? (i.e. are there sands and organics in the channel, fine-grained materials on the floodplain and muds in backswamps?) • Is bed stability appropriate? (Signs of bed instability or disturbance may include incision into sand bed materials) • Are roughness characteristics and the pattern of hydraulic diversity along the reach appropriate for the River Style? • Is the sediment storage/transport function of the reach appropriate for the River Style and its catchment position (i.e. is it a sediment transfer or accumulation zone?)	3 out of 4

5.4.2 The geomorphic condition of reaches in Bega catchment.

Using the set of questions developed for each River Style (**Tables 5.3-5.10**), and the condition matrix (**Table 3.3**), the geomorphic condition of each reach of each River Style in Bega catchment was assessed. An example of how the condition of reaches of the Confined valley with occasional floodplain pockets River Style was assessed appears in **Table 5.11**. Each of the relevant geoindicators (**Table 5.2**) was measured or interpreted (**Table 3.1**) and a table constructed that summarises and explains the character and behaviour of good, moderate and poor condition reaches of each River Style (T**ables 5.12 – 5.24)**.

Table 5.11 Assessing the condition of three reaches of the Confined valley with occasional floodplain pockets River Style in Bega catchment using relevant geoindicators and answering the desirability criteria

Degree of freedom/ Geoindicator	Good condition reach	Moderate condition reach	Poor condition reach
	 (52) Lower Bemboka River	 (51) Middle Bemboka River	 (42) Lower Sandy Creek
Channel attributes	**3 out of 4 = √**	**3 out of 4 = √**	**0 out of 4 = X**
Shape	YES	YES	NO
Bank morphology	YES	YES	NO
Instream vegetation structure	YES	YES	NO
Wood loading	NO	NO	NO
River planform	**1 out of 2 = √**	**1 out of 2 = √**	**0 out of 2 = X**
Geomorphic unit assemblage	YES	YES	NO
Riparian vegetation	NO	NO	NO
Bed character	**3 out of 3 = √**	**1 out of 3 = X**	**0 out of 3 = X**
Grain size and sorting	YES	NO	NO
Hydraulic diversity	YES	YES	NO
Sediment regime	YES	NO	NO

5.4.2.1 Geomorphic condition of the Steep headwater and Gorge reaches

All reaches of the Steep headwater, Gorge and Low sinuosity boulder bed River Styles are located in the uplands and escarpment country of the South-East Forests National Park. Given their confined valley-setting and the calibre of the bedload (boulders and bedrock), they are resilient to change. At the scale of resolution applied in this study, all reaches of these River Styles are considered to be in good geomorphic condition. The desirability criteria in **Tables 5.3** and **5.4** were used to explain the geomorphic condition of these reaches (**Tables 5.12** and **5.12**).

Table 5.12 Explaining the geomorphic condition of reaches of the Steep headwater River Style

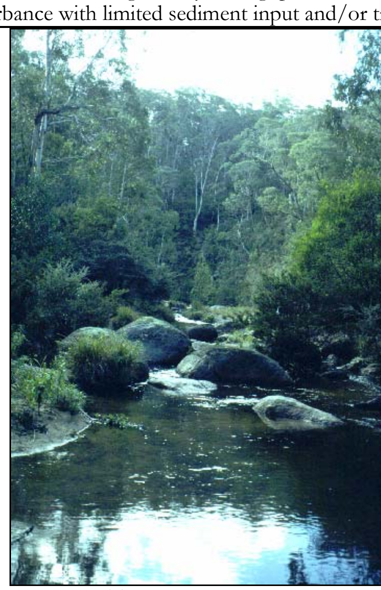
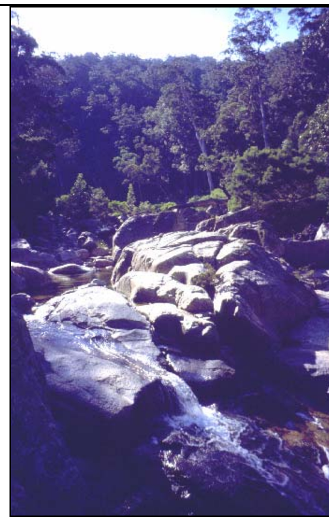
	Good condition
Channel attributes	Low width:depth channels. Pronounced cross-sectional variability may be evident in response to local bed and bank geomorphic units, wood loading, and instream vegetation. Channel is irregular in cross-sectional form. Lomandra lined channel and pools. High wood loading; individual pieces commonly cross the channel.
Channel planform	Other than small reaches with local instream vegetation, these reaches are single-channeled, confined and laterally stable. Diverse range of geomorphic units with pronounced intra-reach variability in response to valley slope, width, instream vegetation, wood loading, etc. Gradient-induced patterns may be observed, from waterfalls through steps, cascades, rapids, pool-riffle and glide sequences with progressively decreasing gradient. Other units may include: discontinuous pockets of floodplain, point bars, mid channel bars, glides, cascades, pools, riffles and islands. Intact, continuous riparian strip colonised by native vegetation.
Bed character	Typically these are boulder streams, but bedrock is common. Wider sections of the channel may have texturally well-segregated gravel bars. Although fine-grained materials are generally flushed, debris dams may promote localised sand and mud sedimentation. Significant local heterogeneity in the roughness characteristics of the reach result from textural as well as wood controls. Gravels are stored in instream geomorphic units, while sands and mud are generally throughput. These reaches are relatively resilient to disturbance with limited sediment input and/or transfer.
Photograph	 Tantawangalo Creek

Table 5.13 Explaining the geomorphic condition of reaches of the Gorge River Style

Degree of freedom	Good condition
Channel attributes	Extensive bedrock outcrops produce an irregular channel shape, set within a v-shaped valley with steep sidewalls. wood commonly spans the channel. Occasional log jams possible.
Channel planform	Confined valley setting in which the channel abuts the valley margin along the length of the river. Channel configuration dictated by alignment of the bedrock valley. Single-channeled and laterally stable. Alternating waterfall-cascades-rapid sequences with bedrock induced pools and glides. May have localised sediment drapes. No floodplain. Continuous riparian strip consisting of native species in an open forest association. Localised exotic weed incursions.
Bed character	Bedrock is dominant, though some segments are boulder streams. Occasional gravel bars are retained within the gorge, but sand and mud are typically flushed downstream. Transient sediment drapes may occur in local gently sloped sections of the reach. Bed organisation reflects high energy setting. Hydraulically diverse.
Photograph	 Tantawangalo Creek

5.4.2.2 Geomorphic condition of Intact valley fill, floodout and Low sinuosity boulder bed reaches

Given their pre-disturbance character and behaviour, reaches of the Intact valley fill, Floodout and Low sinuosity boulder bed River Styles are considered to be in good geomorphic condition. Only 2 reaches of the Intact valley fill River Style, and one reach of both the Floodout and Low sinuosity boulder bed River Styles, remain in Bega catchment. The desirability criteria in **Tables 5.7** and **5.9** were used to explain the geomorphic condition these reaches (**Tables 5.14 - 5.16**).

Table 5.14 Explaining the geomorphic condition of reaches of the Intact valley fill River Style

	Good condition
Channel attributes	Absent channel. Swamp covered with a dense aquatic vegetation association dominated by a *Juncus spp.* and tussock with few exotics. No wood input.
Channel planform	Simple geomorphic structure. Relatively simple geomorphic structure with intact swamp covering entire valley floor. Good coverage of *Melaleuca spp.* in the riparian zone.
Bed character	Mud-dominated, with occasional sand sheets deposited from floodouts. Downstream gradation in sediment sorting. Hydraulic diversity is low. Zone of sediment accumulation atop valley floor. Acts as a sediment sink in the catchment.
Photograph	 Frogs Hollow Creek

Table 5.15 Explaining the geomorphic condition of reaches of the Floodout River Style

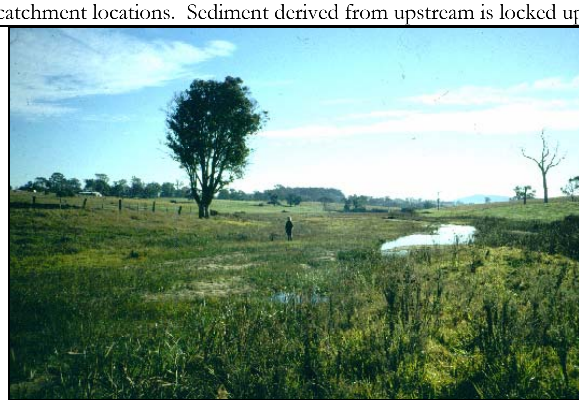
	Good condition
Channel attributes	Discontinuous channel. Swamp covered with an aquatic vegetation association dominated by *Juncus* sp. and tussock with few exotics. No wood input.
Channel planform	Discontinuous channel, floods out over intact valley fill. Localised sand sheets downstream from discontinuous gullies grade into a seepage zone. Occasional pools and remnant shallow channel courses may be evident. Riparian zone consist of *Melaleuca spp.* and tussock grasses.
Bed character	Sand deposition in sheets and floodouts downstream of discontinuous gullies. If vegetated, mud is deposited as flow energy is dissipated over the valley floor. Hydraulic diversity is low. Acts as a sediment sink in mid-catchment locations. Sediment derived from upstream is locked up in valley fills.
Photograph	 Frogs Hollow Creek

Table 5.16 Explaining the geomorphic condition of reaches of the Low sinuosity boulder bed River Style

	Good condition
Channel attributes	Channel relatively wide and shallow. Highly irregular cross-sectional form, with flow around large boulders and islands. Locally symmetrical, wherever the channel can more readily deform its morphology. Islands are well-vegetated with native species and wood jams locally occur around islands and boulders. wood may span low-flow stringers.
Channel planform	Lobes of boulder and gravel material have been deposited over the valley floor. Multiple low flow channels occur around large vegetated islands. Given the boulder morphology lateral stability is high. The primary incised channel has a heterogeneous assemblage of bedrock and boulder induced geomorphic units. Fans, mid channel bars, pools, riffles, cascades, occasional bedrock steps and waterfalls occur. A continuous riparian strip consists of a mix of exotic and native riparian and within-channel species.
Bed character	Well-segregated material mix, with discrete pockets of material of different texture. Smaller boulder materials are retained in geomorphic units such as islands. Coarse boulders and bedrock form steps and waterfalls. Fine sand and gravel are flushed through the reach. Hydraulic diversity is high given the material mix and the instream vegetation structure and loading of wood. Sediment is transferred efficiently through the reach.
Photograph	 Bemboka River

5.4.2.3 Geomorphic condition of Channelised fill reaches

The desirability criteria in **Table 5.8** were used for each reach of the Channelised fill River Style. Given their highly disturbed nature and their high sensitivity to disturbance, most reaches of this River Style are in moderate or poor geomorphic condition.

Only one good condition reach of this River Style occurs in Bega catchment, along Reedy Creek. Here, the incised, compound channel has started to infill, with extensive volumes of sand. Mud and organic matter are being retained on the swampy bed, with scattered vegetation lining the inset features.

Five moderate and two poor condition reaches of this River Style were identified in Bega catchment (**Table 5.17**). Large volumes of material have been removed from incised, overwidened channels along moderate and poor condition reaches (**Table 5.18**). The shift between poor and moderate condition reaches occurs when the reach becomes sediment transport limited and large volumes of material are stored on the channel bed. Moderate condition reaches are characterised by instream sand sheets and inset features with a well-defined low flow channel. Localised bank erosion and slumping occurs. Poor condition reaches are characterised by an enlarged trench through which large volumes of material are flushed. Material retention on the channel bed is limited with homogenous sand sheets dominating. Riparian vegetation is absent.

Table 5.17 The geomorphic condition of reaches of the Channelised fill River Style

Reach number and name (**Fig 3.3**)	Channel attributes	Channel planform	Bed character	Geomorphic condition
(28) Reedy	√	√	√	Good
(15) Wolumla	**X**	√	**X**	Moderate
(39) Sandy	**X**	√	**X**	Moderate
(2) Greendale	√	√	**X**	Moderate
(44) Colombo	√	√	**X**	Moderate
(59) Pollacks Flat	√	**X**	√	Moderate
(12) South Wolumla	**X**	**X**	**X**	Poor
(62) Numbugga	**X**	**X**	**X**	Poor

Table 5.18 Explaining the geomorphic condition of reaches of the Channelised fill River Style

Degree of freedom	Good condition	Moderate condition	Poor condition
Channel attributes	Compound, stepped cross-sectional form within a wide, deep incised trench. Bank erosion minimal. Channel bed dominated by aquatic swamp vegetation and tussock grasses. Insets colonised by some hardy vegetation including Melaleucas.	Compound, stepped cross-sectional form within a wide, deep, incised trench. Localised bank erosion and slumping occurs. Inset units colonised by some hardy vegetation. Occasional tussock grasses on sand bars and along the low flow channel.	Large, symmetrical, overwidened incised trench. Near vertical, exposed banks with significant erosion along the entire reach. Within-channel units are unvegetated.
Channel planform	No lateral adjustment of incised trench. Swamps and a poorly-defined or discontinuous channel characterise the channel bed. Multiple inset features line the channel margin. Increased within-channel sedimentation may promote re-connection of channel and floodplain processes. Scattered riparian strip. Valley fill surfaces are dominated by tussock.	Limited planform adjustment of incised trench. Inset bench features occur along channel banks. Well-defined low flow channels shifts over trench floor reworking sand sheets and bars. Floodplain perched above low flow channel, disconnecting channel from floodplain processes. Little or no riparian strip. Valley fill surfaces are dominated by pasture.	Incised trench experiencing accelerated rates of lateral expansion and bed lowering (incision). Multiple low flow stringers atop sand sheet produce an array of mid-channel and lateral bars. Floodplain disconnected from the channel given the incised nature of the fill. No riparian strip. Valley fill surfaces are dominated by pasture.
Bed character	Segregated sediment mix, with sands in inset units and benches, and mud and organic matter accumulation on the trench floor. Bed stable and aggrading in sediment accumulation reaches.	Moderately segregated sediment mix, with coarse sands in insets and benches, and finer sand in the low flow channel. Low flow channel redistributes and reorganises sediment locally within the incised trench, improving bed material organisation. Moderate bed stability as trench infills. Sand accumulating on the channel bed. Acts as a sediment accumulation or transfer zone.	Bedload dominated with limited capacity to retain finer grained materials. Still releasing sediment from valley fill. Sediment on the channel bed is loose, poorly segregated and poorly sorted. Poor bed stability. Bed may still be incising. High rates of material reworking and sediment transport. Acts as a sediment source zone.
Photograph	 (28) Reedy Creek	 (15) Wolumla Creek	 Anderson Creek (Wolumla tributary)

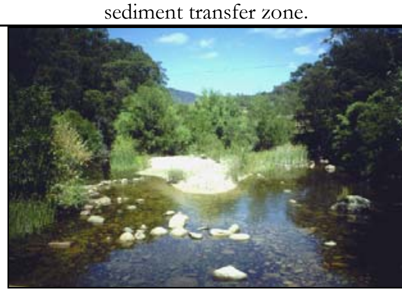
5.4.2.4 Geomorphic condition of the Partly-confined valley with bedrock-controlled with discontinuous floodplain reaches

Given their mid-catchment locations, most reaches of this River Style have experienced off-site impacts associated with large sediment releases from Channelised fill River Styles. Hence, all reaches of the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style that sit downstream of a Channelised fill River Style are in poor geomorphic condition. Those reaches that sit downstream of other River Styles, or which sit higher in the catchment where upstream reaches are minimally impacted, tend to be in moderate or good geomorphic condition. **Table 5.19** outlines the reaches with different geomorphic condition in Bega catchment and **Table 5.20** explains the condition of these reaches.

Table 5.19 The geomorphic condition of reaches of the Partly-confined valley with bedrock-controlled with discontinuous floodplain River Style

Reach name and number (**Fig 3.3**)	Channel attributes	Channel planform	Bed character	Geomorphic condition
(32) Upper Tantawangalo	√	√	√	Good
(69) House	√	√	√	Good
(65) Double	√	√	√	Good
(23) Upper Candelo	√	**X**	**X**	Moderate
(26) Lower Candelo	**X**	√	**X**	Moderate
(36) Middle Tantawangalo	**X**	√	√	Moderate
(45) Colombo	**X**	**X**	**X**	Poor
(29) Reedy	**X**	**X**	**X**	Poor
(3) Greendale	**X**	**X**	**X**	Poor
(13) South Wolumla	**X**	**X**	**X**	Poor
(41) Sandy	**X**	**X**	**X**	Poor
(16) Wolumla	**X**	**X**	**X**	Poor

Table 5.20 Explaining the geomorphic condition of reaches of the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style

Degree of freedom	Good condition	Moderate condition	Poor condition
Channel attributes	Channel has a relatively low width:depth, with significant local variability induced by bedrock outcropping, vegetation and wood. Natural or low rate of erosion of concave banks. Cross-sectional form is asymmetrical on bends and irregular at inflection points. Islands and bars are vegetated with hardy shrubs and aquatic grasses.	Channel has a high width:depth. Asymmetrical-compound on bend apexes. Symmetrical at inflection points. Localised erosion of concave banks. The channel has expanded along the length of the reach, including at inflection points. Point bars and benches remain largely unvegetated or dominated by exotics. No wood.	Channel has a high width:depth. The channel is overwidened along the reach, including at inflection points. Asymmetrical shape on bend apexes, symmetrical shape at inflection points. Accelerated rates of concave bank erosion and channel expansion along the entire reach. No within-channel vegetation or wood.
Channel planform	Low sinuosity, single channel within a meandering valley alignment. Moderate lateral stability is natural for this river. Occasional bedrock outcrops, division of flow around islands and bank-attached bars and sand sheets. Bar-island-riffle complexes are separated by pools. Occasional bank attached bars and sand sheets. Point bars and point benches occur on bends. Discontinuous pockets of floodplain may be scoured around large trees and shrubs. Continuous or scattered riparian corridor consists mainly of natives. Banks are lined with *Lomandra spp.*. Point bars are colonised by tussock. Some hardy shrubs on benches.	Low sinuosity, single channel within a meandering valley alignment. Laterally unstable on concave banks. Point benches, point bars, concave benches, localised sand sheets, well defined low flow channel. Occasional bedrock outcrops. Discontinuous pockets of floodplain either scoured or stripped. Poor riparian vegetation cover. Floodplain dominated by pasture.	Low sinuosity, single channel within a meandering valley alignment. Laterally unstable at concave banks and inflection points reflecting channel expansion. Point bars, sand sheets with localised bedrock outcrops, multi-stringed low flow channel. Discontinuous pockets of floodplain either stripped, characterised by short cutting floodchannels or comprise extensive sand sheets. No riparian vegetation. Floodplain dominated by pasture.
Bed character	Well-segregated bedload, with discrete pockets of material of different texture. Some gravel deposits in riffles, bars and benches comprise sands, with fine grained floodplain. Organic matter accumulation is high in pools and on the floodplain. Bed is stable with no signs of incision or aggradation. High instream roughness (vegetation and wood) promote localised deposition of fine grained materials and organics. Balance maintained between sediment input and output along the reach. Acts as a sediment transfer zone.	Poorly sorted material distribution. Sand sheets present local homogeneity, reducing roughness and the range of hydraulic diversity. Bed is unstable with significant material movement occurring. A balance is maintained between sediment input and output along the reach. Acts as a sediment transfer zone.	Near homogenous sand sheet. Sediment stored as homogenous instream and floodplain sand sheets with a poorly sorted material distribution. Bed is unstable with significant aggradation and/or incision. Hydraulically homogeneous. Reach is sediment transport limited and acts as an accumulation zone.
Photograph	 (32) Upper Tantawangalo Creek	 (26) Candelo Creek	 (16) Wolumla Creek

5.4.2.5 Geomorphic condition of the Confined valley with occasional floodplain pockets reaches

Like other mid-catchment River Styles, reaches of the Confined valley with occasional floodplain pockets River Style are influenced significantly by off-site impacts. However, given their resilience and their flushing capacity, most reaches in Bega catchment are considered to be in good or moderate geomorphic condition. Reaches in poor geomorphic condition are generally responding to large volumes of sediment input from channel incision and expansion processes in upstream reaches.

The questions in **Table 5.5** were asked for twenty-three reaches of this River Style. Eight were considered to be in good condition, six in moderate condition and nine in poor condition (**Table 5.21**). Reaches in good condition (**Table 5.22**) have an irregular cross-section that is comprised of islands separated by bedrock-induced pools and run/glide complexes. Pools are characterised by fine-grained material and organic matter accumulation and bedrock glides and runs produce significant hydraulic diversity. Wood is common around islands. Channels and floodplains are functionally linked in small-moderate flood events. Occasional floodplain pockets and hillslopes have a continuous corridor of largely native vegetation.

Moderate condition reaches are experiencing channel expansion and floodplain reworking, transferring large volumes of bedload material downstream. Pools are partially infilled, extensive mid-channel sand bars occur and there are few vegetated islands. Bedrock induced runs and glides are absent. The channel bed shows signs of increased homogeneity (**Table 5.22**).

Poor condition reaches have no riparian vegetation. Channels are expanding at an accelerated rate, and bed material organisation is limited. The bed is characterised by continuous, homogeneous sand sheets with occasional bedrock outcrops. Pools are infilled and the reach is sediment transport limited (Fryirs and Brierley, 2001). Floodplains are often scoured and reworked.

Table 5.21 The geomorphic condition of reaches of the Confined with occasional floodplain pockets River Style

Reach name and number (**Fig 3.3**)	Channel attributes	Channel planform	Bed character	Geomorphic condition
(1) Lower Frogs Hollow	√	√	√	Good
(24) Upper Candelo	√	√	√	Good
(35) Middle Tantawangalo	√	√	√	Good
(50) Upper Bemboka	√	√	√	Good
(52) Lower Bemboka	√	√	√	Good
(70) House	√	√	√	Good
(66) Upper Double	√	√	√	Good
(72) Brogo	√	√	√	Good
(57) Bottleneck Reach	√	√	√	Good
(51) Middle Bemboka	√	√	**X**	Moderate
(34) Upper Tantawangalo	√	**X**	**X**	Moderate
(37) Lower Tantawangalo	√	**X**	**X**	Moderate
(40) Upper Sandy	√	√	**X**	Moderate
(63) Numbugga	√	**X**	**X**	Moderate
(67) Lower Double	√	**X**	**X**	Moderate
(17) Wolumla	**X**	**X**	**X**	Poor
(9) Upper Frogs Hollow	**X**	**X**	**X**	Poor
(20) Towridgee	**X**	**X**	**X**	Poor
(25) Lower Candelo	**X**	**X**	**X**	Poor
(42) Lower Sandy	**X**	**X**	**X**	Poor
(46) Colombo	**X**	**X**	**X**	Poor
(53) Bega River	**X**	**X**	**X**	Poor
(60) Pollacks Flat	**X**	**X**	**X**	Poor

Table 5.22 Explaining the geomorphic condition of reaches of the Confined valley with occasional floodplain pockets River Style

	Good condition	Moderate condition	Poor condition
Channel attributes	Irregular cross-sectional form induced by bedrock outcrops and heterogeneous assemblage of geomorphic units. wood loading often high around islands. Islands well-vegetated with native shrubs and aquatic grasses.	Irregular cross-sectional form induced by bedrock outcrops and heterogeneous assemblage of geomorphic units. Localised bank erosion along floodplain pockets. wood absent. Islands lightly vegetated, largely with aquatic grasses and exotics.	Regular, trench-like cross-section (enlarging) induced by homogeneous channel bed and near vertical banks. Accelerated rates of bank erosion are evident, reflecting channel expansion. wood and in-stream vegetation absent.
Channel planform	Multiple low-flow stringers around a diverse array of bedrock and within-channel geomorphic units. Occasional pockets of floodplain, within-channel islands, sand bars, bedrock-induced pools, runs and glides. Scattered to continuous riparian strip, with some exotics.	Multiple low-flow stringers around a diverse array of within-channel geomorphic units. Occasional pockets of floodplain, frequent bedrock outcrops, shallow sand based pools, sand sheets and localised islands. Scattered riparian strip, consisting mainly of exotics. Floodplain dominated by pasture.	Multiple low flow stringers over sand sheets and around occasional bedrock outcrops. Occasional pockets of floodplain, near-continuous sand sheets in the channel zone. Extensive lateral (bank attached) and mid-channel bars. Occasional bedrock outcrops. Little or no riparian vegetation cover. Floodplain dominated by pasture.
Bed character	Bedrock-dominated but texturally well-segregated, bars and islands, glides and pools. A diverse range of bed material sizes and hydraulic diversity. Occasional gravels on the bed, arranged into clusters of equivalent material size in bars and islands. Fine grained deposition and organic matter accumulation in pools and around vegetation on islands. Sand and mud deposition on floodplains. Bedrock induces bed stability. Balance maintained between sediment input and output along the reach. Acts as a sediment transfer zone.	Increasingly homogenous sediment distribution dominated by sand. Limited deposition and storage of fine grained materials. Bedrock outcrops common. Sand sheet deposition on floodplains. Large volumes of material accumulation on the channel bed is offset by moderate volumes of sediment transport. This leads to significant bed level fluctuation over time as the reach adjusts towards a balance between sediment supply and transfer. Acts largely as a transfer zone.	Homogenous sands with little differentiation among geomorphic units or across the channel. Low hydraulic diversity. Sand sheet deposition on floodplains. Bedload dominated river, with no trapping of fine-grained materials. Large volumes of material are stored on the channel bed. Reach is sediment transport limited. Acts as a sediment accumulation zone.
Photograph	 (52) Lower Bemboka River	 (51) Middle Bemboka River	 (42) Lower Sandy Creek

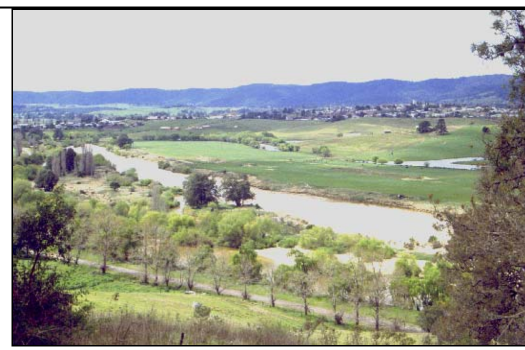
5.4.2.5 Geomorphic condition of the Low sinuosity sand bed reaches

Given their location along the lowland plain, these reaches have experienced the cumulative effects of disturbance propagated from up-catchment. In addition, direct removal of vegetation and the incursion of exotic vegetation means that no good condition reaches of this River Style occur in the catchment. Most reaches are in moderate geomorphic condition (**Table 5.23**). **Table 5.24** explains the geomorphic condition of these reaches.

Table 5.23 The geomorphic condition of reaches of the Low sinuosity sand bed River Style

Reach number and name (**Fig 3.3**)	Channel attributes	Channel planform	Bed character	Geomorphic condition
(56) Bega @ Tarraganda	√	**X**	**X**	Moderate
(55) Bega River @ Grevillea	√	√	**X**	Moderate
(73) Brogo @ Pearces Ford	√	√	**X**	Moderate
(54) Bega River @ Groses Ck	**X**	**X**	**X**	Poor

Table 5.24 Explaining the geomorphic condition of reaches of the Low sinuosity sand bed River Style

Degree of freedom	Good condition	Moderate condition	Poor condition
Channel attributes	For a catchment area of just over 1000 km², the channel is up to 60 m wide and 4 m deep. Irregular-symmetrical with high variability induced by wood and riparian vegetation. Lomandra lined channel and numerous aquatic species. wood and organic matter locally present.	For a catchment area of just over 1000 km², the channel is up to 120 m wide (addition of each low flow thread) and up to 8 m deep. Compound channel, with numerous threads. Within-channel ridges colonised by native shrubs and grasses. Low flow channels clear of vegetation. No wood present.	For a catchment area of just over 1000 km², the channel is up to 160 m wide and 2-5 m deep. Overwidened, symmetrical channel. No instream vegetation.
Channel planform	Single thread, moderately sinuous aligned down the centre of the valley. Laterally stable channel. Continuous floodplains with backswamps and levees. Localised within-channel bars, pools and riffles, the distribution of which is controlled by wood. High channel-floodplain connectivity maintains backswamps. Occasional drapes of sand deposited around vegetation on the floodplain. Densely vegetated riparian zone dominated by *Casuarina cunninghamiana* with open vegetation on the floodplain. Backswamps contain tussock and are lined with Melaleucas.	Anabranching network of ridges and low flow channels. Channel expansion and lateral instability has occurred. Potential exists for channel avulsion into floodplain floodchannels. Sand sheets characterise the floodplain surface and backswamps. Active channel-floodplain processes maintained. Floodchannels are active in high flows. Continuous floodplain, consisting of levees, backswamps. Complex within-channel and channel-marginal assemblage of units, comprising benches, sand sheets, mid-channel bars, ridges, etc. Pools are infilled. Good riparian vegetation coverage, but consists mainly of exotic vegetation. Backswamps have aquatic vegetation associations. Floodplain dominated by pasture.	Low sinuosity, single channel with accelerated rates of channel expansion. Multiple low flow channels flow atop sand sheets. Potential for avulsion into floodplain floodchannels. Continuous floodplain, consisting of levees, backswamps and extensive sand sheets. Lateral bars, sand sheets, shallow runs and mid-channel bars. Pools have been infilled. Channel-floodplain connectivity is high, but out-of – balance with extensive sand sheets deposited over the entire floodplain. Backswamps are infilling with bedload materials. Little or no riparian vegetation coverage. Floodplain dominated by pasture.
Bed character	Well segregated material distribution and storage of sediment. Mud and organic matter accumulate in backswamps. Levees and floodplains comprise sand and organic accumulations. Mix of sand and mud instream, with efficient trapping by bankside vegetation and wood. Bed is stable and hydraulic diversity is high given the vegetation and wood loading of the reach. Acts as a sediment transfer zone.	Sand-dominated, with occasional deposition of finer materials around vegetation on mid-channel ridges and on the floodplain. Bed is stable, but sediment reorganisation is occurring as flow redistributes sediment into well-defined islands and ridges. A series of well-defined low flow channels are formed. Hydraulic diversity is limited. Acts as a sediment accumulation zone.	Bed materials dominated by sands forming a planar homogeneous channel bed. Local sediment redistribution as multiple low flow stringers shift over the sand sheets. Bed stability is low given high rates of sediment accumulation on the channel bed. Channel is sediment transport limited.
Photograph	No examples exist in Bega catchment	 (55) Lower Bega River @ Grevillea	 Lower Bega River @ Wolumla Creek (near (54) Groses Creek)

5.5 Catchment-wide assessment of the geomorphic condition of rivers

Figure 5.11 shows the catchment-wide distribution of good, moderate and poor condition reaches and **Table 5.25** breaks this down in terms of the length of streams and the percentage of river courses in the catchment in each category. Despite considerable variability in the geomorphic condition of rivers across the Bega catchment, a few notable trends emerge. Good condition reaches are largely confined to the Steep headwater and Gorge River Styles, accounting for around 6 % and 16 % of all river courses in the catchment respectively. The Confined valley with occasional floodplain pockets River Style has around 94 km, or around 19 % of all river courses in the catchment, in good geomorphic condition. This is due to the resilience to change of this River Style in a confined valley setting with limited capacity to adjust. Moderate and poor condition reaches of this River Style account for around 10 % and 11 % of all river courses in the catchment respectively. Of the remaining reaches in good geomorphic condition, isolated sections occur along the Channelised fill (2 % of river courses), the Intact valley fill (1 % of river courses), the Low sinuosity boulder bed (around 3 % of river courses), the Floodout (< 1 % of river courses) and the Partly-confined valley with bedrock-controlled discontinuous floodplain (around 3 % of river courses) River Styles. Good condition reaches do not exist along the Low sinuosity sand bed River Style. In total, around 50 % of river courses in Bega catchment remain in good condition. However, around half of this (22 %) is located the uplands and escarpment country.

Table 5.25 Stream lengths for reaches of each River Style in different geomorphic condition

RIVER STYLE	CONDITION	Length (km)	% of total stream length in catchment
Channelised fill	Good condition reaches	9	1.8
	Moderate condition reaches	38	7.6
	Poor condition reaches	17	3.4
Confined valley with occasional floodplain pockets	Good condition reaches	94	18.8
	Moderate condition reaches	49	9.9
	Poor condition reaches	53	10.6
Floodout	Moderate condition reaches	2	0.4
Gorge	Good condition reaches	80	16.1
Intact valley fill	Good condition reaches	4	0.8
	Moderate condition reaches	6	1.1
Low sinuosity boulder bed	Good condition reaches	13	2.7
Low sinuosity sand bed	Moderate condition reaches	39	7.8
	Poor condition reaches	7	1.5
Partly-confined valley with bedrock	Good condition reaches	17	3.3

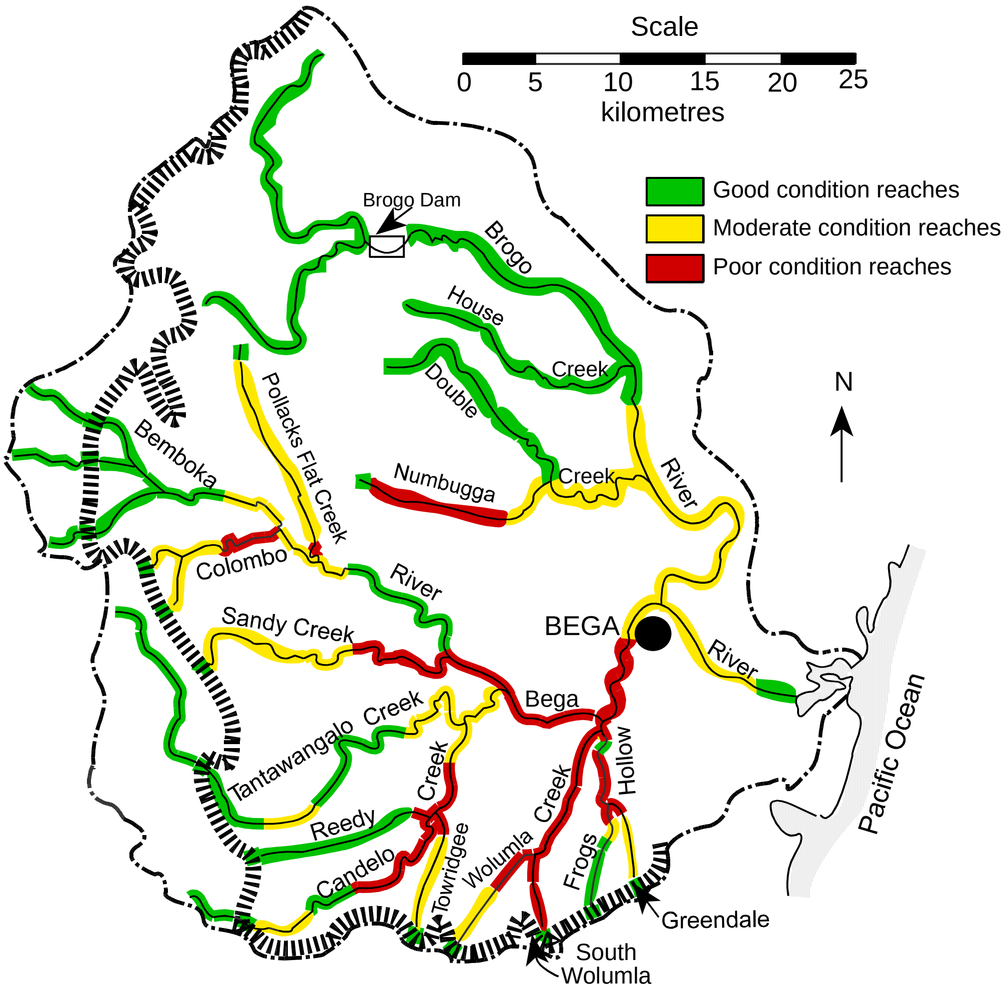
controlled discontinuous floodplain			
	Moderate condition reaches	16	3.3
	Poor condition reaches	23	4.6
Steep headwater	Good condition reaches	28	5.5
Brogo Dam	Good condition reaches	4	0.8

CONDITION	Total stream length in catchment (km)	% of total stream length in catchment
Good condition reaches	244	49.4
Moderate condition reaches	150	30.4
Poor condition reaches	100	20.2

Around 30 % of river courses in Bega catchment are in moderate geomorphic condition, the majority of which (around 10 % or 49 km of river course in the catchment) occur along the Confined valley with occasional floodplain pockets River Style. A large proportion of the Channelised fill and Low sinuosity sand bed River Style reaches are in moderate geomorphic condition (around 8 % each or close to 40 km each of river course in the catchment). Moderate condition reaches make up the largest proportion of these two River Styles (around 59 % and 85 % respectively). Other isolated reaches in moderate geomorphic condition occur along the Intact valley fill, and Partly-confined valley with bedrock-controlled discontinuous floodplain River Styles (around 1 % and 3 % of river courses in the catchment respectively).

Poor condition reaches make up 20 % of river courses in Bega catchment. These reaches are found along four of the nine River Styles, the Channelised fill, Low sinuosity sand bed, Confined valley with occasional floodplain pockets, and Partly-confined valley with bedrock-controlled discontinuous floodplain. Almost half of the poor condition reaches are found along the Confined valley with occasional floodplain pockets River Style (around 11 % or 53 km of river course). These reaches are concentrated in the Bemboka-Bega system and its tributaries, particularly in Wolumla and Candelo subcatchments. The remaining poor condition reaches are found along laterally-unconfined and partly-confined rivers where pronounced geomorphic changes have occurred. These are the most sensitive River Styles to change. Poor condition reaches of the Channelised fill River Style are found along upper South Wolumla Creek and Upper Numbugga Creek (accounting for around 3 % of river courses in the catchment). Interestingly, only one poor condition reach occurs in the Brogo system, along the Channelised fill River Style in Numbugga subcatchment. The poor condition reach of the Low sinuosity sand bed River Style occurs along Lower Bega River and is 7 km long. Poor condition reaches of the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style are concentrated in Colombo, Sandy, Candelo and Wolumla subcatchments and account for around 5 % or 23 km of river course.

Figure 5.11 The geomorphic condition of reaches in Bega catchment



Overall, the central-southern corner of the catchment (Wolumla, South Wolumla, Frogs Hollow and Greendale subcatchments) is in poorest geomorphic condition, with 60 % or 30 km of river course in poor condition (**Figure 5.11** and **Table 5.26**). This is followed by Candelo Creek with around 53 % or 16 km in poor condition, and around 49 % or 23 km of the Bega River. Large sections of Tantawangalo subcatchment and Bemboka River remain in good geomorphic condition. Over 95 % of river courses in the Brogo, House, Double and Numbugga subcatchments are in good or moderate geomorphic condition. The relatively poor condition of the Bega-Bemboka trunk stream and tributaries increases the importance of preserving and rehabilitating the river systems of the Brogo catchment, especially to provide a range of aquatic habitats which are otherwise severely degraded or disconnected in the Bega-Bemboka catchment.

Table 5.26 Stream lengths for each reach in each subcatchment in different geomorphic condition

Subcatchment/River Style	Geomorphic condition	Stream length (km)
Greendale		
Gorge	Good	0.24
Channelised fill	Moderate	3.93
Bedrock controlled discontinuous floodplain	Poor	0.89
Frogs Hollow		
Gorge	Good	0.30
Intact valley fill	Good	4.04
Confined with occasional floodplain pockets	Good	1.17
Floodout	Moderate	1.96
Confined with occasional floodplain pockets	Poor	3.98
	Good	1.49
	Poor	1.18
South Wolumla		
Gorge	Good	0.25
Channelised fill	Poor	6.05
Bedrock controlled discontinuous floodplain	Poor	2.90
Confined with occasional floodplain pockets	Poor	1.13
Wolumla		
Gorge	Good	0.28
Channelised fill	Moderate	6.36
Bedrock controlled discontinuous floodplain	Poor	5.15
Confined with occasional floodplain pockets	Poor	9.03
Towridgee		
Gorge	Good	0.25
Intact valley fill	Moderate	5.72
Confined with occasional floodplain pockets	Poor	1.00
Candelo		
Steep headwater	Good	2.30
Gorge	Good	0.73
Bedrock controlled discontinuous floodplain	Moderate	4.04
Confined with occasional floodplain pockets	Good	3.38
	Poor	16.50
Bedrock controlled discontinuous floodplain	Moderate	4.00
Reedy		
Gorge	Good	0.33
Channelised fill	Good	8.74
Bedrock controlled discontinuous floodplain	Poor	0.83

Tantawangalo		
Steep headwater	Good	15.62
Gorge	Good	1.33
Bedrock controlled discontinuous floodplain	Good	6.79
Confined with occasional floodplain pockets	Moderate	7.12
	Good	12.82
Bedrock controlled discontinuous floodplain	Moderate	8.29
Confined with occasional floodplain pockets	Moderate	8.30
Sandy		
Gorge	Good	0.58
Channelised fill	Moderate	8.45
Confined with occasional floodplain pockets	Moderate	4.79
Bedrock controlled discontinuous floodplain	Poor	9.11
Confined with occasional floodplain pockets	Poor	2.94
Colombo		
Gorge	Good	0.75
Channelised fill	Moderate	7.33
Bedrock controlled discontinuous floodplain	Poor	3.94
Confined with occasional floodplain pockets	Poor	0.84
Pollacks Flat		
Gorge	Good	0.27
Channelised fill	Moderate	9.98
Confined with occasional floodplain pockets	Poor	1.01
Bemboka/Bega		
Steep headwater	Good	3.63
Gorge	Good	0.59
Low sinuosity boulder bed	Good	4.05
Confined with occasional floodplain pockets	Good	11.56
	Moderate	12.46
	Good	12.53
	Poor	15.08
Low sinuosity sand bed	Poor	7.42
	Moderate	3.04
Low sinuosity sand bed (below Brogo River confl.)	Moderate	10.70
Confined with occasional floodplain pockets (Bottleneck reach)	Good	9.24
Brogo		
Gorge	Good	32.15
Confined with occasional floodplain pockets	Good	31.58
Low sinuosity sand bed	Moderate	25.14

House		
Gorge	Good	3.52
Bedrock controlled discontinuous floodplain	Good	4.05
Confined with occasional floodplain pockets	Good	5.45
Double		
Gorge	Good	11.77
Bedrock controlled discontinuous floodplain	Good	5.85
Confined with occasional floodplain pockets	Good	4.61
	Moderate (d/s of Numbugga confl)	11.16
Numbugga		
Gorge	Good	0.29
Channelised fill	Poor	7.13
Confined with occasional floodplain pockets	Moderate	6.95