CHAPTER FOUR
STAGE ONE : BASELINE SURVEY OF RIVER CHARACTER AND BEHAVIOUR IN BEGA CATCHMENT

4.1 Introduction and outline of this chapter

Stage One of the River Styles framework has three steps as noted in **Figure 4.1**.

Figure 4.1 Steps in Stage One of the River Styles framework

STAGE ONE, STEP ONE: Assess regional and catchment setting controls

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STAGE ONE, STEP TWO: Define and map River Styles

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STAGE ONE, STEP THREE: Interpret controls on the character, behaviour and downstream patterns of River Styles

In this case study, the following products are presented in separate sections:

Stage one, Step One

- Regional setting, including landscape units, longitudinal profiles, geology, land use history, flood history etc., and measurement of catchment morphometric parameters.

Stage One, Step Two

- Catchment-specific River Styles tree.
- Catchment-wide map showing the distribution of River Styles.
- River Styles proformas, annotated cross sections and geomorphic unit maps and photographs for each River Style.

Stage One, Step Three

- Summary table of controls for all River Styles.
- Longitudinal profile diagrams with associated plots that outline primary controls on each reach for a representative example of each downstream pattern of River Styles.

4.2 Stage One, Step One: Bega catchment regional setting

4.2.1 Catchment morphometry and geology

Bega catchment is a relatively small coastal catchment located on the South Coast of New South Wales (NSW) (**Figure 4.2; Table 4.1**). The catchment comprises two hydrologically and geologically distinct river systems, the Brogo to the north, and the Bega-Bemboka to the south. The River Styles framework was applied to 16 subcatchments namely the Bemboka-Bega and Brogo trunk stream systems, Greendale, Frogs Hollow, South Wolumla, Wolumla, Towridgee, Candelo, Reedy, Tantawangalo, Sandy, Colombo, Pollacks Flat, House, Double and Numbugga tributary systems (**Figure 4.3**).

Table 4.1 Bega catchment regional setting

<table>
<tr><td>Latitude/Longitude</td><td colspan="2">150º00’ East; 36º30’ South</td></tr>
<tr><td>Geology</td><td colspan="2">Devonian granites and granodiorites of the Bega Batholith with pockets of Ordovician metasedimentary rocks to the north</td></tr>
<tr><td>Catchment size</td><td colspan="2">• Moran’s Crossing = 312 km^2
• Bega trunk stream to Brogo confluence = 1,014 km^2
• Brogo trunk stream to Bega confluence = 797 km^2
• Bega catchment to tidal limit = 1,840 km^2</td></tr>
<tr><td>Channel length</td><td colspan="2">Bega trunk to Bega township ~ 60 km</td></tr>
<tr><td>Average channel slope</td><td colspan="2">• Uplands atop the escarpment = 0.022 m/m
• Escarpment = 0.044 m/m
• Rounded foothills = 0.005 m/m
• Lowland plain = 0.0008 m/m</td></tr>
<tr><td>Discharge</td><td>Moran’s crossing (gauge data)
1 in 2 year = 188 m^{3}s^{-1}
1 in 5 year = 253 m^{3}s^{-1}
1 in 10 year = 764 m^{3}s^{-1}
1 in 50 year = 1,234 m^{3}s^{-1}
1 in 100 year = 1,389 m^{3}s^{-1}</td><td>Bega/Brogo River confluence (data extrapolated using the Rational Method)
1 in 2 year = 577 m^{3}s^{-1}
1 in 5 year = 773 m^{3}s^{-1}
1 in 10 year = 4,039 m^{3}s^{-1}
1 in 50 year = 9,997 m^{3}s^{-1}
1 in 100 year = 13,180 m^{3}s^{-1}</td></tr>
<tr><td>Average annual rainfall</td><td colspan="2">• Escarpment and upland zones = >1,050 mm/yr
• Rounded foothills and along the lowland plain = 750-800 mm/yr
• Summer/autumn maxima</td></tr>
<tr><td>Vegetation and land use</td><td colspan="2">• Native, dry sclerophyll, open forest associations in the escarpment and upland zones.
• 70 % of the catchment has been cleared for grazing. Pasture and exotic vegetation dominate the rounded foothills and lowland plain.</td></tr>
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Figure 4.2 Location of Bega catchment

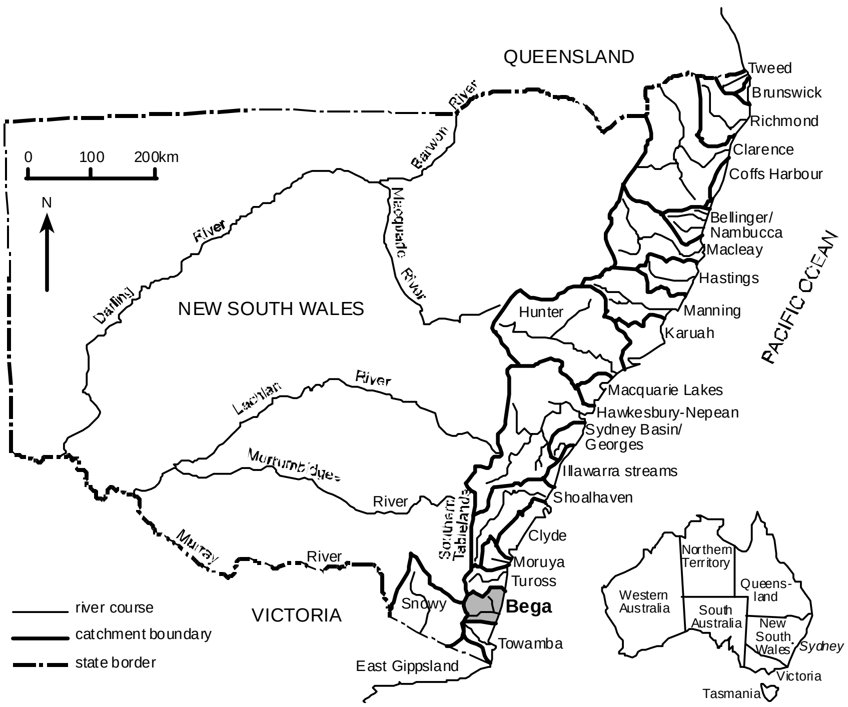
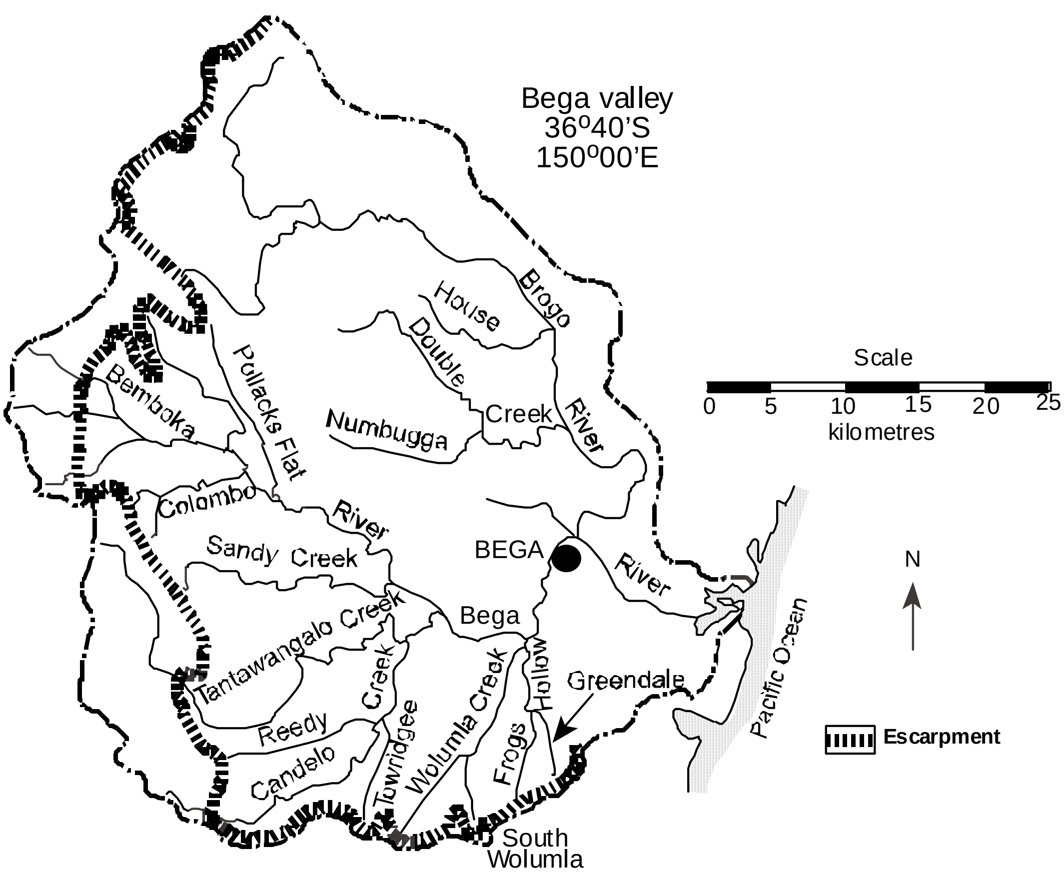


Figure 4.3 Primary river courses Bega catchment



Bega catchment has an amphitheatre shape. The landscape is dominated by the escarpment, which surrounds the catchment. The escarpment rises gradually to the north of the catchment where it attains an elevation of 1070 m. Of the 16 subcatchments, only the Bega-Bemboka trunk stream and Candelo and Tantawangalo Creeks have significant areas that drain from atop the escarpment. All other subcatchments drain directly from the escarpment zone itself. Coincident with the rise in elevation of the escarpment, the maximum elevation of the subcatchments generally increases in a northerly direction from Wolumla through to Bemboka and into the upper parts of the Brogo catchment where elevation is generally over 1000 m.

Most creeks in the catchment are short, extending less than 30 km from source to the trunk stream confluence (**Table 4.2**). An exception is Tantawangalo Creek which extends past the escarpment into the uplands. The Bemboka-Bega trunk stream is around 80 km long which is roughly equivalent to the length of the Brogo River. Brogo Dam occurs about a third the way along the stream line, but disconnects around half the catchment area from downstream (around 400 km^2). The Bega River and Brogo River trunk streams are both 7th order streams. The Bega River below the Brogo River confluence is an 8th order stream. The tributary systems in the catchment are all 5th or 6th order streams with the exception of Greendale Creek which is a 4th order stream.

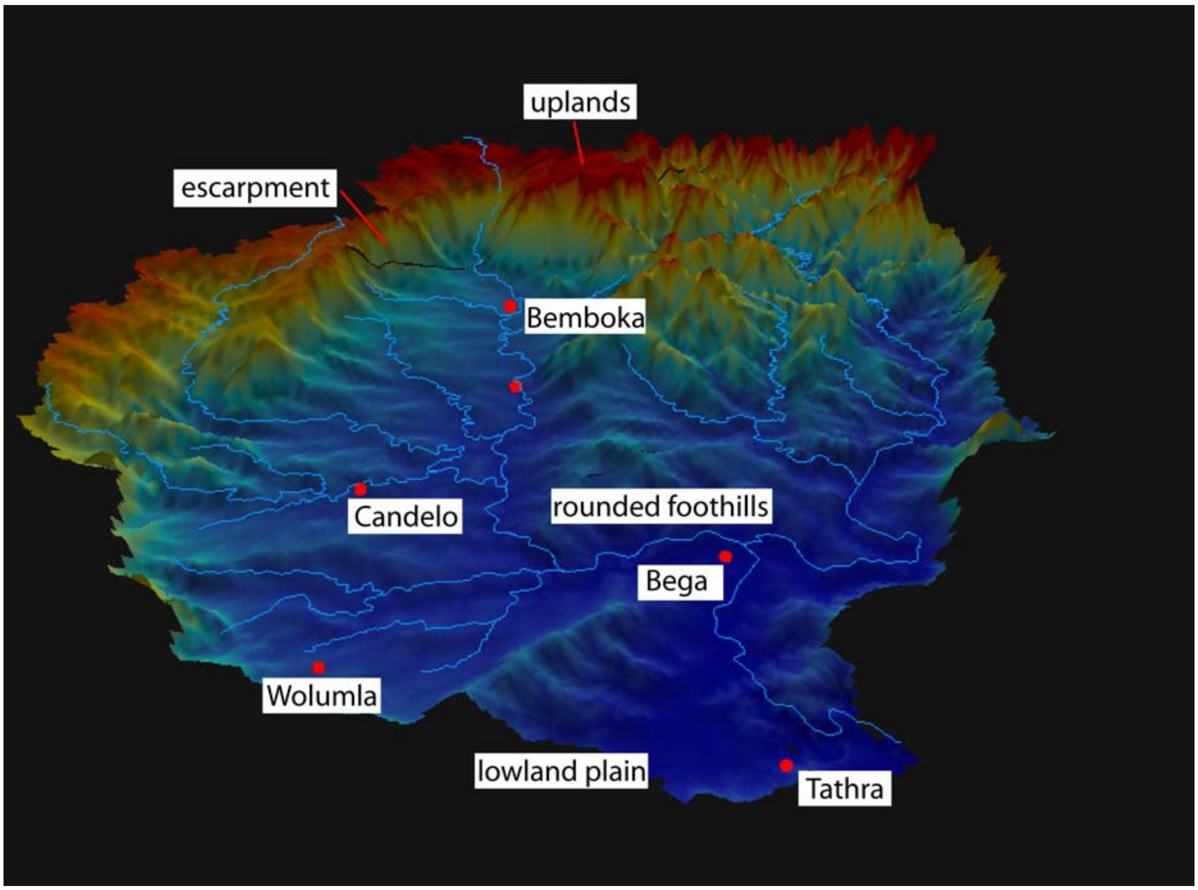
The amphitheatre shape of Bega catchment results in the convergence of several primary tributaries along a relatively short length of the Bega-Bemboka trunk stream (see **Figure 4.4**). Sandy Creek, Tantawangalo/Candelo Creek and Wolumla Creek all join Bemboka-Bega trunk stream within around 10 km of the lowland plain. As such, their cumulative impacts (in terms of water and sediment transfer) are manifest along a short reach. For example, flood peaks in Bega tend to occur within 24 hours of rainfall in the upper catchment.

Table 4.2 Bega catchment morphometric parameters

	Topological linear measurements		**Geometrical linear measurements**				**Other measures**	
Subcatchment	**Drainage pattern**	**Stream order**	**Catchment area (km^2)**	**Stream Length (km)**	**Maximum elevation asl (m)**	**Minimum elevation asl (m)**	**Percent vegetation clearance**	**Average rainfall**
Bega	Dendritic	7 @ Bega 8 below Brogo	1040	38	1240	Tidal limit	70	875
Greendale	Dendritic	4	12	5	350	65	20	810
Frogs Hollow	Dendritic	5	44	14	380	18	70	800
South Wolumla	Dendritic	5	25	10	610	58	70	780
Wolumla	Dendritic	6	131	21	776	15	80	813
Towridgee	Dendritic	5	14	7	530	110	80	850
Candelo	Dendritic	6	114	31	880	75	58	875
Reedy	Dendritic	5	22	10	640	115	50	875
Tantawangalo	Dendritic	6	326	60	980	45	40	890

Sandy	Dendritic	6	95	26	860	65	85	800
Colombo	Dendritic	5	51	13	1050	175	60	775
Bemboka	Dendritic	6	114	44	1240	185	40	1000
Pollacks Flat	Dendritic	5	36	11	1070	170	30	860
Brogo total	Dendritic	7	797	89	1120	<10	40	1000
House	Dendritic	6	35	13	710	40	30	875
Double	Dendritic	6	156	34	950	26	40	875
Numbugga	Dendritic	5	46	14	810	82	70	875

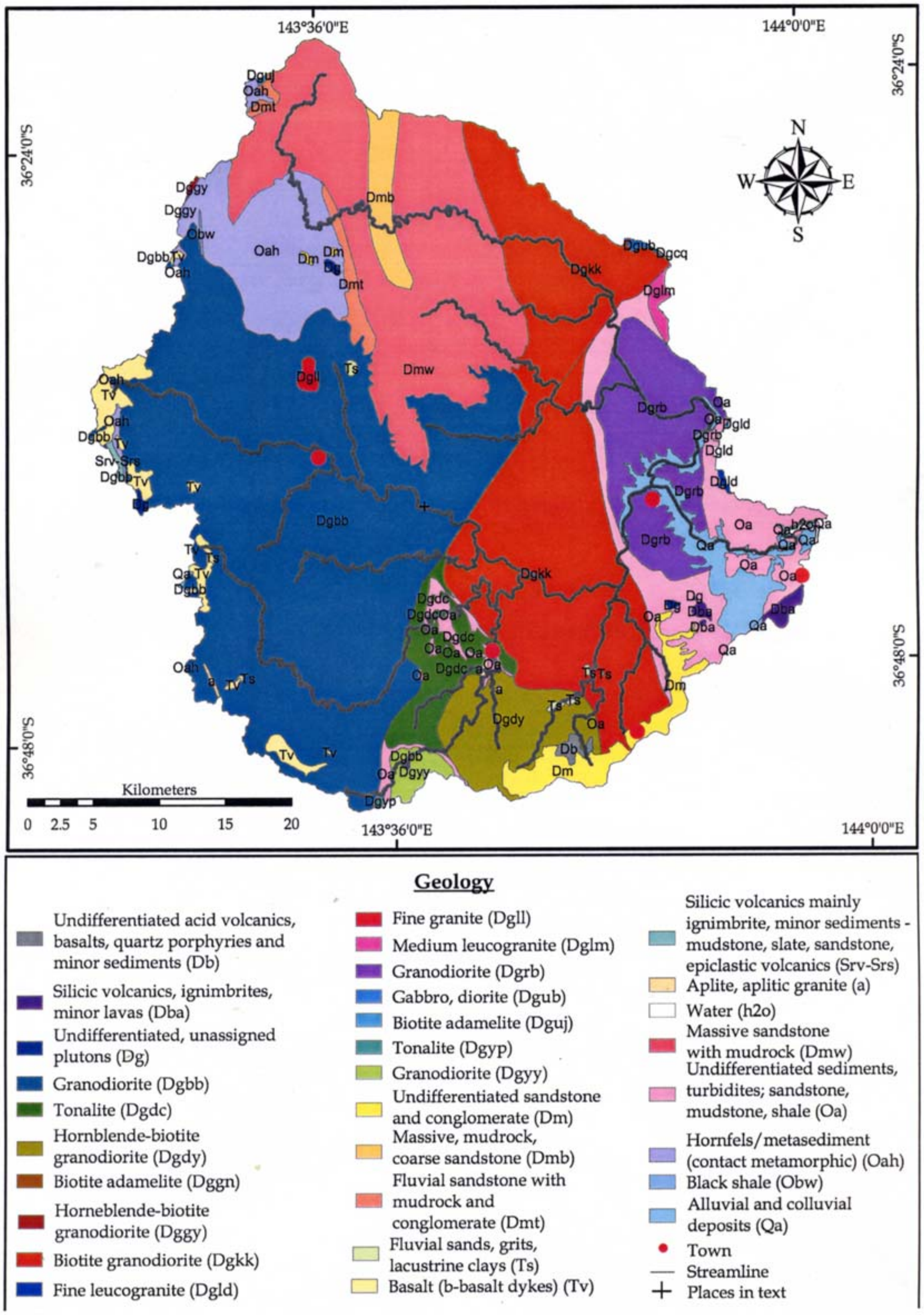
Figure 4.4 Three dimensional oblique view of Bega catchment – viewed from the Pacific Ocean



4.2.2 Geology and landscape evolution

The geology of Bega catchment is dominated by Devonian granites and granodiorites of the Bega Batholith (**Figure 4.5**). Exceptions include parts of the Brogo catchment. The upper Brogo, House and Double Creeks are underlain by Devonian metasediments. A pocket of Ordovician metasedimentary outcrops in the far north-west of the catchment. Tertiary volcanics, comprising basalts, are found in upper Candelo, Tantawangalo and Bemboka subcatchments. Quaternary alluvium (comprised primarily of sands and occasional gravels) lines most of the primary drainage lines in Bega catchment, especially along the lowland plain. The surrounding foothills of the lowland plain are dominated by Ordovician sediments.

Figure 4.5 Geology of Bega catchment



The uplift of the eastern highlands began around 95 million years ago (Ollier and Pain, 1994). During the Late Cretaceous, rifting and sea floor spreading, associated with the separation of the Lord Howe Rise from eastern Australia, formed a new continental edge creating a passive continental margin (Ollier and Pain, 1994). Headward fluvial erosion initially created deep gorges and valleys which eventually coalesced via irregular scarp retreat to create the main escarpment (Ollier, 1982). Subsequent denudation lead to the formation of rounded foothills downstream of the escarpment.

The morphology of the escarpment within Bega catchment is a result of differential erosion due to mineralogy rather than structural control. The more elevated western margin of the Bemboka Granodiorite is felsic and often ademallitic in composition, while the Bega Valley is often more mafic and easily eroded (Tulau, 1996). This likely enhanced the formation of the amphitheatre catchment shape.

The ancestral Bega River drained to the Pacific Ocean via Wallagoot Lake and Penooka Swamp (Nott et al., 1991). Coastal lowlands formed in mid-Oligocene to early Miocene when terrestrial sediments 10-60 m thick were deposited in response to sea level rise (Nott et al. 1991). This deposition caused the diversion of lower Bega River through an incised gorge to the north (named Bottleneck Reach) (Nott et al. 1991).

Holocene sediments have been deposited since sea level stabilised at or near the present level about 6000 years ago. This instigated an extension of coastal zones, estuary sedimentation and changes to river structure (eg. formation of backswamps, terraces etc.). More recently, anthropogenic disturbance has instigated considerable landscape change and river metamorphosis (Brooks and Brierley, 1997, 2000; Fryirs and Brierley, 1998 a; Brierley et al., 1999).

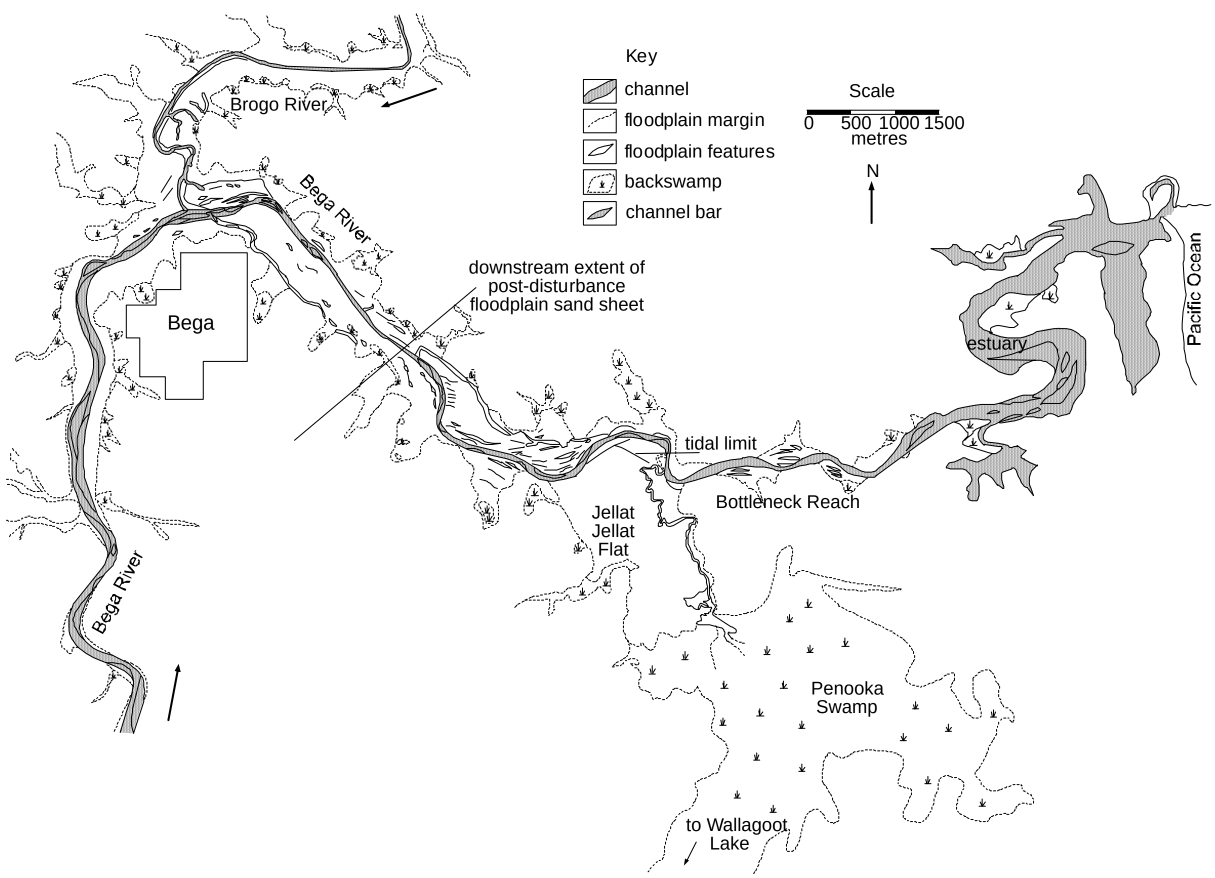
Contemporary rivers in Bega catchment have an abundant sediment supply. The weathering of the granitic geology has produced significant sand and clay-sized materials. Accommodation space at the base of the escarpment, and the topographic control exerted by this escarpment, has aided the accumulation of extensive volumes of sediment over thousands of years (Fryirs and Brierley, 1998 a). Incision into these fills has supplied significant volumes of material downstream (Brierley and Fryirs, 2000). While the fine-grained materials are flushed through the system as suspended load, a significant proportion of the sand-sized materials remain stored within the system, primarily on the channel bed (Fryirs and Brierley, 2000).

Middle reaches of Bega catchment that connect the base of the escarpment to the lowland plain are largely bedrock-controlled. As such, they are able to efficiently flush sediments downstream.

Antecedent controls on valley configuration along the lowland plain have ensured that this reach acts as a choke on sediment transfer to the estuary (**Figure 4.6**). As the valley widens downstream of Wolumla Creek confluence, sands are splayed over the floodplain. Given the low slope (0.002-0.0008 m/m) and the wide valley (over 1000 m wide), these sand sheets have only extended 4 km downstream of Bega township. There is little evidence for post-European sedimentation in the downstream half of the lowland plain.

Figure 4.6 also shows the juxtaposition of the contemporary bedrock-confined outlet to the sea (called Bottleneck Reach), and the large, relict estuarine mud basin at Jellat Jellat swamp (Hudson, 2000; Nott et al., 1991; Sundararamayya, 1983). This large basin effectively ponds water at flood stage. Hudson (2000) found that the character and rate of sediment input to the estuary has changed little over the last 6,000 years and certainly does not spike in the period since European settlement period. There is no evidence for significant, historical infilling of the estuary by river sands. In flood flows very little sediment is actually delivered to the estuary, as flows and sediments either pond behind Bottleneck Reach or are flushed directly off-shore through the channel and the estuary (e.g. during the major flood event in 1971).

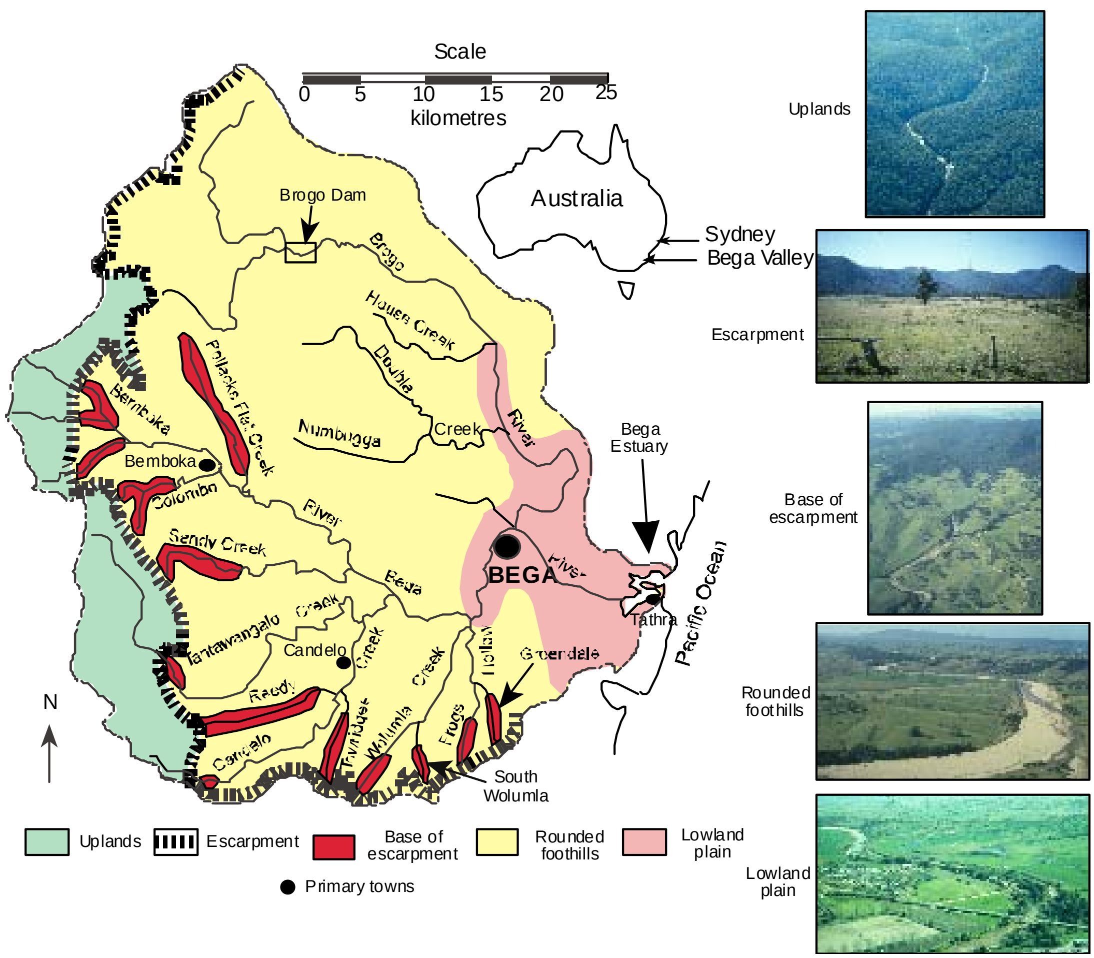
Figure 4.6 The lowland plain of Bega catchment



4.2.3 Landscape units

Five landscape units have been identified in Bega catchment, namely uplands, escarpment, base of escarpment, rounded foothills and lowland plain (**Figure 4.7; Table 4.3**). The uplands landscape unit is characterised by steep slopes, reflecting dissection of the tablelands (**Figure 4.4**). It is only prominent in Bemboka, Tantawangalo and Candelo subcatchments, as the headwaters of other subcatchments lie in the escarpment zone. The variable configuration of landscape units at the upstream end of the subcatchments plays a significant role in determining river morphology in downstream landscape units, especially at the base of the escarpment.

Figure 4.7 Landscape units in Bega catchment



Although the base of the escarpment landscape unit is found in all subcatchments, there is pronounced variability in the type of river formed (and the response to human disturbance) in this part of the catchment. The differing length of the tongues that extend from the escarpment, and the character and extent of sediment accumulation in this landscape unit, account for many of the differences in river character in differing subcatchments.

In areal terms, the rounded foothills are the most significant landscape unit in Bega catchment (**Figure 4.7** and **4.4**). This landscape unit comprises valley sidewalls of 8-15°, and is dissected by a multitude of lower order channels. The rounded foothills, and the lowland plain, have been almost entirely cleared of vegetation. The lowland plain extends to the Pacific Ocean, although lower Bega River flows through a bedrock-confined reach (Bottleneck Reach) prior to its estuary.

Table 4.3 Parameters used to identify and describe landscape units in Bega catchment

Parameter/ Landscape unit	**Uplands**	**Escarpment**	**Base of escarpment**	**Rounded foothills**	**Lowland plain**
Identifiers					
Physiographic character or landscape morphology	Dissected plateau with relatively deep incised valleys	Steep face incised with deep gorges	Tongue shaped or elongate deep valleys that extend downstream from the escarpment.	Rounded hills that form ridges dividing each subcatchment. These ridges extend from the base of the escarpment in many cases	Flat, low lying plain with low lying adjacent hillslopes
Landscape position	Atop the escarpment	Between uplands and central catchment	At the base of the escarpment, extending from an upstream gorge	Between the base of the escarpment and the lowlands	Downstream of the rounded foothills where valleys widen significantly. Feeds into the estuary
Geology	Largely granites with some meta-sediments	Largely granites	Largely granites	Largely granites with some meta-sediments	Largely granites and Quaternary alluvium
Relief	~ up to 400 m	400-600 m	~ 250 m	~ 180 m	~ 15m
Descriptors					
Elevation (asl)	> 600 m, generally >1000 m	> 200 m	150-400 m	15-200 m	<15 m
Longitudinal valley slope (degrees)	Low to < 3	>15	10-15	3-10	Low to < 3
Valley width	Up to 40 m	10-40 m	Up to 300 m	20-240 m	> 650 m widening to several kilometres at Jellat Jellat flat

4.2.4 Longitudinal profiles

Longitudinal profiles for all 16 river courses studied in Bega catchment are presented in **Figures 4.8 – 4.11**. All subcatchments that drain directly from the escarpment have relatively smooth concave-up forms with occasional bedrock steps downstream of the escarpment zone. These steps act as local base level controls, dictating the slope of valley segments and hence river morphology. At the base of the escarpment a gentle break in slope is transitional to the rounded foothills landscape unit. Frogs Hollow subcatchment has a distinct longitudinal profile compared to others that drain directly from the escarpment. At the base of the escarpment between 4-7 km distance, the intact swamp forms a 'bulge' along the long profile. Even more distinct is the 'bulge' that occurs between 12-16 km distance. This is the location of the mid-catchment floodout where an unchannelised fill stores large volumes of material.

All subcatchments that drain from atop the escarpment are characterised by a distinctly stepped profile in their upper sections where river courses are dissected into the tablelands country (**Figure 4.12**). This stepped zone is transitional to a concave-up profile downstream of the escarpment zone. However, the break in slope at the base of the escarpment is abrupt along these river courses. Again occasional bedrock steps occur along these river courses downstream of the escarpment.

Contributing area plots are also shown on these figures. All tributary subcatchments that drain from the escarpment are short and have catchment areas less than ~130 km^2. Those river courses that drain from the uplands (e.g. Tantawangalo) are long and drain significant catchment areas (up to ~325 km^2).

Figure 4.8 Longitudinal profiles, contributing area and slope along Greendale, South Wolumla, Frogs Hollow and Wolumla Creeks

(pink = long profile, green = slope, blue = contributing area)

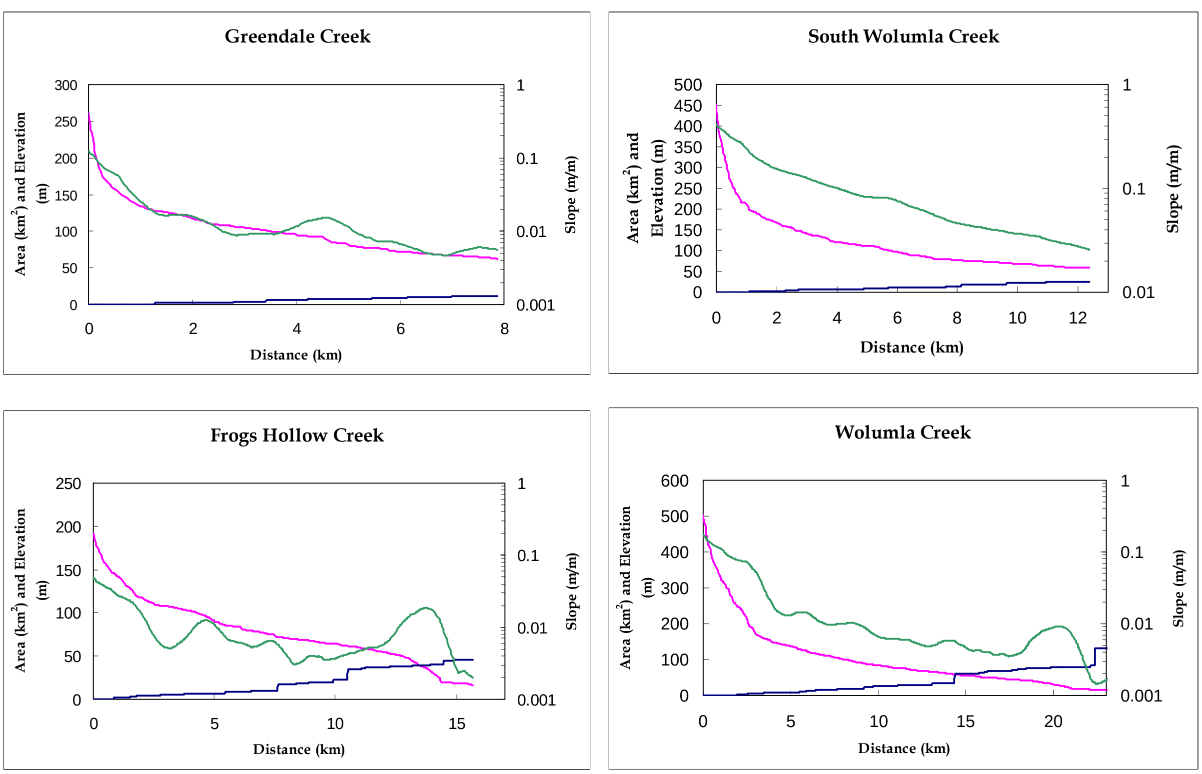


Figure 4.9 Longitudinal profiles, contributing area and slope along Towridgee, Candelo, Reedy and Tantawangalo Creeks (pink = long profile, green = slope, blue = contributing area)

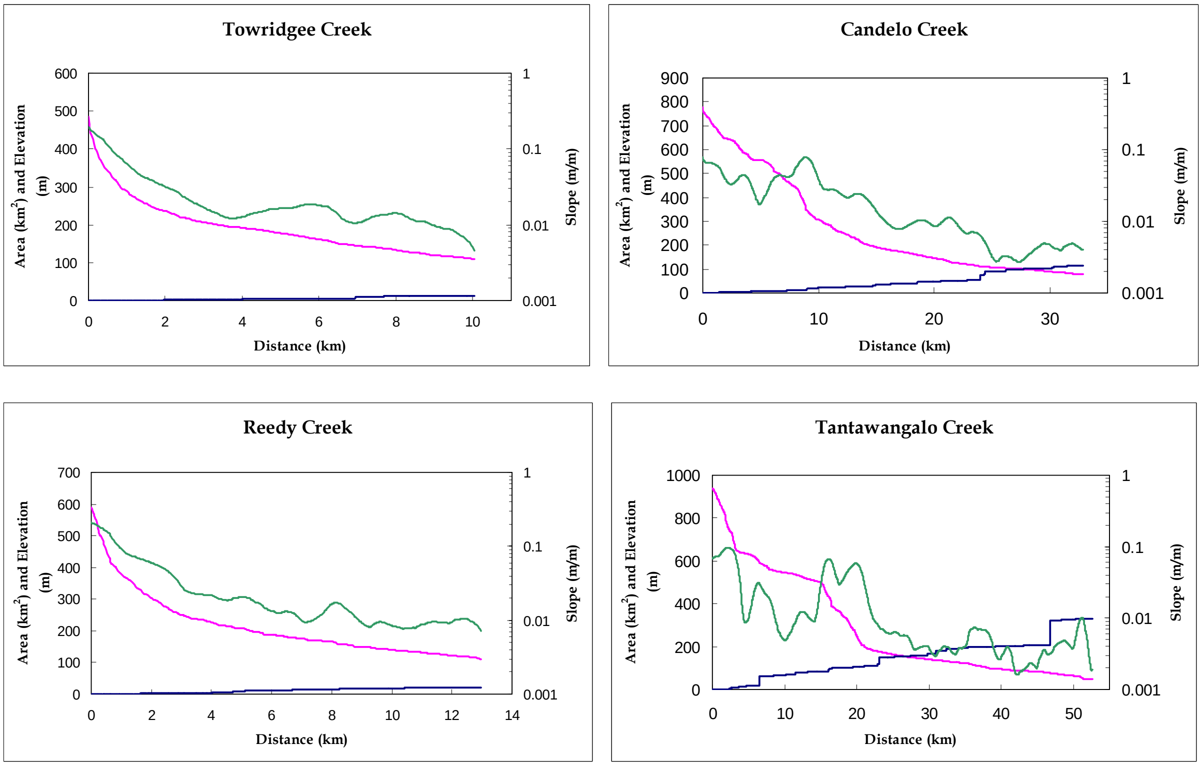


Figure 4.10 Longitudinal profiles, contributing area and slope along Bemboka-Bega River, Sandy Creek, Colombo Creek and Pollacks Flat Creek (pink = long profile, green = slope, blue = contributing area)

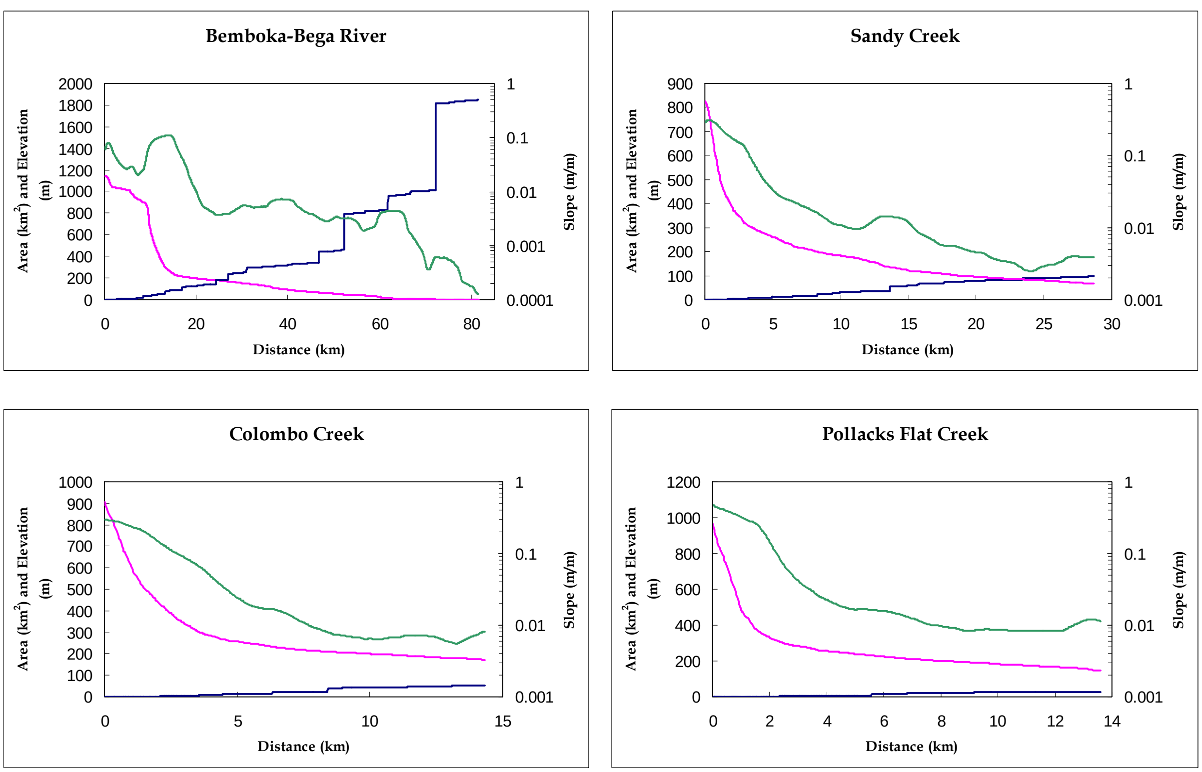


Figure 4.11 Longitudinal profiles, contributing area and slope along Brogo River, Numbugga Creek, House Creek and Double Creek

(pink = long profile, green = slope, blue = contributing area)

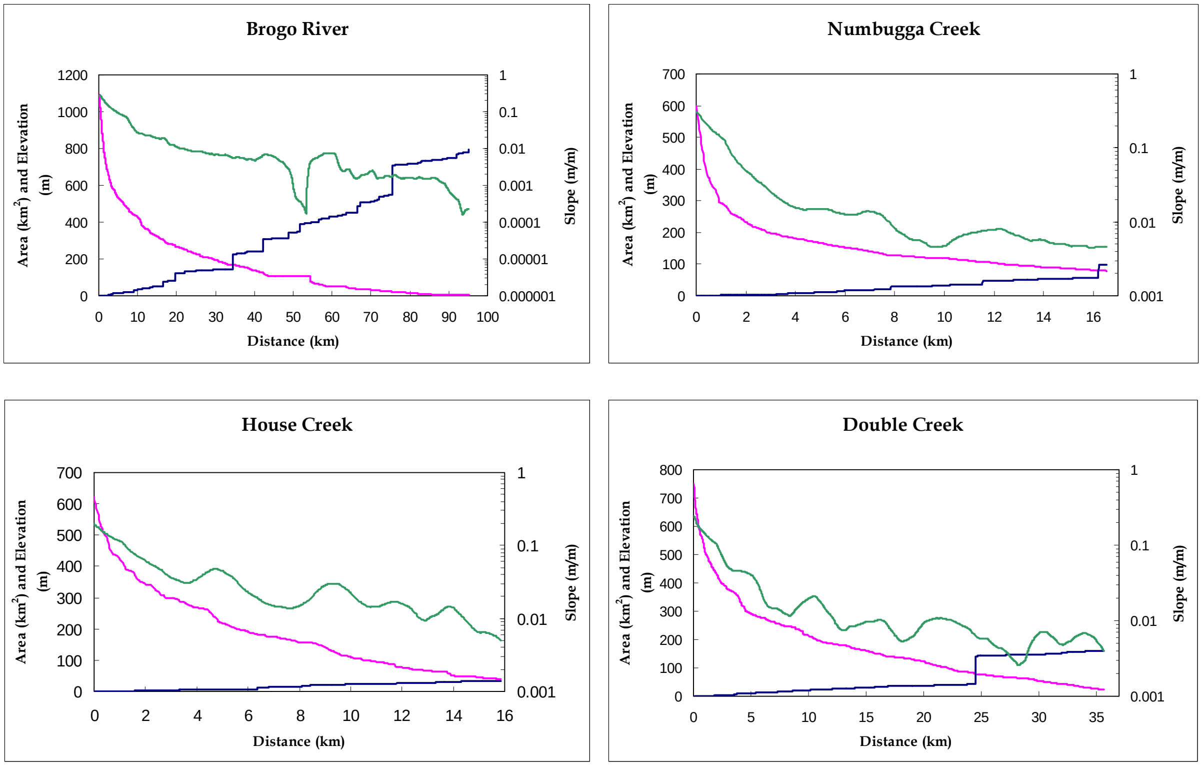
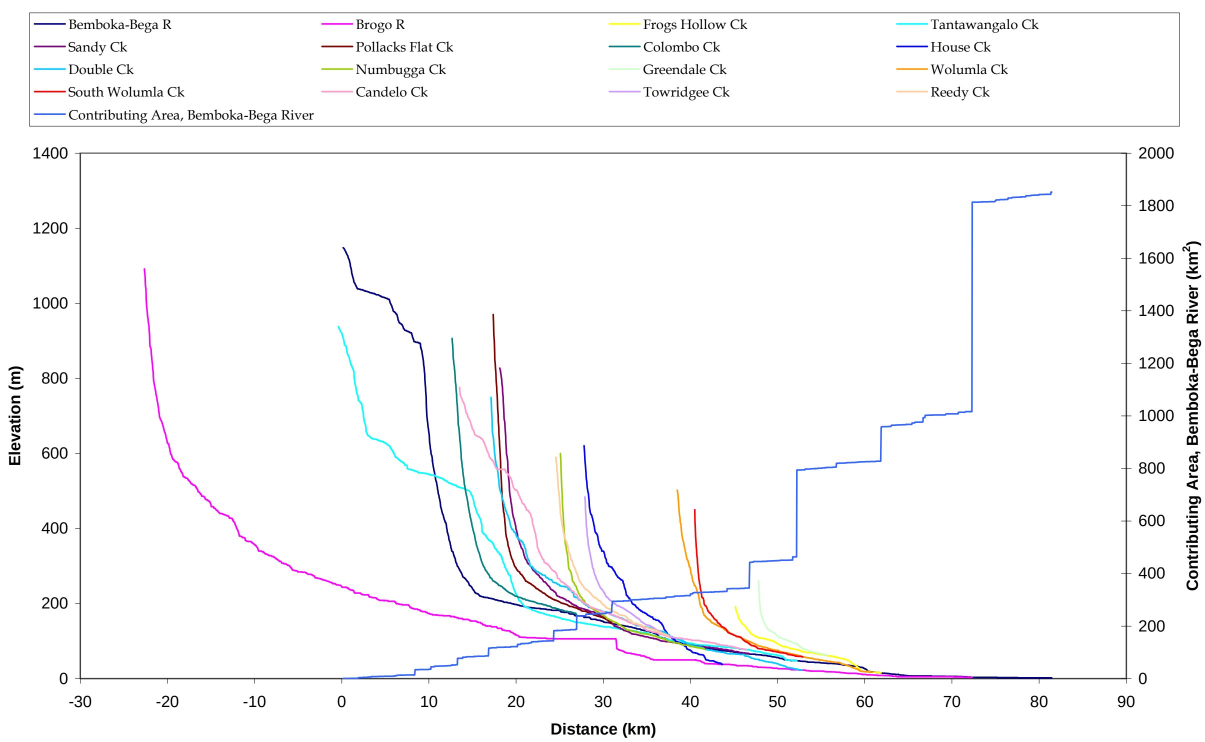


Figure 4.12 Longitudinal profiles of all streams in the Bega catchment

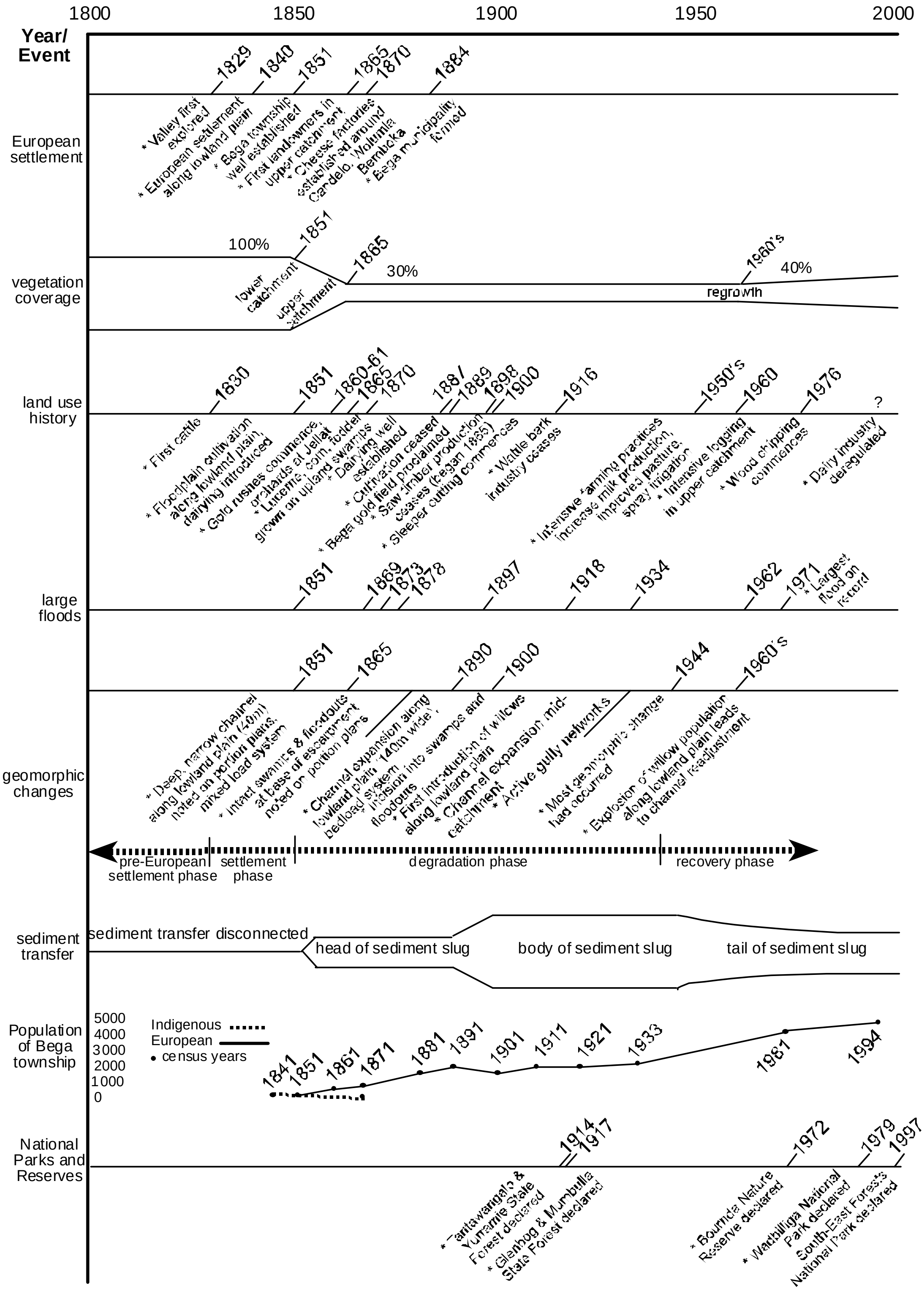


4.2.5 Catchment settlement and population density

The history of catchment settlement and associated land use, flooding and geomorphic changes are depicted in **Figure 4.13**. The onset of European settlement in Bega catchment triggered a range of geomorphic, hydrologic, vegetation and sediment regime changes in the catchment. These changes will be explained in greater detail in later chapters.

The Bega district was first explored in 1829 and settled by Europeans in the 1830s and 40s (Bayley, 1942; Lunney and Leary, 1988). The district was first mapped in 1841 (Bayley 1942) and the settlement is shown to be well established on the 1851 portion plans. Vast squattages had been staked out along the most accessible fertile lands of the lowland sections of the catchment by this time (Bayley, 1942). By the 1860s large squattages were carved up into small acreages, which were intensively farmed. The Municipality of Bega was formed in 1884 (Smith, 1978). The main centres in Bega catchment were around Bemboka, Candelo and Wolumla which were located along the main transport route from the Monaro Region to the ports of Merimbula and Tathra (Lester Firth Associates, 1989). Historical photos show that boats once navigated up the Lower Bega River to Bega township, providing a key transport route.

Figure 4.13 Timeline of changes since European settlement of Bega catchment



Large acreages were settled around the main towns (e.g. Kameruka near Candelo). Throughout much of the catchment, the first surveys were completed around 1865. Creek lines were claimed by the primary landowners, and hillslopes were divided amongst the selectors (Fryirs, 1995). By the late 1870s cheese factories were located within the main centres (Codrington, 1979).

It is difficult to determine the size of the local Aboriginal population at the time of European settlement (Lunney and Leary, 1988). In census returns between 1841 and 1845, 160 Aboriginals were noted in the area. In 1841, births were approximately equal to deaths, but in the following years deaths exceeded births, as a result of diseases such as influenza (Lunney and Leary, 1988). By 1871 the Aboriginal population had decreased to around 33.

In 1851 Bega township had a population of around 100 (**Table 4.4, Figure 4.13**). There was only a handful of European structures outside the township at this stage (Bayley, 1942). With the passing of the Robertson Land Acts in 1861, the population of Bega increased six fold. People lived on small acreages which had been subdivided from large squattages. As a result of this development, the full potential of the area for dairying was recognised (Codrington, 1979). Population continued to increase until the 1890s and then stabilised as the small land holdings were more intensively farmed.

Table 4.4 Population statistics

(Bega township sources Bayley, 1942; Brooks, 1994; Lunney and Leary, 1988

Bega Valley source: Codrington, 1979; Brooks, 1994; ABS, 2001)

Year	Bega township	Bega Valley
1846		56
1851	100	100
1861	625	
1866		2000
1871	872	
1881	1643	
1891	2023	
1901	1898	
1911	1969	
1921	1933	
1933	2227	
1981	4388	
1991		27380
1994	4723	
1996		28845
2001		30524

By 1994 the population of Bega township had reached around 4700 people (**Table 4.4**). In the mid 1990's, the combined population of Bemboka, Candelo and Wolumla was less than 1000. The upper parts of the catchment, especially upper Brogo, are very sparsely populated and in some cases virtually uninhabited. According to the 2001 census (ABS, 2001), the total permanent population of Bega Valley (which includes other small coastal towns such as Bermagui) amounts to about 30,000 people including around 600 of Indigenous origin. The median age of people in the Bega Valley was 42 years, and 83% were Australian born. Of those born overseas, the three main countries of origin were the United Kingdom, New Zealand and the Netherlands.

In recent years, the permanent population of the Bega catchment has declined (as a result of deregulation of the dairy industry amongst other things). Significant land subdivision is occurring (e.g. along Tantawangalo Creek), placing increased demands on limited water resources. Most of these subdivisions are 'hobby farms' or small cottage industries. Hence, seasonal population changes are becoming the norm.

4.2.6 Land use history

4.2.6.1 Land Tenure

Bega catchment primarily consists of freehold land which has been cleared for agricultural purposes. This comprises the majority of the low lying hillslopes and valley flats/floodplains within the catchment. National Parks and State Forests are confined to steeper areas in the uplands and escarpment zones. Small pockets of vacant and reserved crown land are found throughout the catchment.

4.2.6.2 Agriculture

In 1830 the first cattle were taken into the Bega Valley (Bayley, 1942; **Figure 4.13**). Along with sheep grazing, the early squatters commenced farming in a small way (Jauncey, 1918). The first crops to be grown were wheat, with oats, malting barley and potatoes. Cultivation on the floodplain around Bega had been established by 1851, and it can be inferred that the lowland floodplains had been extensively cleared of their original vegetation by that time (Brooks, 1994). Oats, barley, sorghum, corn and wheat were grown along the floodplain (Lunney and Leary, 1988) and good crops of potatoes were grown throughout the district (Bayley, 1942). After 1861 fruit growing was introduced to the district and subsequently an orchard was established at Jellat (Bayley 1942).

Portion plans dating from 1865 show the base of escarpment valley fills in many subcatchments as unincised. These flats were subsequently cleared, swamps drained and cultivated with lucerne, corn and fodder crops (Fryirs, 1995). Cultivation of valley flats largely ceased once these surfaces became incised.

Up to 1870, wool figured largely among the agricultural exports of the district, but gradually sheep gave way to cattle as the primary form of stock (Bayley, 1942). Lunney and Leary (1988) suggest that by the 1870s intensive land use had cleared of virtually the entire lowland zone of its forest cover (Brooks, 1994). In the 1870s "the whole country in every direction was studded with homesteads enclosed by substantial fencing" where "splendid grass lands, timbered like an English park comprise the lowlands" (cited in Lunney and Leary, 1988) (**Figure 4.14**). In 1887 wheat growing ceased in the district altogether, as the crops had been ruined by wetter seasons (Jauncey, 1918; Bayley, 1942).

4.2.6.3 Dairying

Dairying began in the Bega region soon after settlement, and by the 1870s it was the principal form of land use (Bayley, 1942; Lunney and Leary, 1988; **Figure 4.13**). In the 1950s, intensive farming practices were introduced to maximise milk output. Grazed pastures began to be intensively managed, via the cultivation and maintenance of improved pasture species with superphosphate and spray irrigation (Brooks, 1994). Such practices enabled greater numbers of cattle to be carried on the available land. Today, the dairy industry is one of the largest in the country and is the primary water user in the catchment. Deregulation of the dairy industry occurred in 2000.

4.2.6.4 Forestry

The forestry industry was well established by the 1860s but at this stage was confined to the lowland zone (Lunney and Moon, 1988). Sawn timber production was high in lowland areas between 1865 and 1898, coinciding with the period of maximum vegetation clearance in the catchment (**Figure 4.13**). Wattle species quickly established as secondary growth following removal of the tree canopy (Lunney and Leary, 1988). This instigated the wattle bark industry for tanning purposes. In upper parts of the catchment, especially in Wolumla subcatchment, "hundreds of acres of these trees grew in the mountains about five miles from the township (Wolumla)" (Wolumla Centenary Committee, 1982; Fryirs 1995). After 1916, wattlebark ceased to be an important source of revenue for the district although it continued to be cut until the 1970s (Lunney and Leary, 1988).

Figure 4.14 Historical photographs of river courses in the Bega catchment (historical photos courtesy of the Mitchell Library, Sydney)

Wolumla-Bega confluence looking upstream 1926 and 2000

1926

2000

Lower Bega River near Grevillea 1926 and 2000

1926

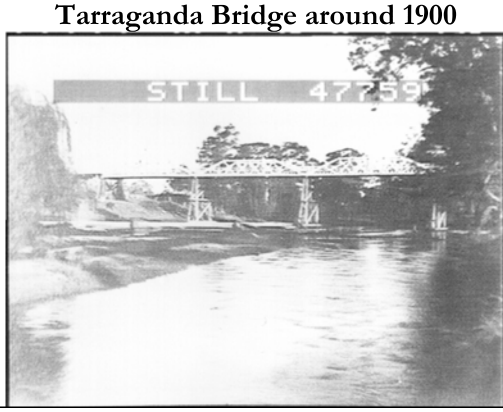
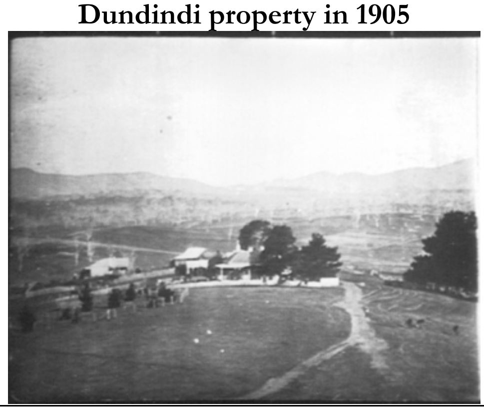
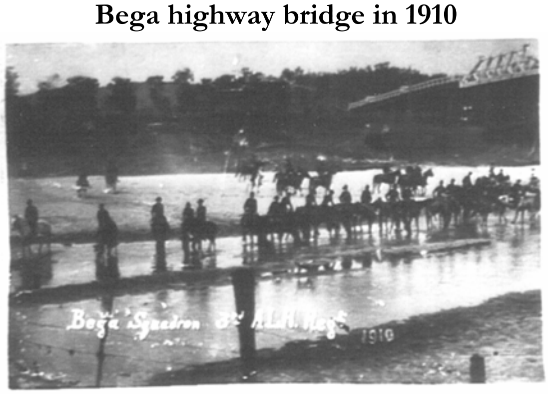
2000

Candelo to Bega Road just upstream of Wolumla confluence 1926 and 2000

1926

2000

Figure 4.14 cont Historical photographs of river courses in the Bega catchment (photos courtesy of the Candelo pub and the Mitchell Library, Sydney)

Candelo pre 1890 	**Candelo around 1890** 
Candelo around 1890 	**1919 flood at Bega - along Bega St from Auckland St** 
Tarraganda Bridge around 1900 	**Dundindi property in 1905** 
Bega highway bridge in 1910 	**Bega-Brogo confluence in 1910** 

From 1900, sleeper cutters opened up many areas of the hills surrounding Bega township (Lunney and Leary, 1988). However, to regulate such commercial use of the forests, the Forestry Commission was formed in 1916 and most of the remaining forest in the district was dedicated as State Forest (Lunney and Leary, 1988). Woodchipping since 1976 instigated a period of utilisation of a wide range of tree qualities (Lunney and Leary, 1988). Extensive logging occurred in the upper parts of many subcatchments, particularly Tantawangalo. Intensive timber extraction in the steeper parts of the catchment has primarily occurred since the mid 1960s, with integrated logging operations and woodchipping since 1969 (Lunney and Leary, 1988; Lunney and Moon, 1987). Prior to this, the escarpment forests were only selectively logged, if at all.

Since 1970 the State Forests of the Eden Management Area, of which Bega catchment is a part, have been managed according to a long-term strategy involving the harvesting of multi-aged forest to produce pulpwood and sawlogs over a cutting cycle of about 40 years (State Forests, 1995). The Code of Logging Practice and site specific Harvesting Plans contain regulations with regards to environmental standards. These standards include restricting the area to be disturbed to suitable locations; soil erosion control; retaining wildlife habitat and maintaining undisturbed vegetation around streams, drainage lines and wildlife corridors; the rehabilitation of logging sites; and avoiding environmentally sensitive areas (State Forests, no date). The majority of forest in the upper parts of Bega catchment are now contained within the South-East Forests National Park.

4.2.6.5 Gold Mining

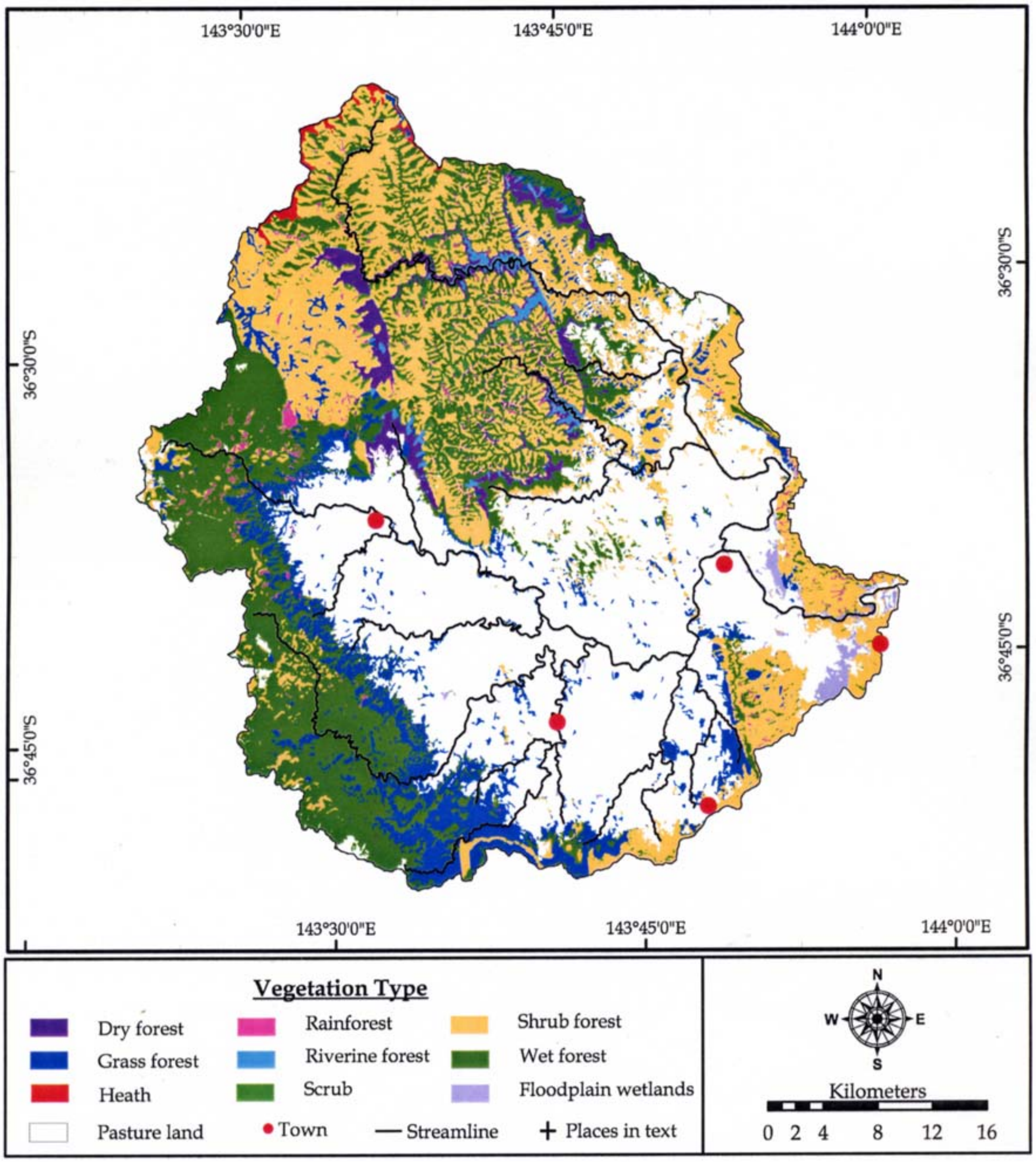
In 1860 and 1861 the Kiandra and Nerrigundah Gold Rushes occurred in the Bega district (Bayley, 1942). Bega Gold Field was proclaimed on the 30th of November 1889, and gold mining continued as a primary industry in Wolumla until 1950, when torrential rain caused landslides and closure of the mine shafts (Fryirs, 1995). In 1916 gold was discovered on the Bega River. However, although much capital was expended, the returns from mining the river were not favourable (Bayley, 1942).

4.2.7 Vegetation and wetland character and distribution

Vegetation coverage in Bega catchment today is around 30 % of that of prior to European settlement (**Figure 4.15**; modified from NSW DNR). Vegetation clearance has been extensive and most subcatchments have had over 50 % of their vegetation removed (**Table 4.2**). The majority of vegetation clearance occurred within the first few decades of settlement (**Figure 4.13**). Photographs taken at the turn of the century show the character of the landscape to be very similar to today (see

Figure 4.14; Bega Family Museum). Riparian vegetation associations along most creeks in Bega catchment are scattered or non-existent.

Figure 4.15 Vegetation associations in Bega catchment



The majority of the remaining vegetation in Bega catchment is concentrated in the escarpment zone and upland areas. An increasing proportion of this cover is regrowth forest (Brooks, 1994). The vegetation associations in these zones can be broken into two key areas, the Bemboka-Bega system and the Brogo system (**Figure 4.15**). By comparing **Figure 4.5** with **Figure 4.15**, the distribution of vegetation associations and the boundaries between vegetation types cross-compare closely with the underlying geology.

Within the Bemboka-Bega system, the uplands vegetation is dominated by a wet forest association with pockets of rainforest occurring in upper Bemboka catchment. The escarpment vegetation consists of a tall open forest association on the higher slopes that grades into an open forest on the lower slopes. *Eucalyptus sp.* and *Acacia mearnsii* dominate these associations. These forests are now part of State Forests and National Parks. The base of the escarpment zone is dominated by grass forest.

The Brogo River system and its associated tributaries are dominated by shrub forest and scrub along the lower order drainage lines. Dry forest occurs in pockets of the uplands and gorge country. Riverine forest is confined to the riparian zones of large, uncleared river courses in Brogo catchment. Heath is found close to the drainage divide in upper Brogo catchment.

The foothills and lowland plain have effectively been cleared of all vegetation, with only scattered, small pockets remaining. Prior to disturbance, the lowland plain was likely dominated by an open forest/woodland association with a scrubby understorey (M. Tulau pers. comm. 1997). Primary species in this lowland zone included spotted gum (*Eucalyptus maculata*), forest red gum (*E. tereticornis*), woollybutt (*E. longifolia*), rough-barked apple (*Angophora floribunda*), stringybark (*E. myellerana*), Maiden's gum (*E. maidenii*) and mountain grey gum (*E. cypellocarpa*) with kangaroo grass (*Themeda australis*) (Lunney and Leary, 1988; Brooks, 1994; Tulau, 1996). Aboriginals probably altered some parts of this environment and the vegetation associations through the use of fire. This appears to have restricted the growth of rainforest communities to moist pockets in the escarpment zone (Lunney and Leary, 1988). Today, there is less than 10 % vegetation coverage on the lowland zone, with pasture grasses dominating the hillslopes and floodplain.

Prior to European settlement, the lowland zone was colonised by *Casuarina cunninghamiana* and *Lomandra sp.*. Today, *Salix spp.* (willow) dominate. Up to six known species of *Salix* occur in Bega catchment. However these species are hybridising and there are likely numerous more undocumented varieties. Weeping willows (*Salix babylonica*) and basket willows (*Salix alba x fragilis*), which were introduced in 1830, are the dominant species (Lunney and Leary, 1988; Brooks, 1994). The understorey consists of an array of exotic vegetation dominated by dense grasses, primarily kikuyu (*Pennisetum clandestinum*), blackberry (*Rubus fruticosus*) and ragweed (*Artemisia verlotorum*) (Brooks, 1994).

Wetlands in Bega catchment are classified into a number of categories, the distribution of which accords directly with areas of sediment accumulation (**Figure 4.16**; modified from NSW DNR). In the uplands, swamps occur in depressions along wide, low slope valleys (e.g. Nunnock Swamp in upper Tantawangalo catchment). Along the tributary drainage systems, lower order drainage lines can contain trapped tributary fills. These tend to occur where floodplain pockets along the trunk stream close the mouth of a lower order drainage line effectively trapping sediments behind (see Brierley and Fryirs, 1999). The protective floodplain tends to be elevated higher than the lower order drainage line fill, producing a swampy depression with no well defined channel (**Figure 4.17**). The distribution of these features in Bega catchment tends to occur along river courses where discontinuous floodplains occur along the primary drainage line. This is characteristic of river courses in the rounded foothills landscape unit.

Figure 4.16 Wetland distribution in Bega catchment

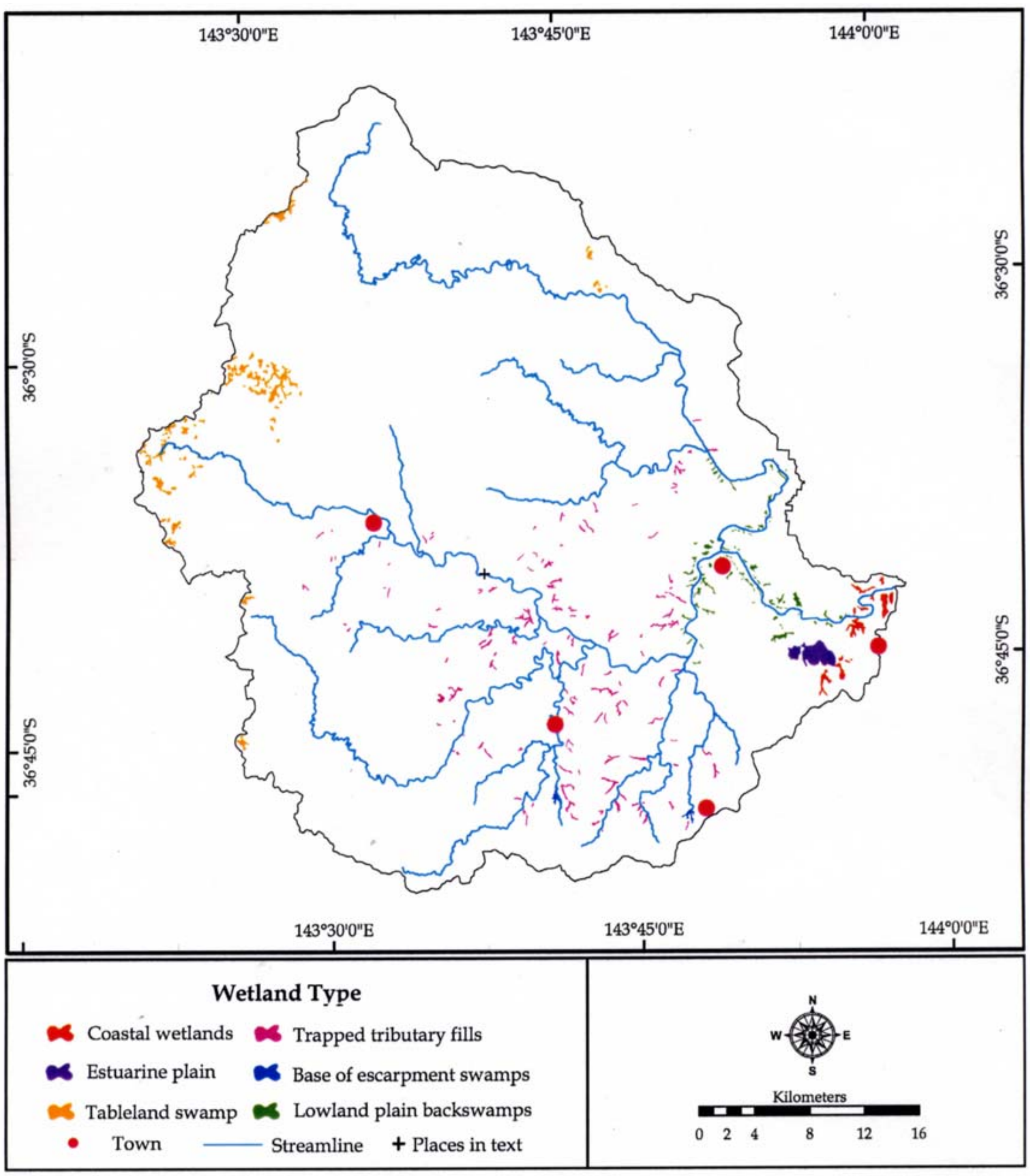


Figure 4.17 Types of wetlands in Bega catchment

Trapped tributary fill – upper Wolumla Creek

Base of escarpment swamps – Frogs Hollow swamp

Lowland plain backswamps – Lower Bega River

Lowland plain backswamp - Lower Bega River at Grevillea

Coastal wetlands and estuarine plain- Bega estuary

Base of escarpment swamps are found in wide, deep alluvial valleys at the exit of the escarpment gorge where large volumes of material have accumulated over thousands of years (see Fryirs and Brierley, 1998 a; **Figure 4.17**). Base of escarpment swamps were noted on 1862 and 1865 portion plans in most subcatchments. Today, only two remaining swamps occur in Bega catchment along Frogs Hollow and Towridgee Creeks. These swamps have a distinct vegetation association. Specht (1981) commented that tea tree swamps occur where impervious clay layers create waterlogged conditions and a build up of organic matter in the soil. This enables a closed swamp scrub to colonise the margins of the swamp (cf. Briggs, 1981). This community is found on poorly drained peaty soils in coastal and highland N.S.W. and is characterised by *Melaleuca ericifolia* (tea tree) shrubs, with an understorey of *Juncus sp.* and

Poaceae sp. In the central swamp zone, the vegetation is dominated by *Poaceae sp*. grasses and *Juncus sp*. rushes and has been classified as a hummock grassland. Due to disturbance and cattle grazing, there are also introduced species of *Verbena bonariensis L*., which is endemic to South America, and *Plantago lanceolata L*., which is a native of Europe and Asia (Fryirs, 1995).

Backswamps in Bega catchment are found along the lowland plain (**Figure 4.17**). These swamps occur along the distal sections of continuous floodplains. Distal fining of sediments as flow exits the channel and spreads over the floodplain produces a distal dipping floodplain surface. Backswamps are formed in this depression. These features tend to be characterised by aquatic vegetation species.

Large estuarine wetlands are found at Jellat Jellat (**Figure 4.17**). These broad plains are the remnants of palaeoestuarine conditions. These valleys contain thick estuarine mud with a thin cap of contemporary floodplain deposits. Water tends to pond in these wetlands in high flow conditions. Coastal wetlands are located in the fringe adjoining the coast.

4.2.8 National Parks and Reserves

Within the Bega catchment there are numerous National Parks and Nature Reserves. South East Forest National Park was gazetted in 1997, and has a total area of 90,000 ha (**Figure 4.13**). Wadbilliga National Park was gazetted in 1979 and has a total area of 76,399 ha. The third national park that falls partially within Bega catchment is Biamanga National Park. This national park was gazetted in 1994 and has a total area of 7,418 ha. Bournda Nature Reserve is the only nature reserve in the Bega catchment. It was gazetted in 1972 and has a total area of 5,831 ha.

There are four State Forests within the Bega catchment. Tantawangalo and Yurramie State Forests were gazetted in 1914 and have a total area of 1,130 ha and 2,595 ha. Glenbog and Mumbulla State Forest were gazetted in 1917 and have a total area of 3,598 ha and 2,417 ha.

4.2.9 Climate, flood history and dams

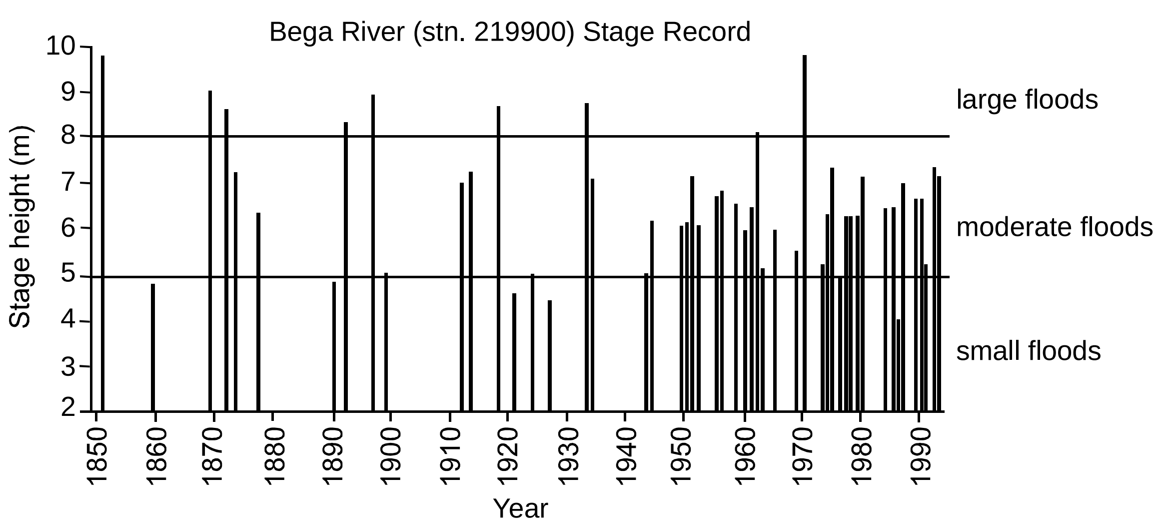
The Far South Coast of New South Wales is characterised by a warm temperate maritime climate with mild summers. Average summer maxima and minima at Merimbula airport are around 25 and 15 ^{0}C (February). Coastal winter maxima and minima are 16 and 4 ^{0}C (July). Average temperatures fall by about 6 ^{0}C per 1000 m increase in elevation (Tulau, 1996). South-westerly to westerly winds prevail during winter. South-easterly winds are dominant in summer, with north-easterly sea breezes along the coastal fringe.

Orographic effects imposed by the escarpment largely control the distribution of rainfall in upper areas of the catchment. Regional rainfall is greatest in the escarpment zone and upland areas, where average rainfall is in excess of 1050 mm/yr. Rainshadow effects decrease this average to around 750-800 mm/yr in the central and lowland sections of the catchment (Brooks and Brierley, 1997). Average annual rainfall at the base of the escarpment is between 850-1000 mm/yr. Mean annual rainfall in Bega township is 875 mm (**Table 4.1**).

Rainfall in Bega catchment shows no strong trend in seasonality (Wiggins, pers comm.). However, for the 123 years of record, maxima do occur during the Summer/Autumn period, with ~30 mm more rainfall/month. Historical sources indicate that 1885 was the driest year on record (399 mm). However, the period May-October 2002 had the lowest rainfall for any equivalent time in the past 123 years. The wettest year on record was in 1934 (1833 mm).

The flood of record occurred in February 1971 when over 320 mm of rain fell in 24 hours at Candelo and a total of 700 mm fell in Bega. The discharge was around 1800 m^3sec^{-1} at Morans Crossing ($450km^2$) and a 1 in 140 year event was recorded (WRC, 1971). Other large floods occurred in 1851, 1869, 1873, 1878, 1893, 1897 and 1962 (**Figure 4.18 and 4.13**; Willing and Partners, 1987; Bega Valley Historical Society, 1971; Lunney and Leary, 1988; Bayley, 1942; Brooks and Brierley, 1997; Fryirs, 1995; Codrington, 1981; Smith, 1978).

Figure 4.18 Flood stage record at North Bega Bridge (modified from Brooks and Brierley, 1997 who noted that the official record did not include at least 7 small floods in the period 1850-1926)



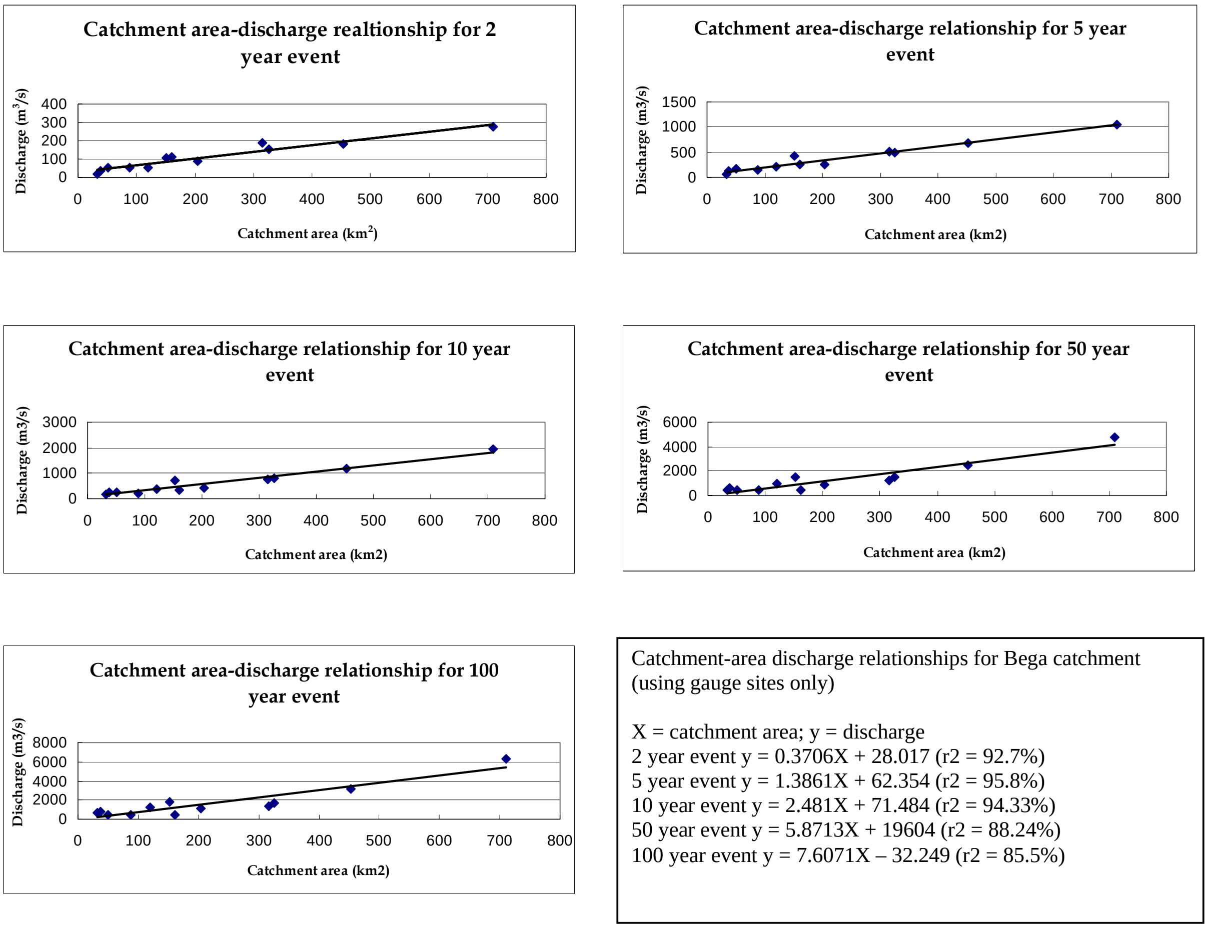
From the combined analysis of flood and rainfall data undertaken by Brooks (1994) for the North Bye gauge, it is apparent that over the length of the record there has been a distinct decline in the amount of rainfall required per unit of flood stage (**Figure 4.18** - Brooks, 1994, p21-22). Flood events were fewer prior to 1950, but on average were larger floods associated with higher magnitude rainfall events. Prior to 1920, average daily rainfall rates per unit of flood magnitude were higher within individual events (Brooks, 1994). Such a trend can be interpreted as indicative of either secular climate regimes (Kirkup et al., 1997) or an alteration to the catchment hydrologic regime associated with the clearance of vegetation from a large proportion of the catchment. After 1920, it appears that the hydrological condition of the catchment stabilised to a condition with higher runoff per unit rainfall than in pre-European times (Brooks, 1994) (ie. it took less rain to produce a flood of similar magnitude to one pre-disturbance). This indicates that by this time river structure had adjusted in response to altered flow regime and catchment conditions.

Figure 4.19 shows the catchment area-discharge relationships derived for gauge data in Bega catchment that has a continuous record of >10 years. This data set is used to derive discharge values for ungauged sites in the catchment which are then used to model stream power and bedload transport rates. The regression coefficient for each of these graphs are all greater than 85 %, suggesting that it is a relatively tight set of data.

There are two dams in the Bega catchment. Cochrane Dam on the upper Bemboka River sits above the escarpment and feeds the Bemboka Power station (run by Eraring Energy) situated at the base of the escarpment. The dam has a capacity of 2,700 megalitres (ML) and a catchment area of about 30 km^2. About 3 km of river course is bypassed above the power station. Cochrane Dam is small relative to its inflows (annual inflows are about 9 times the capacity of the dam) (HRC, 2000). Thus, except in drought years, water retention in the dam has little effect on the flow regime of the Bemboka River system. Once released from the power station, the water is available to water users and the environment (HRC, 2000). Under the Bega-Bemboka Flow Plan (NSW DLWC, 1999), water extraction is managed between the 80^{th} and 95^{th} percentile, and irrigation ceases below the 95^{th} percentile. This means that there is mean flow of < 20 ML/day at Morans Crossing, there is surface flow at Kanoona Rocks, and negligible flow at Bega. Under these conditions, refuge pools are maintained and visible surface flow connects these pools (NSW DLWC, 1999).

Brogo Dam provides regulated flows for extraction for irrigation, riparian use and restricted supply to the coastal town of Bermagui (HRC, 2000). It has a storage capacity of 9,800 ML and a catchment area of about 400 km^2 (about half the Brogo catchment area). Water release from Brogo Dam does not follow a 'natural' regime. In the absence of the dam, it is likely that the lower section of the Brogo River would sometimes have dried up in summer, but irrigation releases now keep low flows in the river for extended periods during the irrigation season (generally October to April) (HRC, 2000). The average irrigation release from the dam is around 50-100 ML/day and in the non-irrigation season the normal riparian release is 15-20 ML/day. This maintains flow through to the Lower Bega River.

Figure 4.19 Catchment area-discharge relationships for the Bega catchment



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

4.3.1 The character and behaviour of River Styles in Bega catchment

Using the River Styles procedural tree, and procedures outlined in Brierley and Fryirs (2005), nine River Styles were identified in Bega catchment (**Figure 4.20** and **4.21**). The character and behaviour of each River Style is summarised in **Table 4.5** (Brierley and Fryirs, 2000). River Styles proformas are presented in **Tables 4.6** through **4.14**. These River Styles proformas summarise the character, behaviour and controls for each River Style across the range of reaches in the catchment. This includes the continuum of geomorphic condition. The cross-sections and diagrams are for the best available representative example. Given the level of detail at which this analysis was undertaken in Bega catchment, examples from different subcatchments have been chosen and numerous photographs presented.

Figure 4.20 depicts the distribution of River Styles in Bega catchment. Three River Styles were identified in the confined valley-setting (Gorge, Steep headwater and Occasional floodplain pockets), one in the partly-confined valley-setting (Bedrock-controlled with discontinuous floodplain) and five in the laterally-unconfined valley-setting (Intact valley fill, Channelised fill, Low sinuosity boulder bed, Floodout and Low sinuosity sand bed). The boundaries between River Styles were sharp or gradual. Sharp boundaries occur at distinct breaks in slope on the longitudinal profile, areas of valley narrowing and at tributary confluences. Gradual boundaries occurred over hundreds or thousands of metres of river course.

Table 4.5 Distinguishing attributes of River Styles in Bega catchment

River Style	Valley setting/ Landscape Unit	River character: Channel planform	River character: Geomorphic units	River character: Bed material texture	River behaviour
Steep headwater	Confined/ Uplands	Single, highly stable channel.	Discontinuous floodplain pockets, pools, riffles, glides, runs, vegetated islands.	Boulder-bedrock-gravel-sand	Bedrock channel with a heterogeneous assemblage of geomorphic units. Flushes sediments through a confined valley. Limited ability for lateral adjustment.
Gorge	Confined/ Escarpment	Single, straight, highly stable channel.	No floodplain, bedrock steps, pools and riffles, cascades.	Boulder-bedrock	Steep, bedrock controlled river with an alternating sequence of bedrock steps and pool-riffle-cascade sequences. Efficiently flushes all available sediments. Channel cannot adjust within the confined valley setting.
Confined valley with occasional floodplain pockets	Confined/ Rounded foothills	Single, straight, highly stable channel,.	Discontinuous pockets of floodplain, extensive bedrock outcrops, sand sheets, pools.	Bedrock-sand	Sediment conveyance via downstream propagation of sand sheets in narrow valleys. Bedrock induced pools and riffles. Occasional island development
Partly-confined valley with bedrock-controlled discontinuous floodplain	Partly-confined/ Rounded foothills and base of escarpment	Single channel. Sinuous valley alignment. Moderately stable.	Discontinuous floodplain, point bars, point benches and sand sheets, mid-channel bars, pools and riffles, bedrock outcrops.	Bedrock-sand	These rivers are found in sinuous valleys. They progressively transfer sediment from point bar to point bar. Sediment accumulation and floodplain formation is restricted primarily to the insides of bends. Sediment removal along concave banks. Over time, sediment inputs and outputs are balanced. Floodplains are formed from suspended load deposition behind bedrock spurs.
Low sinuosity boulder bed	Laterally-unconfined/ Base of escarpment	Single channel trench consisting of multiple low flow threads around boulder islands. Highly stable.	Fans extend to valley margins. Channel consists of boulder islands, cascades, runs, pools, bedrock steps.	Boulder-bedrock	Lobes of boulder and gravel material have been deposited over the valley floor. The primary incised channel has a heterogeneous assemblage of bedrock and boulder induced geomorphic units that are only reworked in large flood events.
Intact valley fill	Laterally-unconfined /Base of escarpment	No channel	Continuous, intact swamp. Occasional floodout lobes and/or small pools.	Mud-sand	Intact swamps are formed from dissipation of flow and sediment over a wide valley floor as the channel exits from the escarpment zone. Suspended and bedload materials are deposited as sheets or floodout lobes.
Channelised fill	Laterally-unconfined /Base of escarpment	Single, straight channel, unstable.	Continuous valley fill, terraces, inset features, sand sheets, sand bars.	Sand	Incised channel has cut into the swamp deposits of the intact valley fill River Style. Large volumes of sediment are released and reworked on the channel bed. The channel has a stepped cross section with a series of inset features and bar forms. These are a function of cut and fill processes within the incised channel. Channel infilling, lateral low flow channel movement and subsequent re-incision produce the stepped profile.
Floodout	Laterally-unconfined / Rounded foothills	No channel	Continuous intact swamp with floodout.	Mud-sand	Formed downstream of an incised channel, this river contains a swamp over which materials supplied from upstream are splayed over the valley floor in a number of lobes.
Low sinuosity sand bed	Laterally-unconfined / Lowland plain	Single channel with an anabranching network of low flow channels within sand sheets. Potentially avulsive and unstable.	Continuous floodplain with backswamps, levees. Benches, mid-channel islands and sand bars.	Sand	Found in a broad, low slope valley, the river accumulates sand sediments in wide, continuous floodplains. Floodplains contain levees and backswamps. Floodchannels may short circuit floodplain segments at high flow stage. The channel zone is characterised by extensive sand sheets and sand bars. Where these are colonised by vegetation, islands are formed. Benches are formed by oblique accretion against the channel margin.

Figure 4.20 The distribution and downstream patterns of River Styles in Bega catchment, South Coast, NSW, Australia

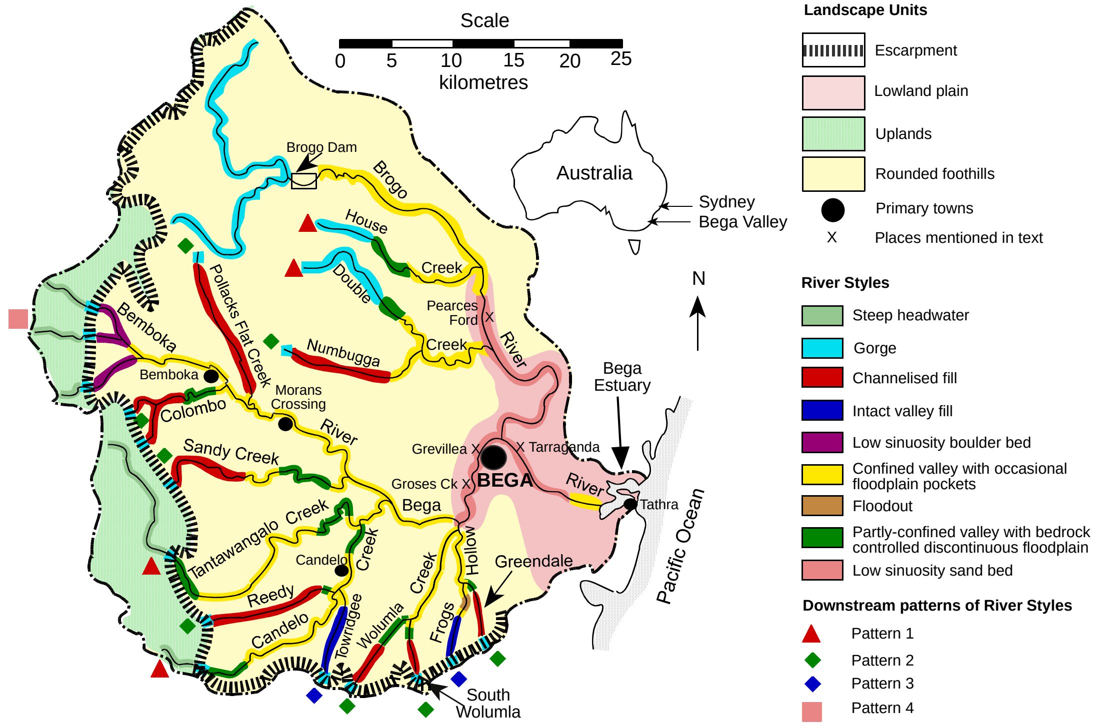
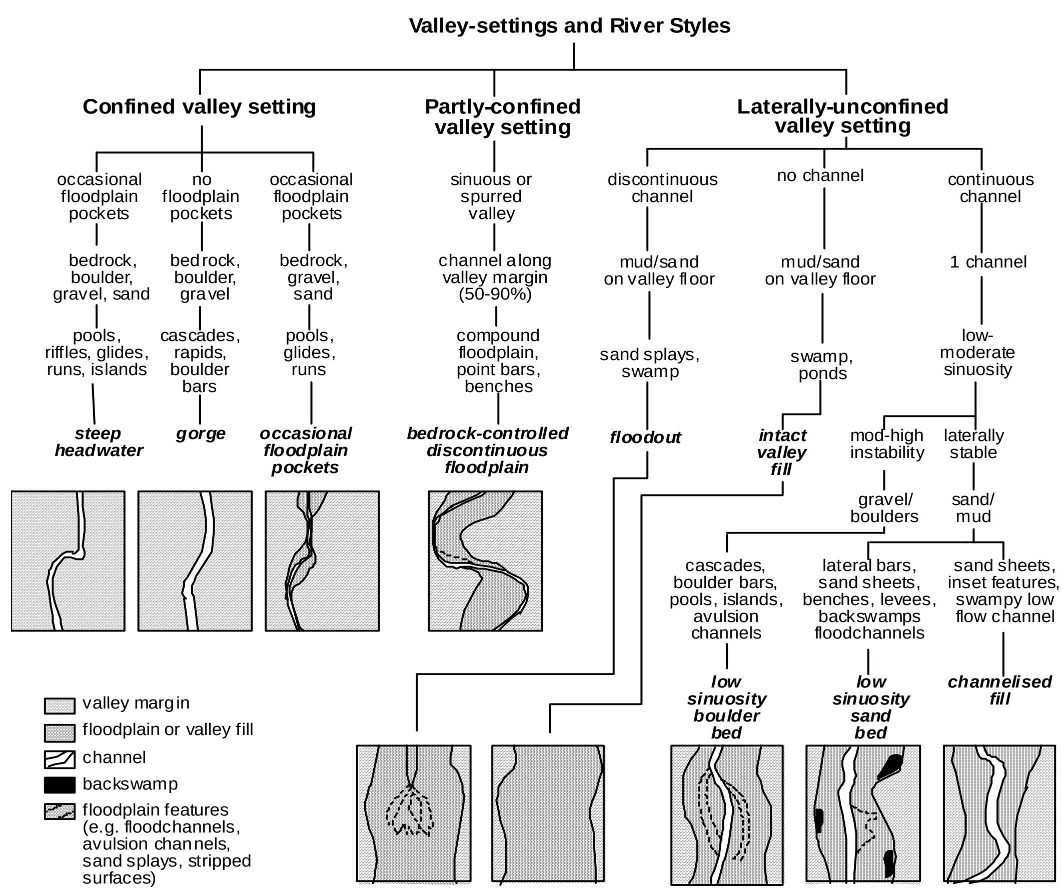


Figure 4.21 The Bega catchment River Styles tree



Tables 4.6 through 4.14 – River Styles proformas. These can be found in the separate pdf file for this book.

The three River Styles found in confined valley-settings occur in different landscape units. The **Steep headwater** River Style is found in the uplands landscape unit. It comprises a wide range of instream geomorphic units including bedrock and boulder pools, riffles, mid-channel and lateral sand bars. A confined, laterally stable channel is set within a dissected plateau atop the escarpment. The **Gorge** River Style is found within the escarpment zone, set within a deeply incised v-shaped valley. A bedrock channel occupies the entire valley floor (i.e. there is no floodplain), with a series of bedrock-induced pools and vertical drops (either cascades or waterfalls). The **Confined valley with occasional floodplain pockets** River Style is found in the rounded foothills landscape unit and occurs along the majority of tributary and trunk stream river courses in the catchment. This River Style is bedrock-confined, with the channel often occupying the entire valley floor. The channel is stable, and acts as an efficient conveyor of sediment. The extent of bed aggradation and degradation indicates the volume of material moving through the system and the efficiency of flushing. Bedrock-induced pools, glides and runs characterise the channel bed. Shallow, narrow floodplain pockets occur along the valley margins. These are either protected behind bedrock spurs or are located in locally wider sections of valley (e.g. at tributary confluences).

The Partly-confined valley with bedrock-controlled discontinuous floodplain River Style is found in the rounded foothills landscape unit, but also occurs at the base of the escarpment along two river courses. This River Style has an imposed sinuous channel within a meandering valley alignment. It is characterised by point bar and point bench deposition on the inside of bends and by erosion of near-vertical concave banks. The floodplain occurs along the convex banks of bends and may be characterised by floodrunners. In some instances, sections of floodplain may be stripped.

Five River Styles were identified in laterally-unconfined setiings in Bega catchment. Unlike reaches in Confined and Partly-confined valley-settings, these are localised, short reaches in this catchment. Given their alluvial setting, these River Styles have been the most sensitive to change in the period post-European settlement. In many instances, there have been profound off-site impacts. Three laterally-unconfined River Styles are found in the base of the escarpment landscape unit. The **Channelised fill** River Style is characterised by a deeply incised trench that can extend over 150 m wide and 12 m deep. The channel bed is characterised by sand sheets, lateral bars and in some cases a discontinuous, swampy low flow channel. Along the channel margins, inset features record phases of cut-and-fill activity (Fryirs and Brierley, 1998 a). The **Intact valley fill** River Style is characterised by an unincised swamp that covers the entire valley floor. A channel is absent or discontinuous. These River Styles store large volumes of material and are pre-disturbance remnants of the Channelised fill River Style. The third Laterally-unconfined River Style that is found in the base of the escarpment landscape unit is a **Low sinuosity boulder bed** River Style. The floodplain surfaces along this River Style have a convex profile. Lobes of coarse grained boulders have been deposited in a fan-like feature. A primary, wide, deep channel down the central axis of the valley is characterised by an assemblage of boulder dominated geomorphic units including cascades, boulder bars, islands, etc.

Only one Laterally-unconfined River Style has a discontinuous channel. The **Floodout** River Style is located in the rounded foothills, in one subcatchment. This River Style accumulates materials from upstream. The swampy intact valley fill surface also comprises local sand sheets which are deposited in lobe-like forms. These deposits become finer in a downstream direction. In many ways, this River Style is an analogue for numerous former river courses in the Bega Valley (Brierley and Fryirs, 1998; Brierley et al., 2002).

Finally, the **Low sinuosity sand bed** River Style is set within the wide valley of the lowland plain landscape unit. This River Style has an extensive, continuous floodplain. The macrochannel is wide, relatively shallow and has a straight alignment. It is characterised by large vegetated ridges, mid-channel and bank-attached bars, sand sheets and densely vegetated channel-marginal benches. Locally, an anabranching network is evident within the channel zone, as instream geomorphic units are reworked within the macrochannel. The floodplain, which is characterised by proximal levees and distal backswamps, has been inundated by sand sheets. Floodplain reworking is evidenced by floodchannels.

4.3.2 Catchment-wide assessment of the distribution of River Styles

Table 4.15 outlines the stream lengths and percentage of total river course for each River Style in Bega catchment. In **Table 4.16** the stream lengths for each River Style are shown for each subcatchment.

Table 4.15 Stream lengths for each River Style in Bega catchment

RIVER STYLE	Length (km)	% of total stream length in catchment
Steep headwater	28	5.5
Gorge	80	16.1
Confined valley with occasional floodplain pockets	196	39.2
Partly confined valley with bedrock-controlled discontinuous floodplain	56	11.3
Intact valley fill	10	2.0
Floodout	2	0.4

Channelised fill	64	12.8
Low sinuosity boulder bed	13	2.7
Low sinuosity sand bed	46	9.3
Brogo Dam	4	0.8
	Total 499	

The Confined valley with occasional floodplain pockets River Style occurs along 39 % of all river courses in the catchment, with a total stream length of around 200 km. The largest continuous length of this River Style occurs along the Bemboka-Bega River trunk stream at 52 km. Along this river course four other River Styles occur. The Steep headwater and Gorge occupy the upstream areas, whereas the Low sinuosity boulder bed occurs at the base of the escarpment and the Low sinuosity sand bed River Style is evident along the lowland plain. The Low sinuosity boulder bed River Style extends just over 13 km (representing around 3 % of total river course) and occurs nowhere else in the catchment. The Bega and Brogo trunk streams are the only river courses that have the Low sinuosity sand bed River Style. At 46 km of river length, this River Style occurs along 9 % of the total river course length in Bega catchment.

The Channelised fill River Style occurs along 64 km or around 13 % of total river course in Bega catchment. There are eight occurrences of this River Style along eight different river courses. Each section is between 3 km and 10 km in length. This River Style is only found along tributary systems. Similarly, the Partly confined valley with bedrock-controlled discontinuous floodplain River Style is only found along tributary river courses. This River Style occupies short sections of river course between 3 km and 9 km in length. There are 12 occurrences of this River Style along ten river courses with a combined length of around 56 km, representing around 11 % of the total river course length in Bega catchment.

The Gorge and Steep headwater River Styles comprise approximately 80 km and 28 km of river courses, representing around 16 % and 6 % of river courses in the catchment respectively. The Gorge River Style occurs in all subcatchments, while the Steep headwater River Style only occurs in those subcatchments that extend atop the escarpment. If combined with other lower order drainage lines, these River Styles would occupy a much more significant proportion of the catchment (i.e. this analysis has been restricted to primary tributaries, and does not include the majority of first order streams).

Only small sections of river course are occupied by the Intact Valley fill and Floodout River Styles. The Intact valley fill River Style occurs twice, extending over reaches of 4-6 km in length. This represents only 2 % of river courses in the catchment. Again, if combined with lower order drainage lines that contain small swampy fills, this number would increase. The Floodout River Style occurs in only one location in the catchment. It is about 2 km long and occurs along < 1 % of stream length in Bega catchment. The Intact valley fill, Floodout and Low sinuosity boulder bed River Styles are rare rivers in this catchment.

In subsequent analyses of condition, recovery potential and management prioritisation, some of these River Styles are broken into shorter reaches (e.g. along the Confined valley with occasional floodplain pockets River Style along Bemboka River).

Table 4.16 Stream lengths for each River Style in each subcatchment

Subcatchment/River style	Stream length (km)	Totals for each subcatchment (km)
Greendale		
Gorge	0.24	
Channelised fill	3.93	
Bedrock controlled discontinuous floodplain	0.89	5.07
Frogs Hollow		
Gorge	0.30	
Intact valley fill	4.04	
Confined with occasional floodplain pockets	1.17	
Floodout	1.96	
Confined with occasional floodplain pockets	6.64	14.12
South Wolumla		
Gorge	0.25	
Channelised fill	6.05	
Bedrock controlled discontinuous floodplain	2.90	
Confined with occasional floodplain pockets	1.13	10.33
Wolumla		
Gorge	0.28	
Channelised fill	6.36	
Bedrock controlled discontinuous floodplain	5.15	
Confined with occasional floodplain pockets	9.03	20.82
Towridgee		
Gorge	0.25	
Intact valley fill	5.72	
Confined with occasional floodplain pockets	1.00	6.97
Candelo		
Steep headwater	2.30	
Gorge	0.73	
Bedrock controlled discontinuous floodplain	4.04	
Confined with occasional floodplain pockets	19.88	

Bedrock controlled discontinuous floodplain	4.00	30.93
Reedy		
Gorge	0.33	
Channelised fill	8.74	
Bedrock controlled discontinuous floodplain	0.83	9.90
Tantawangalo		
Steep headwater	15.62	
Gorge	1.33	
Bedrock controlled discontinuous floodplain	6.79	
Confined with occasional floodplain pockets	19.94	
Bedrock controlled discontinuous floodplain	8.29	
Confined with occasional floodplain pockets	8.30	60.27
Sandy		
Gorge	0.58	
Channelised fill	8.45	
Confined with occasional floodplain pockets	4.79	
Bedrock controlled discontinuous floodplain	9.11	
Confined with occasional floodplain pockets	2.94	25.87
Colombo		
Gorge	0.75	
Channelised fill	7.33	
Bedrock controlled discontinuous floodplain	3.94	
Confined with occasional floodplain pockets	0.84	12.86
Pollacks Flat		
Gorge	0.27	
Channelised fill	9.98	
Confined with occasional floodplain pockets	1.01	11.26
Bemboka/Bega		
Steep headwater	3.63	
Gorge	0.59	
Low sinuosity boulder bed	4.05	
Confined with occasional floodplain pockets	51.63	
Low sinuosity sand bed	3.05	
Low sinuosity sand bed (below Brogo River confl.)	10.70	
Confined with occasional floodplain pockets (Bottleneck reach)	9.24	82.89
Brogo		
Gorge	32.15	
Confined with occasional floodplain pockets	31.58	
Low sinuosity sand bed	25.14	88.87

House		
Gorge	3.52	
Bedrock controlled discontinuous floodplain	4.05	
Confined with occasional floodplain pockets	5.45	13.02
Double		
Gorge	11.77	
Bedrock controlled discontinuous floodplain	5.85	
Confined with occasional floodplain pockets	15.77	33.38
Numbugga		
Gorge	0.29	
Channelised fill	7.13	
Confined with occasional floodplain pockets	6.95	14.36

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

Controls on the character and behaviour of River Styles in Bega catchment are summarised in **Table 4.17** and **Figures 4.22** and **4.23**. **Figure 4.22** summarises the differences between each River Style in terms of their position in the catchment (determined by the landscape unit in which they occur), their slope and valley confinement. **Figure 4.23** shows a plot of the catchment area-slope relationship for each reach of each River Style in the catchment similar to that produced by Montgomery et al. (1996). When combined, these analyses show that a distinct set of attributes and controls dictates the character and behaviour of each River Style in Bega catchment. **Figure 4.23** shows the clumping of each River Style within a certain catchment area-slope range. These controls are discussed for each River Style in **Section 4.4.1** and more specifically in relation to downstream patterns of River Styles in **Section 4.4.2**.

Figure 4.22 Summary controls on the character and behaviour of River Styles in Bega catchment

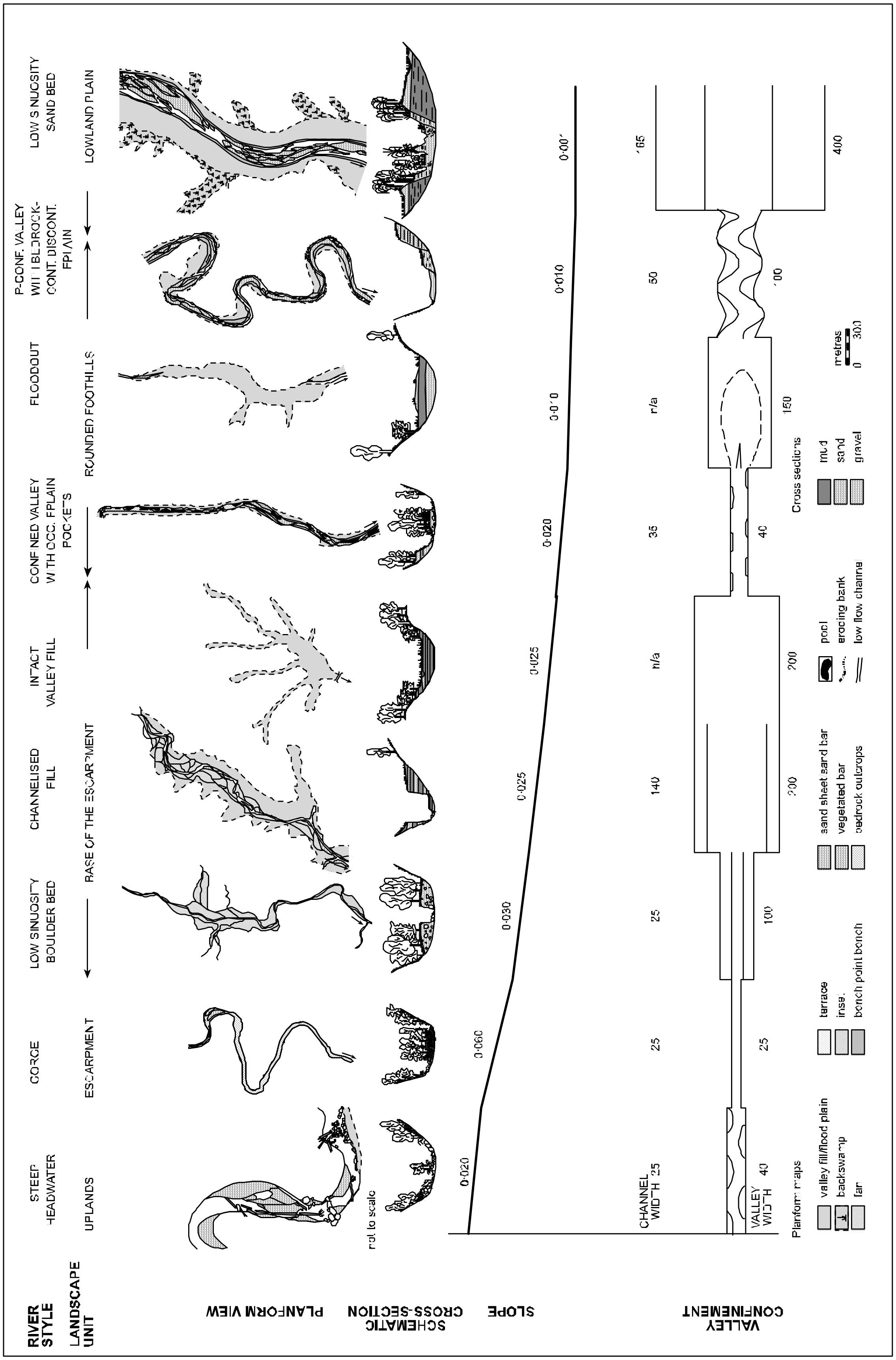
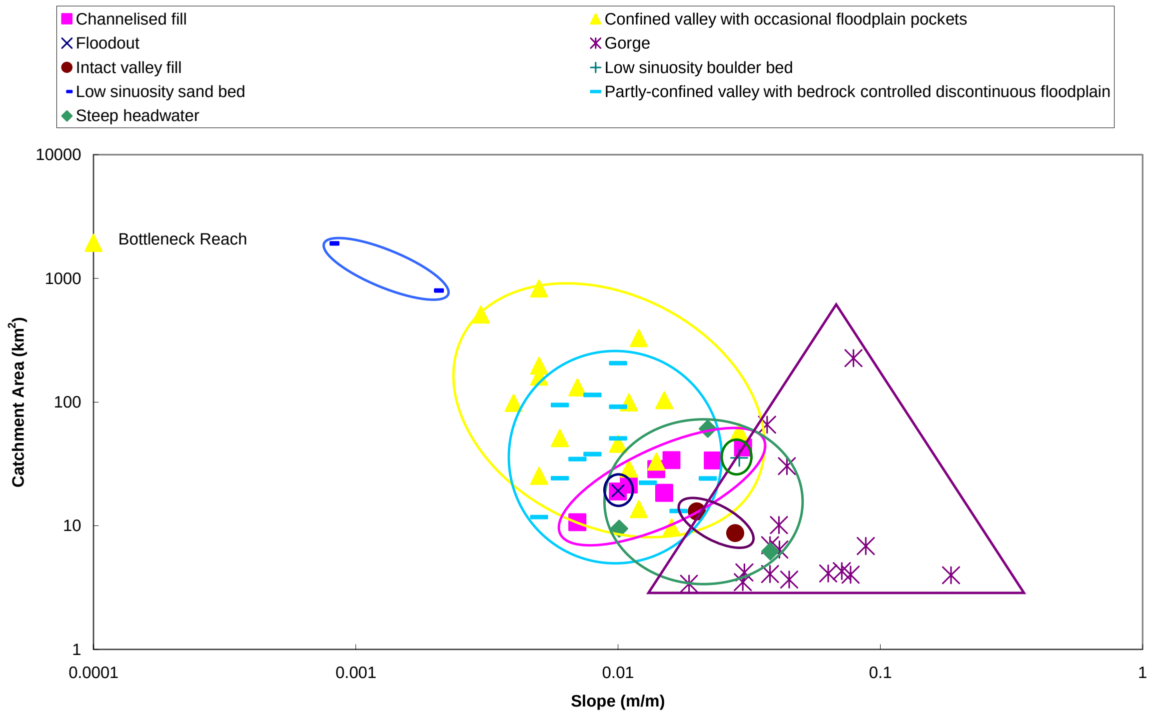


Figure 4.23 Catchment area- slope plot for reaches of differing River Styles in Bega catchment (based on Montgomery et al., 1996). Note that the population boundaries are schematic only.



4.4.1 Controls on the character and behaviour of River Styles in Bega catchment

The **Steep headwater** River Style is set within a dissected plateau atop the escarpment. Valley slope and alignment dictates the local morphology and assemblage of geomorphic units of this River Style. Valley widths are narrow, and slopes are relatively high (around 0.020 m/m). Given that these are the most upstream River Styles, catchment areas are low, but generally >20 km^2. The high slope-low catchment area relationship, results in high unit stream powers estimates for floods up to the 5 year recurrence interval event (> 400 Wm^{-2}).

The **Gorge River Style** is set within a deeply incised v-shaped, narrow valley (<40 m wide). Located within the escarpment zone of all subcatchments, this River Style is the steepest in the catchment (0.040-0.080). In those subcatchments where this is the most upstream River Style, catchment areas are low, whereas in those subcatchments which extend beyond the escarpment, catchment areas are up to 135 km^2. Gorge reaches sit quite distinctly on the slope-catchment area plot, with a relatively high slope-low catchment area relationship. Given the high slopes and confined valley-setting, unit stream powers are the highest in the catchment, with estimate > 2000 Wm^{-2} for events of 10 year recurrence or greater.

The **Confined valley with occasional floodplain pockets** River Style is found in elongate valleys of the tributaries and trunk streams (width 20-240 m). Valley slope is generally high (up to 0.029 m/m along tributaries), but highly variable given the bedrock character of the channel bed. Given the widespread distribution of this River Style in Bega catchment, upstream catchment areas are highly variable. The slope-catchment area range for this River Style demonstrates significant overlap with other confined and partly confined River Styles. This results in a wide range of formative (bankfull-stage) flows (from 2 to 100 years). In general, floodplains are absent and all flows utilise the entire valley floor. Elsewhere, occasional floodplain pockets up to several metres thick characterise one valley margin. Given the confined valley setting and relatively steep slopes, tributary reaches of this River Style generate among the highest stream powers in the catchment. Unit stream powers range from around 165 Wm^{-2} for a 1 in 2 year event to over 1500 Wm^{-2} for the 1 in 100 year event. Sediments are readily reworked (i.e. flushed downstream) along these river courses. Lower slopes along the trunk stream result in lower unit stream power estimates for this River Style, ranging from around 100 Wm^{-2} for the 1 in 2 year event to over 700 Wm^{-2} for the 1 in 100 year event. Given their expanded channels, formative (bankfull) flows for this River Style reflect high magnitude-low frequency events.

The **Partly-confined valley with bedrock-controlled discontinuous floodplain** River Style is formed in a sinuous valley (valley sinuosity > 1.44). Hence, the primary control on channel alignment is valley configuration. The valleys are generally wider (up to 210 m) and slopes gentler (0.005-0.012 m/m) than the Confined valley with occasional floodplain pockets River Style. However, these reaches drain similar catchment areas and are located at a similar position in the catchment. Hence, the slope-catchment area range for this River Style overlaps significantly with reaches of the Confined with occasional floodplain pockets River Style. Along the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style, bankfull events occur infrequently (> 1 in 10 years). Tributary reaches of this River Style generate among the lowest stream powers of all tributary River Styles (with the exception of the unchannelised Intact valley fill and Floodout River Styles). This reflects the gentler slopes and wide valleys in which this River Style forms. Unit stream powers range from around 95 Wm^{-2} for the 1 in 2 year event to 1030 Wm^{-2} for the 1 in 100 year event. These conditions effectively rework and redistribute the material stored in this River Style, maintaining roughly balanced sediment input and output via transfer mechanisms.

Table 4.17 Controls on river character and behaviour in Bega catchment

River style	Valley slope	Valley width (m)	Catchment area (km^2)	Unit stream power (Wm^{-2})					Formative (bankfull) recurrence interval (years)
				1 in 2	1 in 5	1 in 10	1 in 50	1 in 100	
Steep headwater	0.02	40	>20	180	415	500	270	390	N/a
Gorge	0.04-0.08	10-40	0-135	685	1730	2305	2530	2770	N/a
Channelised fill	0.005-0.03	< 300	<20	100	125	440	1020	1140	>100
Intact valley fill	0.020-0.028 (valley fill surface)	200	<20	3	4	25	70	100	n/a
Low sinuosity boulder bed	0.03	100	>50	70	90	390	900	1190	-
Confined with occasional floodplain pockets (trunk)	0.004-0.006	60-240	100-1000	100	130	390	640	730	>100
Confined valley with occasional floodplain pockets (tributaries)	0.005-0.029	20-80	20-325	165	210	680	1270	1520	2-50
Floodout	0.010 (valley fill surface)	150	<30	3	4	25	70	100	n/a
Partly-confined valley with bedrock-controlled discontinuous floodplain	0.005-0.012	40-210	30-200	95	120	410	820	1030	10-50
Low sinuosity sand bed	0.002-0.0008	100-650	500-1840	30	35	95	220	280	5-10

The **Channelised fill** River Style is located in wide funnel-shaped laterally-unconfined valley settings (valley width <300 m) that occur downstream of distinct breaks in slope at the base of the escarpment. The downstream boundary of the River Style is characterised by a narrowing of the valley or a bedrock step behind which the valley fill accumulates (Fryirs, 2002). Reaches of this River Style drain small catchment areas (<20 km^2), and are found in subcatchments that drain directly from the escarpment zone. The slope of the valley floor is relatively high (up to 0.03 m/m). Surprisingly, these River Styles have a relatively high slope-low catchment area relationship that overlaps with some of the more confined, bedrock-controlled River Styles. Given the deep, wide trench, all flows including the 1 in 100 year event are contained within the channel. For the small catchment areas they drain, the Channelised fill River Style generates high stream powers. Estimates of unit stream power are roughly equivalent to the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style, but these flows are generated in catchment areas half the size or less. This reflects flow containment within the channel and steep slopes at the base of the escarpment. Unit stream powers range from around 100 Wm^{-2} for the 2 year event to over 1100 Wm^{-2} for the 100 year event. Hence, even small events have the potential to rework large volumes of sediment stored in the incised trench.

The **Intact valley fill** River Style is found in an equivalent valley-setting to the Channelised fill River Style. Valley width extends up to 200 m. In contrast to their incised counterparts, the Intact valley fill River Style generate very low stream powers, as flow energy is dissipated over unincised valley fill surfaces, with dense tussock grass associations. Unit stream powers generated on surfaces such as Frogs Hollow Swamp and Ryans Swamp (in Towridgee subcatchment) range from around 3 Wm^{-2} for the 1 in 2 year event to around 100 Wm^{-2} for the 1 in 100 year event. Under these conditions it is difficult for incision to be initiated (Prosser and Slade, 1994). However, with concentration of flow in a continuous channel, and the generation of high stream powers in River Styles located immediately downstream of these features, headcuts retreat quickly through these fills. Interestingly, the surface slope of the valley fills is relatively high at between 0.020-0.028 m/m. Indeed, the high slope-low catchment area relationship overlaps with the range of the Steep headwater River Style.

The **Low sinuosity boulder bed** River Style is formed in steep (0.030 m/m) valleys at the base of the escarpment. Valleys are moderately wide (up to 100 m) and drain a large catchment area (>80 km^2). Equivalent types of deposits are found beneath valley fills in Channelised fill valleys. In the only 'surface' example, along Bemboka River, large discharges have prevented extensive sediment accumulation, leaving these features exposed. Unit stream powers are high for the largest of flood events with modelled values of over 900 Wm^{-2}. These high energy, high slope conditions at the base of the escarpment efficiently flush virtually all sediments other than coarse boulders downstream.

The only remaining example of the **Floodout** River Style is formed in a wide, mid-catchment laterally-unconfined valley (up to 150 m), on a moderately low slope (around 0.010 m/m). Sediment supply to mid catchment locations and the formation of floodouts is directly linked to sediment supply from gullying into base of escarpment valley fills. Estimates of unit stream power are low (ranging from around 3 Wm^{-2} for the 1 in 2 year event to just over 100 Wm^{-2} for the 1 in 100 year event). This reflects the dissipation of flow energy and deposition of sand lobes over a wide intact valley floor. Given the high stream powers generated in River Styles both upstream and downstream of these features, headcuts may retreat quickly once initiated, releasing large volumes of sediment.

The **Low sinuosity sand bed** River Style occurs along the lowland plain of the Bega-Brogo trunk stream, where the valley extends up to 650 m wide, and the slope is gentle (0.002-0.0008 m/m). This River Style does not occur along any tributary. Given the large upstream catchment area (> 500 km^2), low slopes and wide valley, extensive floodplains with backswamps have developed. Given its position in the catchment, this is the only River Style in Bega catchment with a relatively low slope-high catchment area relationship. Overbank events occur frequently (every 5-10 years) as a result of the wide, shallow channel and high discharges that characterise these sections of the catchment. Floodchannels are backflooded in the 1 in 5 year event, as these features often lie lower than the trunk stream channel. Backswamps, however, are only inundated in events that exceed bankfull stage. The low slope, and flow dispersion over the extensive floodplain, result in low estimates of unit stream power, ranging from around 30 Wm^{-2} in the 1 in 2 year event to around 280 Wm^{-2} in the 1 in 100 year event. Unlike other River Styles that contain a continuous channel, unit stream power does not exceed 100 Wm^{-2} until events greater than the 1 in 10 year event.

4.4.2 Controls on the downstream patterns of River Styles in Bega catchment

River character and behaviour in Bega catchment is dictated by topographic controls exerted by longer term landscape evolution (see Fryirs, 2002, Fryirs and Brierley, 2001). Each River Style is found at a particular position within the catchment, reflecting a distinct response to imposed boundary conditions (**Figures 4.20 & 4.22**; **Table 4.17**). As a consequence of differing patterns of controls in differing subcatchments, the downstream sequence of River Styles varies from subcatchment to subcatchment. This results in significant within-catchment variability in the connectivity of biophysical processes along rivers, with associated implications for the downstream transfer of water and sediment.

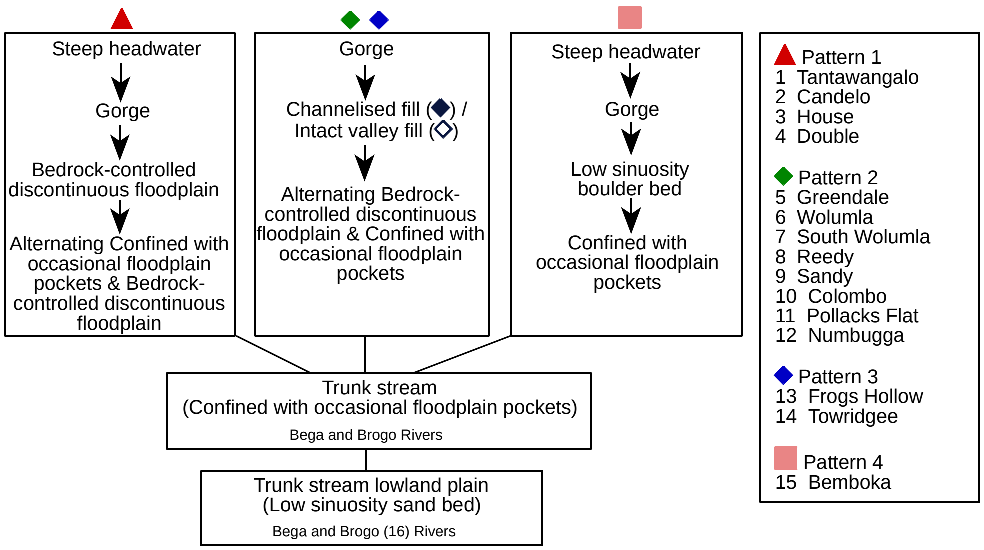
In this section, representative examples of each downstream pattern of River Styles in Bega catchment are used to demonstrate the longitudinal controls on river character and behaviour. Note that gross stream power and contributing area are plotted over the long profile, and a series of other parameters including valley confinement, sediment regime etc. are plotted below the long profile. Trends and relationships are described for each.

Four downstream patterns of River Styles were identified in Bega catchment (see Brierley and Fryirs, 2000 and **Figures 4.20** and **4.24**).

- Pattern 1 occurs in subcatchments where headwaters are transitional to long, elongate, bedrock-controlled valleys downstream of the escarpment.
- Patterns 2 and 3 occur in subcatchments with wide valley settings at the base of the escarpment in which extensive Holocene fills have formed (Pattern 2 rivers have channelised fills, Pattern 3 rivers have intact valley fills).
- Pattern 4 occurs in subcatchments in which boulder fans at the base of the escarpment are transitional to bedrock-controlled valleys and the lowland plain.

These downstream patterns of River Styles are controlled, in large part, by the valley setting conditions at the base of the escarpment which reflect antecedent landscape evolution associated with long-term escarpment retreat (Fryirs, 2002). This dictates the contemporary valley morphology and sediment storage and supply in this catchment (Fryirs, 2002; Fryirs and Brierley, 2001). The position of the escarpment within each subcatchment, the catchment area draining from atop the escarpment, valley morphology (especially accommodation space), and the shape of the valley longitudinal profile are primary controls on river character and behaviour, and produce distinctive valley types at the base of the escarpment. Based on differing combinations of valley morphology, slope and upstream catchment areas, four differing River Styles are found at the base of the escarpment, namely Channelised fill, Intact valley fill, Partly-confined valley with bedrock controlled discontinuous floodplain and Low sinuosity boulder bed River Styles (Fryirs, 2002). Each of these River Styles has a different capacity to store and rework alluvial sediments.

Figure 4.24 The downstream patterns of River Styles in Bega catchment (colours denote the downstream pattern of River Styles noted in Figure 4.22)

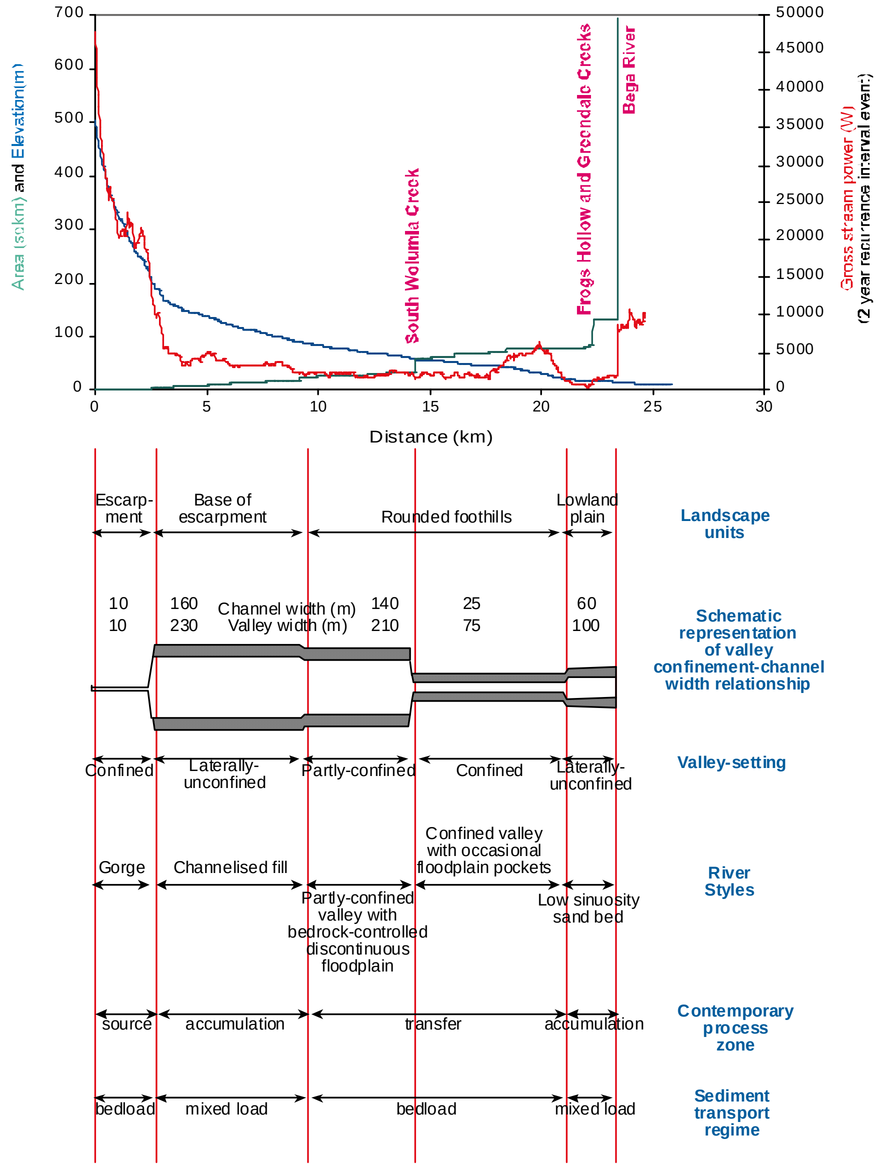


4.4.2.1 Pattern One: Subcatchments with the Channelised fill River Style at the base of the escarpment

The headwaters of most subcatchments in Bega catchment lie in either the uplands or escarpment landscape units, resulting in smooth, concave-up longitudinal profiles with a gentle break in slope at the base of the escarpment. Where the uplands landscape unit is absent, the downstream pattern of River Styles follow Patterns 1 and 2, which are distinguished by the occurrence of the Channelised Fill and Intact Valley fill River Styles at the base of the escarpment. A representative example of Pattern 1 is presented for Wolumla subcatchment in **Figure 4.25**. In this subcatchment, broad asymmetrical valleys, just downstream of the gentle break in slope at the base of the escarpment, provide the boundary conditions for the characteristic Channelised fill River Style. The downstream margin of these valleys is characterised by either a significant narrowing of the valley or a bedrock step that gives the valley a funnel shape. Large accommodation spaces store significant volumes of material behind this constriction. The formation of these laterally-unconfined valley settings is a direct result of interactions between escarpment retreat and valley-sidewall expansion (see Fryirs, 2002). When infilling, these valleys are characterised by the Intact valley fill River Style (see Pattern 2). When cutting, these valleys are characterised by the Channelised fill River Style. Eight subcatchments in Bega catchment display a Pattern 1 sequence.

In the rounded foothills of Pattern 1 subcatchments, the Confined valley with occasional floodplain pockets and the Partly-confined valley with bedrock-controlled discontinuous floodplain River Styles extend to the trunk stream.

Figure 4.25 Controls on the downstream pattern of River Styles along Wolumla Creek



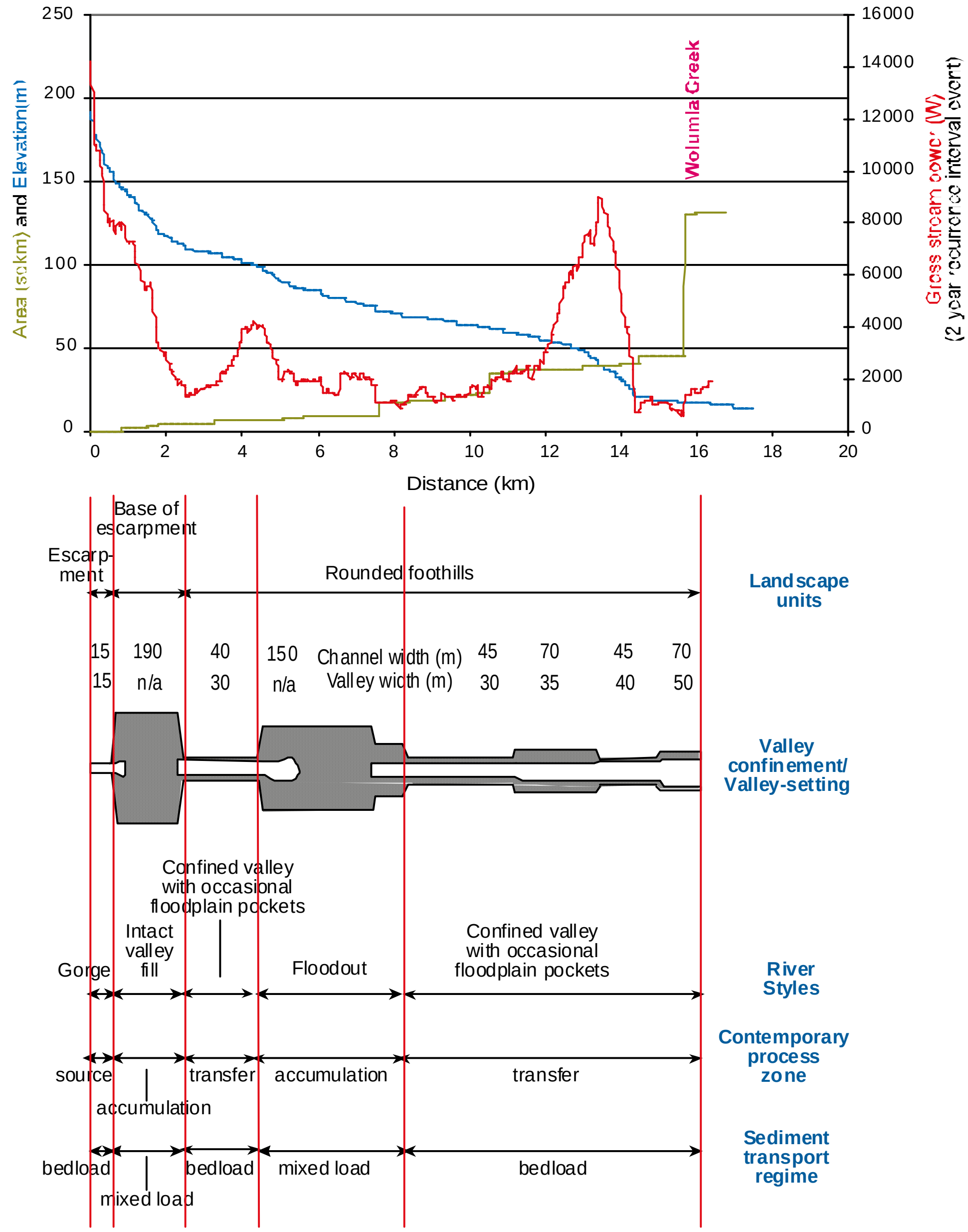
Unlike the classical downstream sequence of channel geometries and process zones along long profiles presented by Church (1992) and Schumm (1977), streams along this pattern of River Styles have large laterally-unconfined valleys with wide, deep channels at the base of the escarpment. These channels are mixed load in composition, with sand and mud accumulating on the channel bed. These drain into narrow, shallow channels in the confined and partly-confined valley-settings in the middle and lower sections of the catchment. These bedrock-controlled valley-settings transfer bedload materials through to the lowland plain.

The highest gross stream powers are generated in the escarpment zone of these catchments. Beyond the escarpment, gross stream powers are relatively high in both the Channelised fill and Confined valley with occasional floodplain pockets River Styles. This indicates the significant potential for flow to rework sediments stored along these river courses, especially in the Channelised fill settings, and to throughput materials within the confined valley-setting. Gross stream power tends to be lower along reaches of the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style in the middle sections of the catchments.

4.4.2.2 Pattern Two: Subcatchments with the Intact valley fill River Style at the base of the escarpment

Only two subcatchments exhibit the downstream pattern of River Styles with the Intact valley fill River Style at the base of the escarpment (Frogs Hollow Creek and Towridgee Creek, **Figure 4.20**). The pattern of River Styles in Frogs Hollow subcatchment is also characterised by a Floodout River Style in part of the rounded foothills landscape unit. This example is shown in **Figure 4.26**. Landscape unit configuration and valley confinement/valley-settings are equivalent along Pattern 1 and 2 rivers. The Intact valley fill River Style is found in an equivalent valley-setting to the Channelised fill River Style, and its mechanisms of formation are analogous. The Floodout River Style is found in similar settings to the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style along Pattern 1 rivers. Should the Floodout and Intact valley fill sections of these river courses become incised, the downstream sequences indicated in **Figures 4.25** and **4.26** would become directly equivalent. Hence, the controls on river character and behaviour tend to be equivalent along Patterns 1 and 2. The striking difference along Pattern 2 rivers is the discontinuity of the water courses, with intact valley fills and floodouts extending along the majority of the length. As a result of this channel discontinuity, gross stream powers tend to be low along these river courses. This reflects dissipation of flow energy over extensive valley floors. Given that the Intact valley fill and Floodout River Styles store significant volumes of material within large accommodation spaces, sediment accumulation zones are found along the length of the river course and mixed load/suspended load deposition dominates. Very little sediment is transferred along these river courses. Base flow retention in swamps is also high.

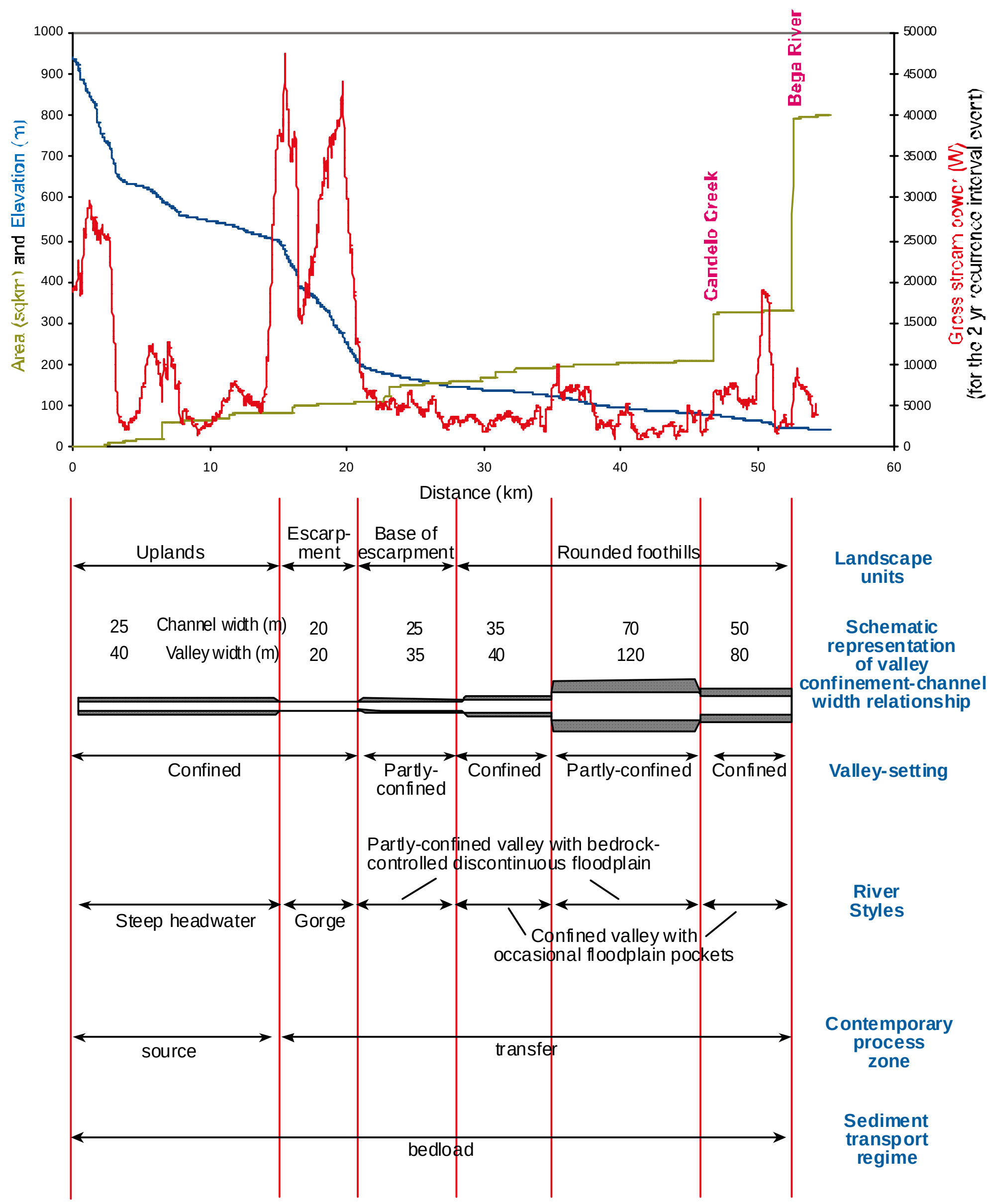
Figure 4.26 Controls on the downstream pattern of River Styles along Frogs Hollow Creek



4.4.2.3 Pattern Three: Subcatchments with the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style at the base of the escarpment

There are two subcatchments in which the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style is found at the base of the escarpment (Tantawangalo and Candelo; see **Figure 4.20**). These subcatchments have narrow, elongate valleys that extend along their entire length. Valley morphology is dominated by Confined and Partly-confined valley-settings, which alternate along the length of these river courses. Hence, no Laterally-unconfined River Styles are found along these water courses and bedload materials are effectively transferred or flushed through the system. A schematic representation of downstream changes in channel and valley width along the longitudinal profile of Tantawangalo Creek is shown in **Figure 4.27**.

Figure 4.27 Controls on the downstream pattern of River Styles along Tantawangalo Creek



These subcatchments drain extensive areas of the uplands landscape unit characterised by the Steep headwater River Style. This extends downstream into the Gorge River Style in the escarpment zone, where slopes are steepest and rivers are set within v-shaped, deeply incised valleys. At the base of the escarpment, a Partly-confined valley with bedrock-controlled discontinuous floodplain River Style occurs. These River Styles are found where there is an abrupt break in slope at the base of the escarpment and there is a lack of a downstream constriction in the valley morphology. In contrast to the laterally-unconfined rivers found at the base of the escarpment along Pattern 1 and 2 rivers, it is proposed here that the rate of escarpment retreat has been greater than the rate of valley sidewall retreat along Pattern 3 rivers, leading to the formation of narrow, elongate valleys in which a Partly-confined River Style has developed (Fryirs, 2002).

In the rounded foothills, an alternating series of Confined valley with occasional floodplain pockets and Partly-confined valley with bedrock-controlled discontinuous floodplain River Styles extend to the trunk stream. The Confined valley with occasional floodplain pockets River Style is found in the narrow and steeper sections of these tributaries, while reaches of Partly-confined valley with bedrock-controlled discontinuous floodplain River Style are formed in wider, sinuous valleys which have gentler slopes.

Along this downstream pattern of River Styles, valley width changes little downstream, only widening in the lower part of the rounded foothills setting. There is an equivalent pattern of minimal downstream change in channel width. Only occasional or discontinuous pockets of narrow, shallow floodplain are formed along these river courses.

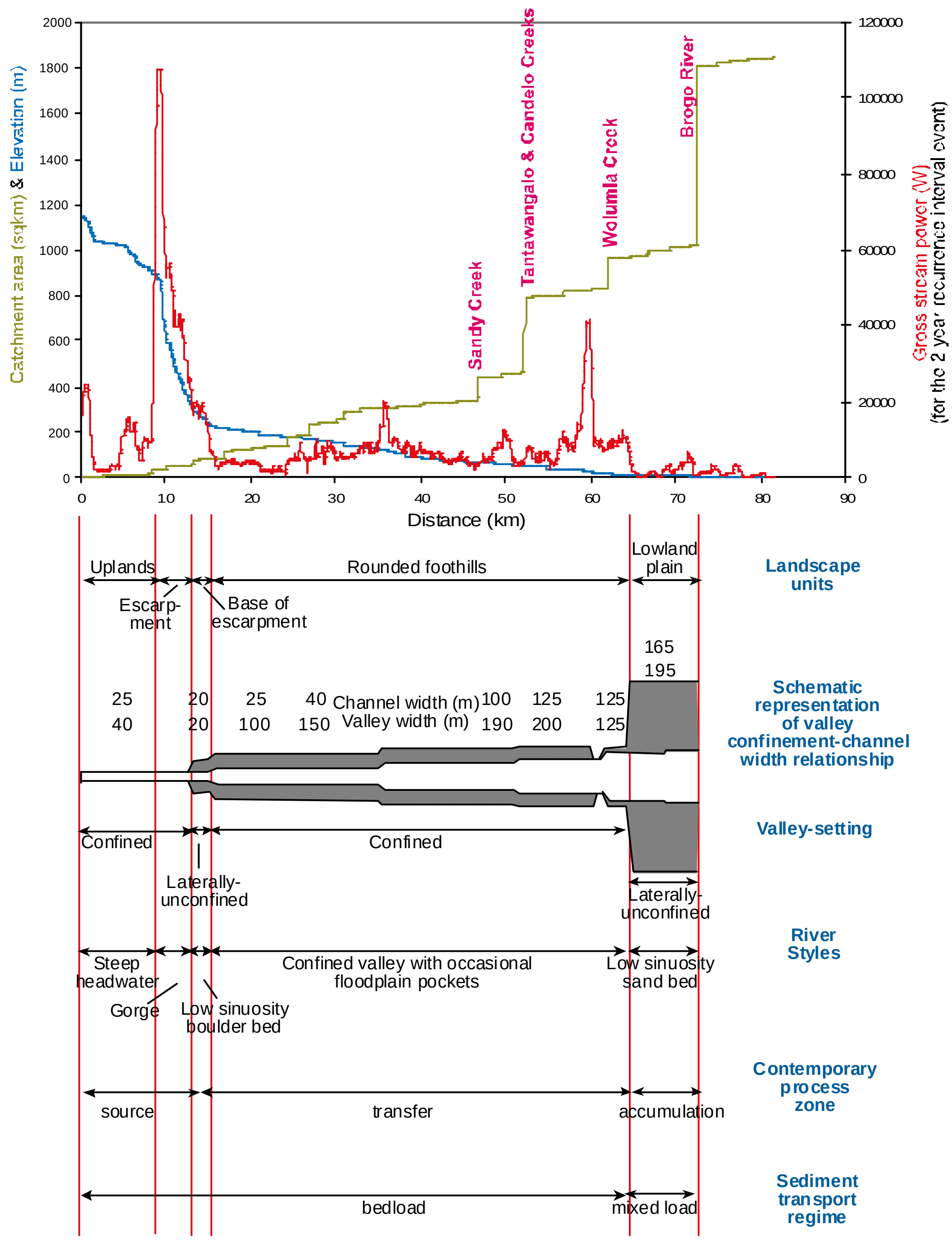
Gross stream power throughout this pattern of River Styles is consistently high, with peaks occurring in the steepest sections of the uplands, in the escarpment zone and along the Confined valley-setting along the lower course of these rivers. Not surprisingly, the peak in gross stream power occurs in the escarpment zone where slopes are steepest and there is significant discharge to produce high stream powers. These gross stream powers are the highest in the catchment.

4.4.2.4 Pattern Four: Subcatchments with the Low sinuosity boulder bed River Style at the base of the escarpment

The final downstream pattern of River Styles is found along the trunk streams where a Low sinuosity boulder bed River Style is found at the base of the escarpment (**Figure 4.20**). The Bega River is represented in **Figure 4.28**. The Steep Headwater River Style drains significant catchment area in the uplands landscape unit. The longitudinal profile has a distinct step in the escarpment zone where the Gorge River Style is formed. Beyond the escarpment, the longitudinal profile has a relatively smooth, concave-upwards form. Associated with this progressive downstream change in slope, there is progressive downstream widening of both the channel and the valley through the base of the escarpment, the rounded foothills and the lowland plain landscape units.

The Low sinuosity boulder bed River Style occurs at the base of the escarpment where slopes are high and flow exits from the escarpment zone. Large boulder fans have formed in this setting. Like Pattern 3 rivers, there is a lack of a valley constriction along the downstream margin of the base of escarpment landscape unit. The lack of constriction prevents the accumulation of valley fills at the base of the escarpment. Instead, bedload materials are transferred through the system, until they reach the lowland plain where they accumulate.

Figure 4.28 Controls on the downstream pattern of River Styles along Bemboka-Bega River



Along the majority of the Bega-Bemboka trunk stream, the Confined valley with occasional floodplain pockets River Style occurs. As catchment area and discharge increase with inputs from the numerous tributaries, gross stream powers along this River Style progressively increase in a downstream direction. Peaks occur where bedrock steps occur in the longitudinal profile (e.g. at ~60km where Kanooka nickpoint is located). It is not until the valley widens and slope decreases significantly around the Wolumla Creek confluence that the transition to a Low sinuosity sand bed River Style occurs. This transition coincides with the start of the lowland plain landscape unit and a drop in the gross stream power generated. No Partly-confined valleys are found along this pattern of River Styles in Bega catchment.

The configuration of the catchment, and variable responses to human disturbance experienced by differing River Styles, result in marked variability in geomorphic condition across Bega catchment, as highlighted in the following chapter.