CHAPTER SIX

STAGE THREE : THE FUTURE TRAJECTORY OF CHANGE AND RECOVERY POTENTIAL OF RIVERS IN BEGA CATCHMENT

6.1 Introduction and outline of this chapter

The analysis of river recovery potential interprets the trajectory of likely future reach adjustments under circumstances in which the reach is not subject to direct intervention (i.e. whether geomorphic condition improves, remains relatively the same, or deteriorates). This analysis is framed in terms of the current trajectory of change under current management practices and predictions of recovery potential based over a 50-100 year timeframe. We recognise explicitly that future river responses/pathways will reflect management strategies. Hopefully, as strategies are implemented, the trajectory and potential for recovery will improve throughout the system. Hence, this assessment provides a contemporary statement of recovery pathways for river courses in Bega catchment. The procedures employed aid determination of the types of measures that can be undertaken to enhance the natural recovery processes of each river course. Adoption of these adaptive management principles requires responses to limiting factors and pressures that operate in the system.

There are two steps in the determination of geomorphic recovery potential in Stage Three of the River Styles framework (**Figure 6.1**).

Figure 6.1 Steps in Stage Three of the River Styles framework

Stage Three, Step One: Determine the trajectory of river change

⇓

Stage Three, Step Two: Assess river recovery potential: Place reaches in their catchment context and assess limiting factors to recovery

In the sections that follow, core products that appraise the geomorphic recovery of rivers across Bega catchment are presented. These include:

Stage Three, Step One

- Recovery diagrams for each River Style noting the trajectory of change of each reach.

Stage Three, Step Two

- Tables and flow diagrams that evaluate limiting factors to recovery operating in the catchment.

- Assessment of likely future pressures that may influence the system's capacity for recovery.
- A 'catchment tree' that outlines the linkage of geomorphic processes and their off-site impacts throughout the catchment.
- A map showing the recovery potential of each reach within the catchment.

6.2 Stage Three, Step One: Determining the trajectory of river change

Assessment of the trajectory of change for each reach of each River Style in Bega catchment was made using procedures outlined in Brierley and Fryirs (2005). The key is to determine where each reach sits on the recovery diagram, and evaluate its likely future trajectory of change. If suitable reaches are available, prediction of potential future target conditions entails space-time transformation (i.e. ergodic reasoning), where field sites that show differing stages of adjustment for the same type of river are used to make inferences about temporal patterns and rates of change. Where no examples existed, prediction was based on geomorphic insight, wherein an assessment is made of how the various geomorphic units that make up a reach are likely to adjust in the future, and how channel capacity and vegetation associations are likely to change.

In Bega catchment, sensitive reaches have experienced irreversible change in River Style and now operate under altered catchment boundary conditions. These reaches are unlikely to regain their pre-disturbance condition. The range of potential recovery trajectories has been reduced and restoration is unachievable over 50-100 years. This scenario is evident for reaches of the Low sinuosity sand bed River Style and Channelised fill River Style, such that *creation* of a new condition is underway.

Those River Styles that have experienced reversible geomorphic change but operate under altered catchment boundary conditions (i.e. rivers in confined and partly-confined valley-settings) have the potential to recover along either a *restoration* or *creation* trajectory. The trajectory taken depends largely on the geomorphic condition of the reach. The poorer the condition of the reach, the lower it sits on the degradation scale of the recovery diagram, and the less likely it is that restoration will occur. Reaches of the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style and Confined valley with occasional floodplain pockets River Style fall into this category.

Those reaches that have experienced reversible geomorphic change and operate under unaltered catchment boundary conditions either remain intact or sit on a *restoration* trajectory. In Bega catchment, these rivers are located in upland and escarpment zone settings (i.e. the Steep Headwater and Gorge River Styles), or are remnants of pre-disturbance geomorphic conditions (e.g. the Intact valley fill, Floodout and Low sinuosity boulder bed River Styles).

6.2.1 Trajectory of change for reaches of the Steep headwater, Gorge and Low sinuosity boulder bed River Styles

All reaches of the Steep headwater, Gorge and Low sinuosity boulder bed River Styles are located in the most upstream reaches of river systems in Bega catchment. The catchment boundary conditions under which these River Styles operate have remained largely unaltered since European settlement. Many reaches of these River Styles are located in National Parks or Reserves. All reaches remain in good geomorphic condition. As these reaches retain their predisturbance structure and function, they are considered to be intact and sit at the top of the degradation pathway on the recovery diagram (**Figure 3.11**). To date, these reaches are yet to move into a degradation phase.

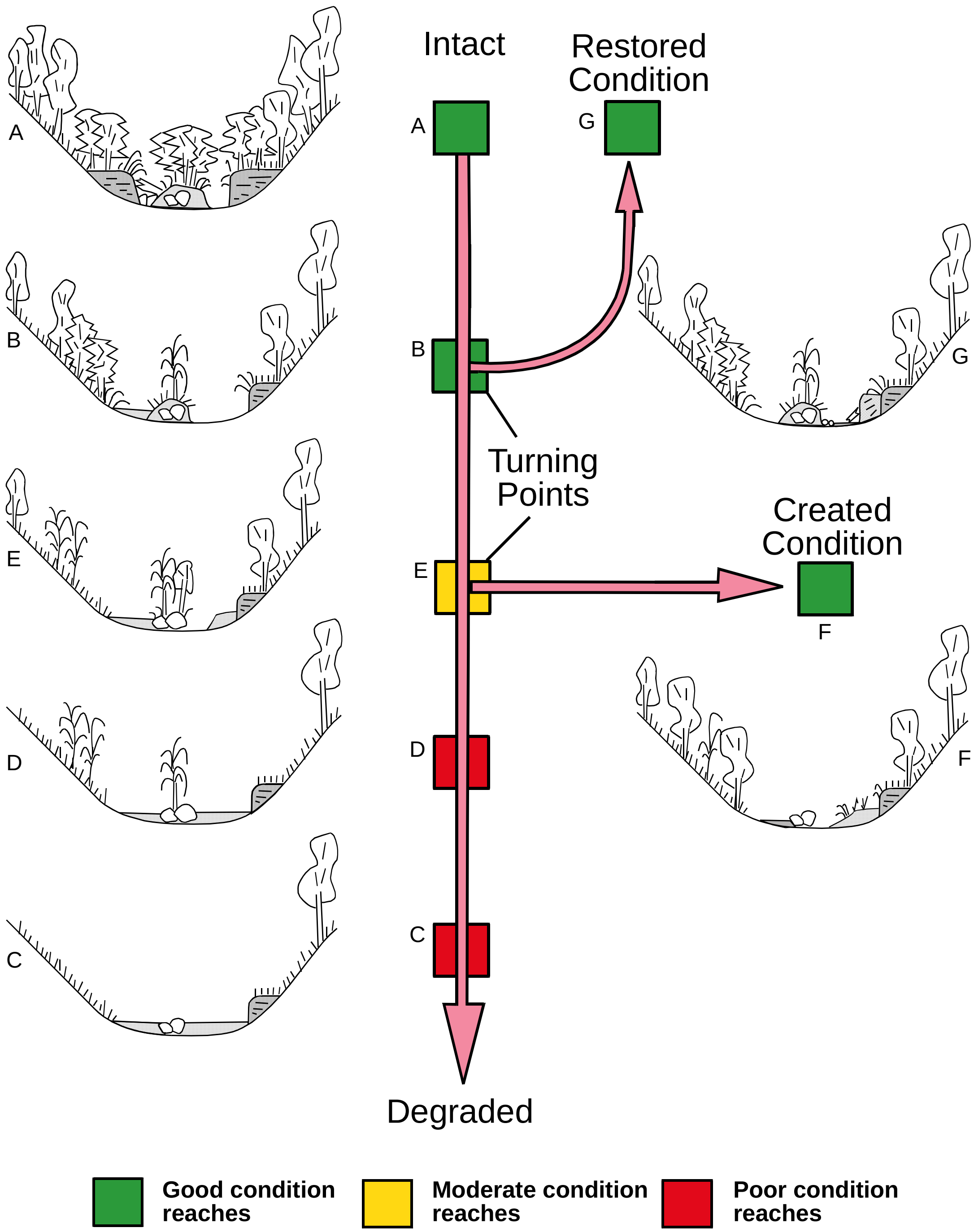
6.2.2 Trajectory of change for reaches of the Intact valley fill and Floodout River Styles

Reaches of the Intact valley fill and Floodout River Styles are the last remaining remnants of discontinuous laterally-unconfined rivers in Bega catchment. The catchment boundary conditions under which they operate have remained largely unaltered following European settlement. All reaches are in good geomorphic condition and display pre-disturbance geomorphic structures. While vegetation associations on the fill surfaces have been altered, reaches are considered to be geomorphologically intact and sit at the top of the degradation pathway on the recovery diagram. They have not yet moved into a degradation phase. Concerted efforts are being made to restore the pre-disturbance vegetation associations of these River Styles.

6.2.3 Trajectory of change for reaches of the Confined valley with occasional floodplain pockets River Style

The boundary conditions under which most reaches of this River Style operate have been altered following European settlement, inducing changes to vegetation, sediment and flow regimes. However, this River Style is resilient to change. As such, the pattern of morphological adjustment, and associated adoption of a restoration or creation pathway, depends on the extent of disturbance and subsequent degradation experienced by these reaches (**Figure 6.2**). No truly intact reaches remain in Bega catchment. However, reaches along Bemboka River, for example, have undergone minimal change. These reaches are considered to sit high on the degradation scale, approaching the turning point. With the re-emergence of pools and the improvement of vegetation associations, these reaches will move onto a restoration pathway with the potential to move back towards a predisturbance state. Those reaches that sit low on the degradation pathway have experienced considerable disturbance following alterations to their catchment boundary conditions. Such reaches, including those along Wolumla Creek and lower Bega River, sit low on the degradation scale. They are characterised largely by sand sheets with (or without) exotic vegetation. Restoration is less likely along these reaches. Rather, creation towards a new geomorphic structure is the more likely pathway of future adjustment.

Figure 6.2 Recovery diagram for the Confined valley with occasional floodplain pockets River Style



6.2.4 Trajectory of change for reaches of the Partly-confined valley with bedrock controlled discontinuous floodplain River Style

Like the Confined valley with occasional floodplain pockets River Style, reaches of this River Style operate under altered catchment boundary conditions. However, the River Style is inherently resilient to change. Hence, depending on the degree of disturbance, reaches may adjust along either creation or restoration pathways (**Figure 6.3**). In Bega catchment, most reaches of this River Style have experienced significant geomorphic change and sit lower on the degradation scale of the recovery diagram. Hence, restoration is unrealistic throughout the catchment. Geomorphic features such as islands and benches, which do not appear at any other stage in the evolutionary sequence, may develop. Channel capacity continues to adjust to the altered catchment boundary conditions. In Bega catchment, only one reach has adjusted towards restoration, along upper Tantawangalo Creek. With sustained recovery, it is likely that there will be a re-emergence of pools along this reach. Increased channel roughness will result in the retention of fine grained sediment and organic matter. Elsewhere in Bega catchment, reaches of this River Style remain on the degradation pathway. A few show initial signs of recovery, such as isolated reaches along Wolumla Creek where benches and point bars store sediment and act to reduce channel capacity. These reaches sit at the turning point to recovery.

6.2.5 Trajectory of change for reaches of the Channelised fill River Style

All reaches of the Channelised fill River Style have experienced irreversible geomorphic change since European settlement. These rivers are sensitive to change and a wholesale shift from the Intact valley fill to Channelised fill River Style has occurred (**Figure 6.4**). Only two examples of an Intact valley fill River Style remain in Bega catchment. For the Channelised fill River Style, restoration is impossible over management timeframes (50-100 years) and this trajectory of change has been eliminated. Reaches of the Channelised fill River Style now operate under altered catchment boundary conditions. Hence, they adjust along the creation trajectory. Most reaches of this River Style sit low on the degradation scale. Reaches along Numbugga and South Wolumla Creeks, for example, continue to adjust to disturbance. However, there are also some reaches, such as those along Wolumla Creek, which sit at the turning point, and show signs of geomorphic recovery such as the formation of inset benches and the accumulation and storage of sediment on the channel bed. This indicates that the filling phase of this cut-and-fill river type is under way. However, depending on the nature of future flood events, this reach could move back along the degradation pathway if disturbance is severe and sediment evacuated, or onto a creation trajectory if sediment can be stabilised. The only reach in the catchment that shows significant recovery is along Reedy Creek. In this instance, fine grained materials and discontinuous swampy channels are reforming along the bed of the incised trench. With rehabilitation and replacement of exotic vegetation, and maintenance of the swamp, a created condition is possible along this reach.

Figure 6.3 Recovery diagram for the Partly-confined valley with bedrock controlled discontinuous floodplain River Style

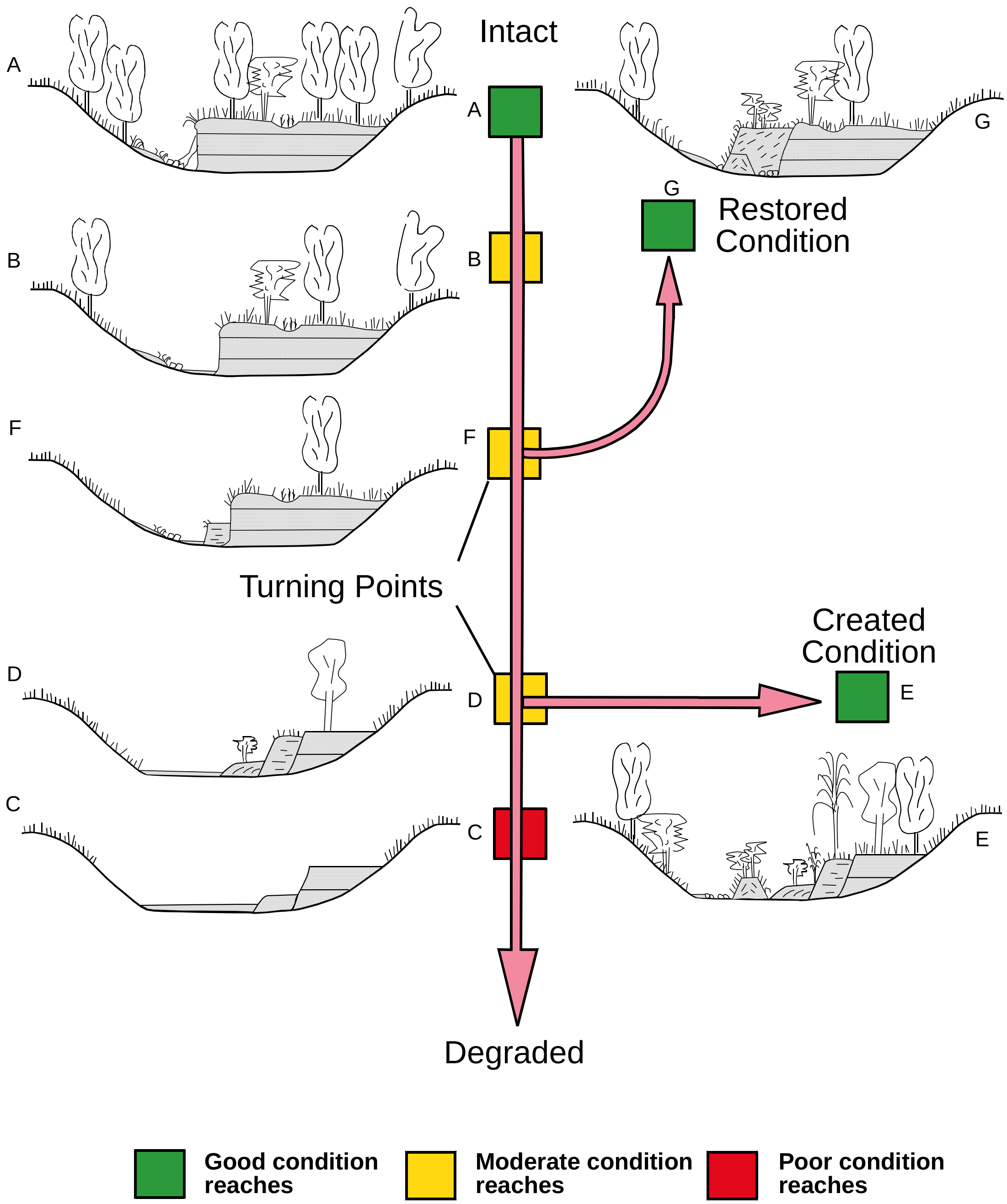
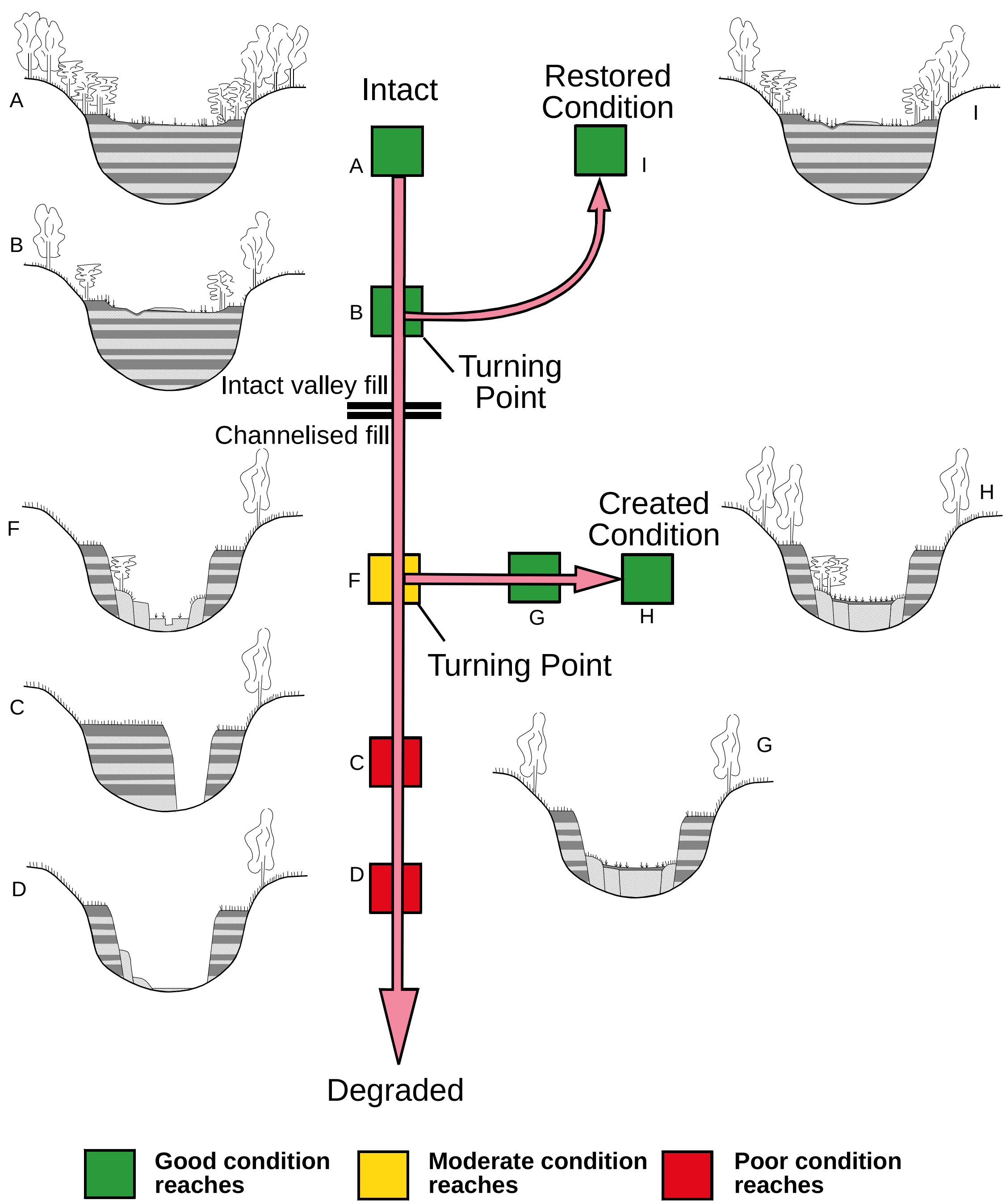


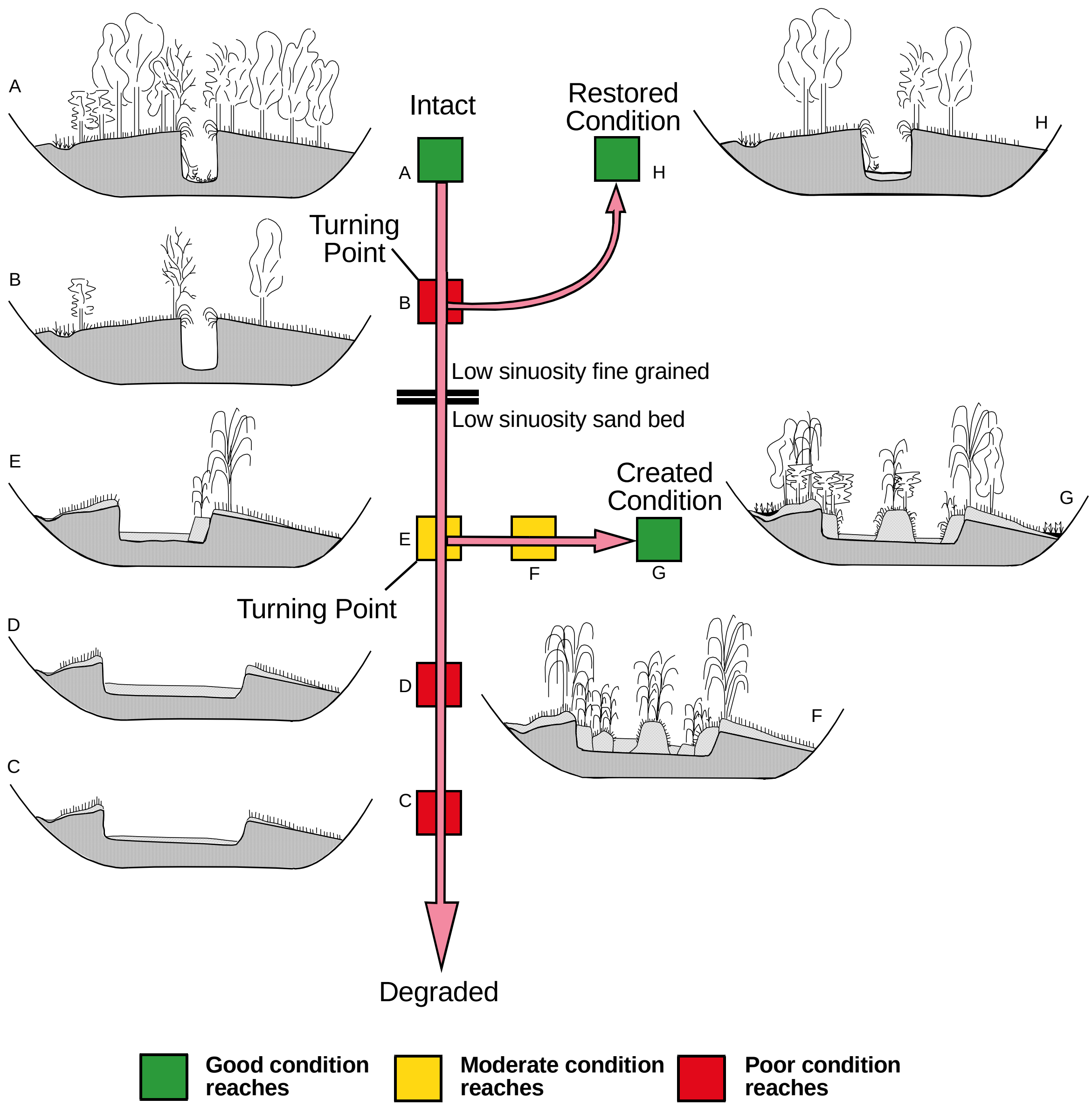
Figure 6.4 Recovery diagram for the Channelised fill River Style



6.2.6 Trajectory of change for reaches of the Low sinuosity sand bed River Style

Like the Channelised fill River Style, all reaches of this River Style have experienced irreversible geomorphic change since European settlement. This lowland plain section of the catchment was highly sensitive to disturbance and a wholesale shift from a Low sinuosity fine grained to a Low sinuosity sand bed River Style has occurred (**Figure 6.5**). There are no remaining examples of the pre-European

Figure 6.5 Recovery diagram for the Low sinuosity sand bed River Style



settlement condition, although insights into this type of river can be interpreted from portion plans, old photographs and field evidence (see Brooks and Brierley, 1997). The Low sinuosity sand bed River Style now operates under fundamentally altered catchment boundary conditions and restoration is impractical. Rather, these lower reaches of the Bega and Brogo Rivers will adjust along the creation trajectory. As yet, however, most reaches of this River Style remain on the degradation pathway, and moves towards recovery are not well established. Along degraded reaches (e.g. Bega River at Groses Creek), the channel bed is covered with sand sheets and vegetation associations are restricted to sparse, primarily colonising species that are readily reworked. Reaches along the Bega River at Tarraganda and the Brogo River at Angledale sit at the turning point. These reaches have not expanded to the same degree and show initial signs of geomorphic recovery with the formation of benches and the scour of pools around instream vegetation of wood. The lower Bega River at Grevillea and the Brogo River at Greendale Bridge are considered to sit on the creation trajectory. Primary colonising species (both exotic and native) indicate that recovery is underway. Sediment reworking and storage in mid-channel islands and the formation of distinct anabranches within the macrochannel indicate that the channel capacity is adjusting to altered catchment boundary conditions. Unfortunately, present vegetation associations are largely exotic along these sections of river and weed management strategies are required.

6.3 Stage Three, Step Two: Assess river recovery potential: Place reaches in their catchment context and assess limiting factors to recovery

6.3.1 Note the sensitivity and condition of each reach in the catchment

Although human-induced, systematic disturbance to catchment boundary conditions has been evidenced across much of Bega catchment (i.e. catchment-wide vegetation removal and disturbance of antecedent alluvial sediment stores), the effects of this disturbance have varied markedly. Differing reaches have recorded irreversible and reversible geomorphic change, reflecting the resilience and sensitivity of different River Styles to change.

As noted in **Table 5.1**, the sensitivity of each River Style to change is directly related to its capacity for adjustment. Given the control exerted by bedrock along Confined and Partly-confined valley settings that make up most of Bega catchment, many reaches have limited capacity to adjust and are considered resilient to change. The sensitivity of rivers in the laterally-unconfined valley-setting is dependent on the continuity of the channel and/or the character of bed and bank materials. The Intact valley fill and Floodout River Styles are considered to be resilient to change given the discontinuous nature of the channel and hence their limited capacity for adjustment. However, once disturbed, these River Styles become highly sensitive to change. The Low sinuosity boulder bed River Style has limited capacity to adjust due to its coarse bedload material, and hence the River Style is considered resilient to change. The most sensitive River Styles in the catchment are the Channelised fill and Low sinuosity sand bed River Styles. Both these River Styles have significant capacity to adjust and are highly sensitive to change as marked by their capacity to rework alluvial materials. They have experienced irreversible geomorphic change following European settlement. Disturbance to these River Styles contributed largely to the pattern and rate of geomorphic change across much of Bega catchment.

6.3.2 Limiting factors and pressures in Bega catchment

To determine the potential for river recovery, each reach is placed in its catchment context and limiting factors to recovery are assessed. In Bega catchment, the sediment regime (i.e. availability and supply) is considered to be the primary limiting factor affecting geomorphic river recovery. Associated changes to the discharge regime and with altered riparian vegetation cover are considered to be secondary limiting factors to recovery. In this case study, the sediment regime was examined in detail to assess how sediment availability and supply affects the recovery potential of rivers (see Fryirs and Brierley, 2001). Short sections on changes to the flow regime and vegetation associations follow the detailed sediment budget.

6.3.2.1 Changes to the alluvial sediment regime in Bega catchment

The changing nature of sediment source, transfer and accumulation zones since European settlement in Bega catchment

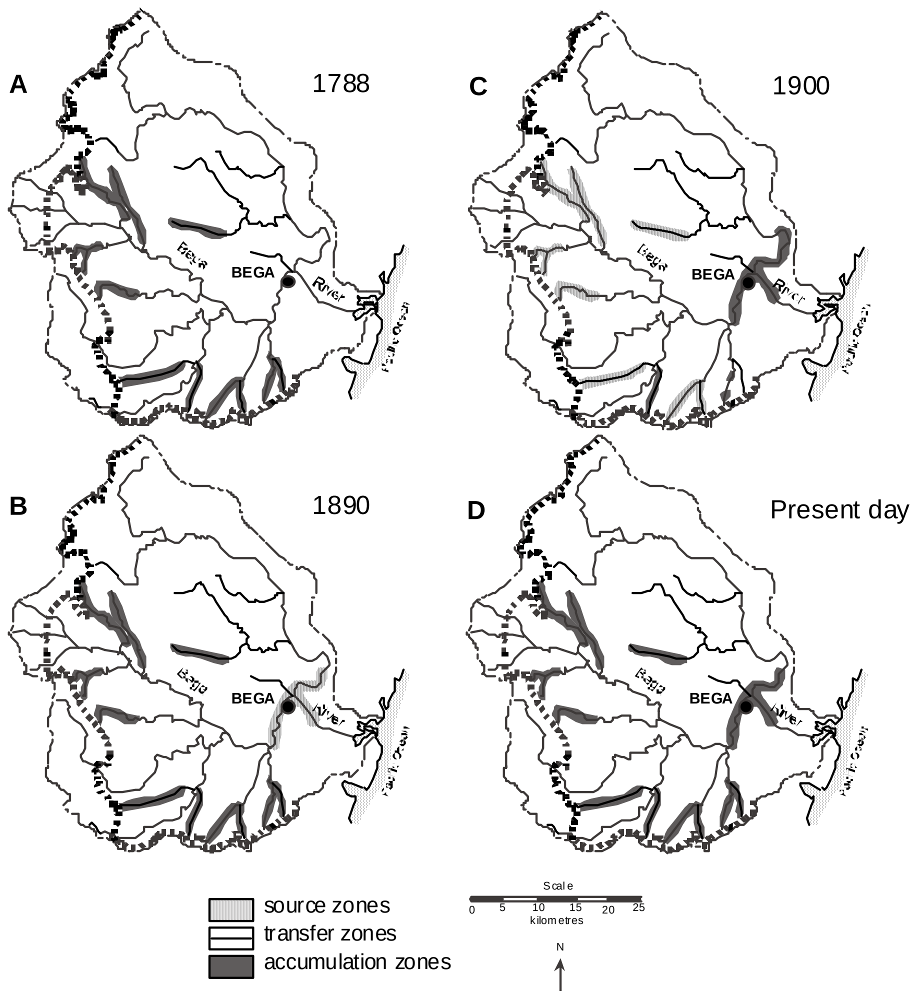
Analysis of the distribution of sediment source, transfer and accumulation zones provides a logical basis with which to interpret the pattern and processes of sediment movement within a landscape. **Figure 6.6** depicts the changing nature of alluvial sediment accumulation, transfer and source zones in Bega catchment for various timeslices since 1788.

In pre-European times many of the dominant drainage lines contained intact swamps that acted as sediment accumulation zones (**Figure 6.6 A**; Fryirs and Brierley, 1998 a). These swamps and floodouts extended into the middle parts of the catchment. Sediments released from these sinks were likely to comprise fine grained suspended load deposits. These materials were flushed through the middle and lower parts of the catchment, which acted as sediment transfer zones, and either accumulated along the lowland plain in the pre-disturbance, fine grained floodplains or were flushed through to the estuary.

Following human disturbance, the lowland plain was transformed into a sediment source (**Figure 6.6 B**). Significant sediment release had occurred by the late 1800's, as removal of riparian vegetation triggered massive channel expansion (Brooks and Brierley, 1997, 2000). At this stage, swamps at the base of the catchment remained as sediment sinks (Fryirs and Brierley, 1998 a).

Following human disturbance to valley floors in the latter half of the nineteenth century, cut-and-fill landscapes at the base of the escarpment shifted from sediment accumulation to sediment source zones (**Figure 6.6 C**). Sediment release was rapid, and a large volume of bedload material (i.e. sand), that was previously retained in swamps, was transferred to the lowland plain (Fryirs and Brierley, 1999). Once these channels became continuous, the linkage of water and sediment transfer processes throughout the catchment was fundamentally altered. In response to this sediment influx, the lowland plain became a sediment accumulation zone, with extensive deposition of bedload calibre sands atop the floodplain. The decades that followed were characterised by pulsed sediment transfer along the middle and lower courses of the contributing catchment. It has taken around 100 years for the tail of the sediment slug to move to the lowland plain. The rate of movement has reduced significantly over the last 50 years.

Figure 6.6 The changing nature of sediment source, transfer and accumulation zones in Bega catchment since European settlement



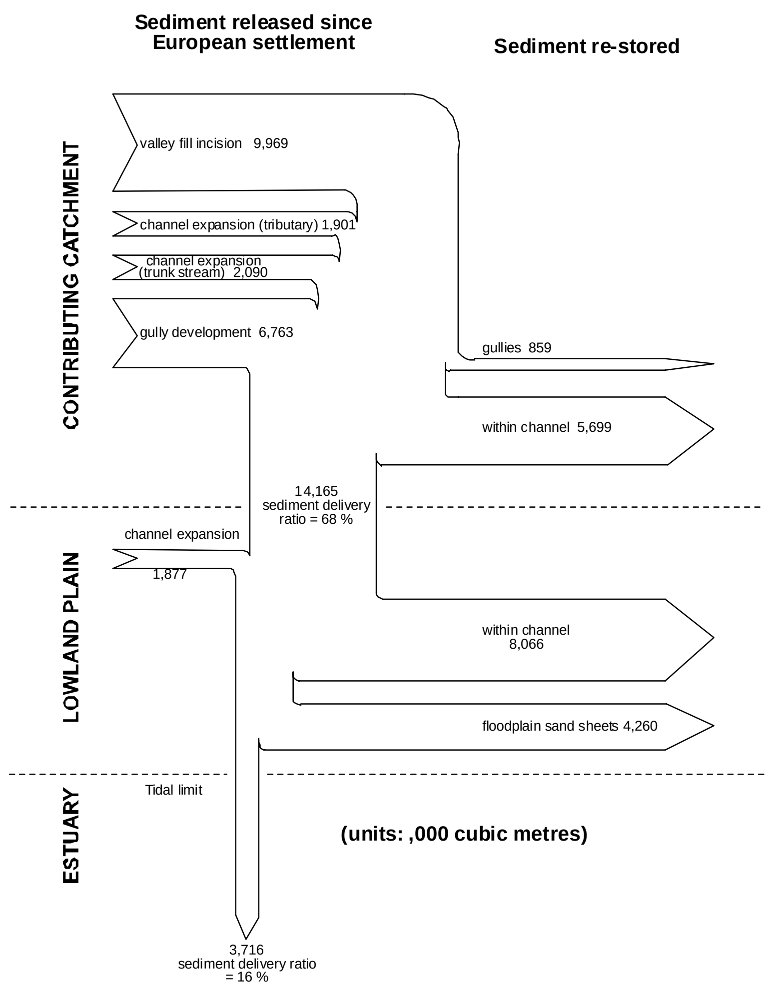
While the lowland plain will continue to act as a sediment accumulation/storage zone, the remainder of the catchment is now adjusting to a phase of decreased sediment supply. Channelised fill settings at the base of the escarpment have reverted to filling phases. Several metres of sand have accumulated on the channel bed and inset features store sediment along the channel margins. Hence, these reaches now act as sediment accumulation zones (**Figure 6.6 D**). The sedimentologic character of recent infilling by bedload deposits differs notably from the alternating swamp and floodout/sand sheet sedimentation that characterised the pre-disturbance valley fill (cf., Fryirs and Brierley, 1998 a).

The efficiency of downstream transfer of a major sediment slug has resulted in systematic exhaustion of sediment from the fluvial system. Given the limited availability of sediment from upstream, initial signs of geomorphic recovery are only now beginning to be manifest in the system (Fryirs and Brierley, 2001).

Catchment wide sediment delivery and links to the estuary

At the time of European settlement, 56.6 million m^3 of material was stored along major river courses in Bega catchment. Volumes of material released from different sediment sources over the last 150 years, and volumes re-stored along river courses, are presented schematically for the catchment as a whole in **Figure 6.7**. In this figure, the contributing catchment comprises all areas of the river system upstream of the lowland plain.

Figure 6.7 Sediment budget flow diagram for the Bega catchment



In the period since European settlement, almost 10 million m^3 of material has been removed from intact drainage lines in the middle and upper parts of the catchment. Channel expansion along mid-catchment reaches is estimated to have released a further 2 million m^3 of material (see **Figure 6.7**). An equivalent volume of material has been released from along the Bega River trunk stream. With the incision and expansion of channels, secondary incision into lower order drainage lines occurred (Brierley and Fryirs, 1999). Gully networks which extended through these lower order drainage lines released almost 7 million m^3 of material (**Figure 6.7**).

The estimated volume of material that has been re-stored along river courses in the contributing catchment is 6.5 million m^3. Of this, 0.85 million m^3 of material has been re-stored along the downstream sections of gully networks, while 5.7 million m^3 of material has been re-stored in the channel zone (**Figure 6.7**). In summary, 68 % of material eroded from the catchment has been supplied to the lowland plain. The high value of this sediment delivery ratio reflects efficient sediment movement through the upper and middle parts of the catchment, where bedrock-confined reaches have readily conveyed materials to the lowland plain since European settlement. Over 12 million m^3 of material has been re-stored along the lowland plain.

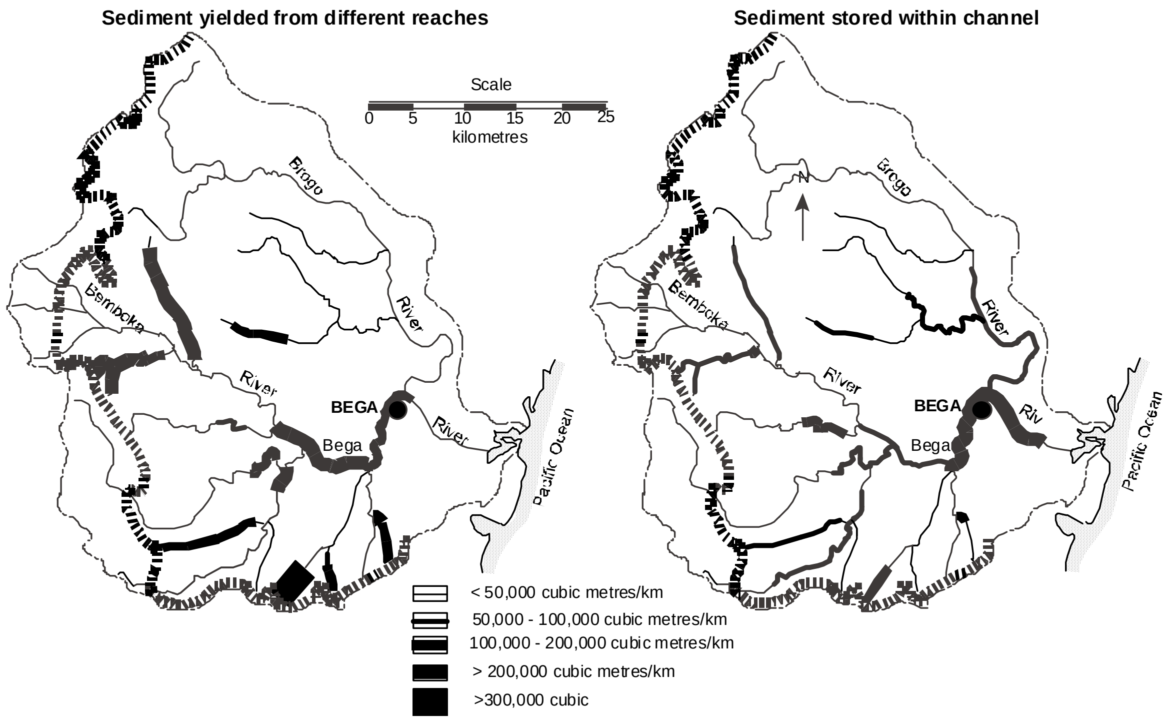
When the volume of material released by channel expansion along the lowland plain (i.e. 1.9 million m^3 of material) is added to the volume released from the contributing catchment, an estimated total of 22.6 million m^3 of material has been released from river courses in Bega catchment in the last 150 years. Of this, around 18.9 million m^3 of material remains stored within-catchment, primarily along the lowland plain. Hence, only 16 % of all sediment released (around 3.7 million m^3 of material) is estimated to have been transferred to the estuary (see **Figure 6.7**). Around 50 % of this volume is purported to have moved offshore during the 1971 flood (Hudson, 2000).

Subcatchment sediment delivery

The volume of sediment released from each subcatchment, expressed per river kilometre for differing river reaches, is shown in **Figure 6.8**. Pronounced variability in sediment release is demonstrated across the catchment. Material volumes >100,000 m^3/km have been released from the upper courses of Wolumla, Colombo, Pollacks Flat, South Wolumla, Greendale, Reedy and Numbugga subcatchments, and from along the middle-lower course of the Bega trunk stream.

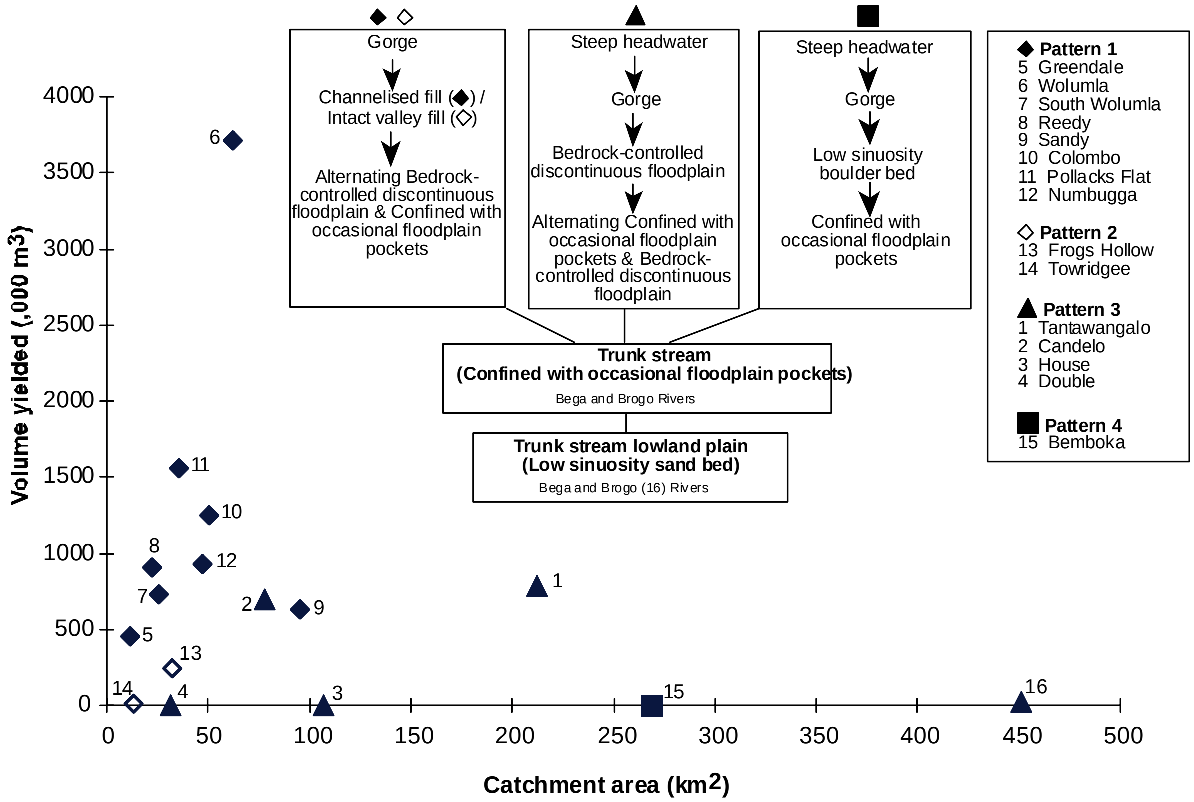
Figure 6.8 indicates that no systematic patterns of sediment release are evident from subcatchment to subcatchment. Furthermore, no general relationship to within-catchment position can be discerned. Rather, areas of sediment release are concentrated in those parts of the catchment where extensive volumes of material were stored in locally wider sections of valley. This within-subcatchment pattern of valley width determines, in large part, the downstream pattern of River Styles in different subcatchments (Brierley and Fryirs, 2000). As noted on **Figures 4.25** and **6.9**, three different downstream patterns of River Styles explain the distribution of sediment release across Bega catchment. The non-linear relationship between subcatchment area and total sediment yield indicates that subcatchment area, in itself, provides a poor guide to the pattern of sediment sources that have yielded material to the lowland plain. Rather, the distribution of sediment release is explained by the type of River Style found at the base of the escarpment, especially the presence/absence of the Channelised fill River Style.

Figure 6.8 Volumes of sediment yielded from, and stored along, river courses of the Bega catchment



Subcatchments which plot to the upper left of **Figure 6.9** have a high sediment yield/km^2. In all these subcatchments, the Channelised fill River Style is evident at the base of the escarpment. These subcatchments are funnel shaped, drain small catchment areas (<100 km^2), and accumulate sediments over extended periods behind bedrock constrictions or steps in the longitudinal profile. All Channelised fill River Styles occur in 3rd-5th order streams. Wolumla subcatchment sits high on this plot because of the volume of sediments that have infilled this valley (Brierley and Fryirs, 1998; Fryirs and Brierley, 1998 a).

Figure 6.9 Variability in sediment yielded along different downstream patterns of River Styles in Bega catchment



In total, 67 % of the sediment accumulation along the lowland plain was contributed from the 25 % of Bega catchment that contains the Channelised fill River Style at the base of the escarpment. Of the 56.6 million m^3 that was stored along river courses at the time of European settlement, over 20 million m^3 was stored in valley fills, i.e. in intact swamps at the base of the escarpment, and in floodouts. Around 48 % of all available valley fill materials in the catchment has been released. Not only were these subcatchments the primary sediment sources in the catchment, they also remain one of the largest sediment stores.

Subcatchments with a relatively low sediment yield/km^2 in **Figure 6.9** can be split into two types, namely those with the Intact valley fill River Style at the base of the escarpment, and those with the Partly-confined valley with bedrock controlled discontinuous floodplain or Low sinuosity boulder bed River Styles at the base of the escarpment. The Intact valley fill River Style in Towridgee and Frogs Hollow subcatchments is formed in the same valley setting as the Channelised fill River Style but continues to act as an intact swamp (i.e. a sediment sink) and therefore yields very little sediment. These 3rd order streams drain small catchment areas (<30 km^2). In subcatchments with vertically accreted floodplain or fan River Styles at the base of the escarpment, narrow, elongate valleys and significant upstream catchment areas (>100 km^2) have prevented the accumulation and storage of large volumes of material in these 5th to 6th order streams.

Although different River Styles at the base of the escarpment store and release sediment in quite different ways, the sediment delivery ratios from all subcatchments to the trunk stream are greater than 70 %. In all instances, the middle and lower courses of tributary systems are characterised by bedrock-confined reaches which efficiently flush sediment to the lowland plain.

The contemporary spatial distribution of sediment stores and sinks

Although vast volumes of material have been released and transferred along river courses since European settlement in the Bega Catchment, significant sediment stores and sinks remain. Less than one-third of the material removed from the tributary systems has been re-stored in the channel zone. In many instances, almost all this eroded sediment was evacuated. As shown on **Figure 6.6**, the focus of sediment accumulation has shifted to the lowland plain where the sediment slug is presently situated. The tributaries and upper parts of the trunk stream presently store very little within-channel and channel margin material. These sections of the catchment are experiencing the tail of the sediment slug and hence are adjusting to decreased rates of sediment supply. The vast proportion of released material has not yet made it to the estuary.

The relative balance of sediment stores and sinks is very different today to that interpreted at the time of European settlement. Many long-term sinks have been transformed into transient stores. Of the 56.6 million m^3 of material that was stored in sediment sinks at the time of European settlement, around 14 million m^3 has been reworked into within-channel storage units (sand sheets, bars, islands, benches and inset forms), 4 million m^3 has been restored as sand sheets atop the floodplain of the lowland plain and around 4 million m^3 has been evacuated from the catchment (i.e. transferred to the estuary and beyond). The spatial pattern of these changes has been determined by long term geomorphic controls on the distribution of sediment sinks.

6.3.2.2 Changes to the discharge regime and stream power relationships in Bega catchment

In pre-disturbance times, intact swamps and floodouts maintained base flows throughout the catchment for extended periods, reducing the peakedness of flood events (Brierley et al., 1999). Given the discontinuous character of many river courses, upper parts of the catchment were largely diconnected from river courses along the lowland plain. In addition, small channel capacities along the lowland plain at the time of European settlement allowed more frequent inundation of floodplain surfaces, maintaining the connectivity of biophysical processes between the channel and the floodplain. Following the formation of large, continuous channels since European settlement, and wholesale vegetation clearance, the transport times for runoff have decreased as flows are more peaked and concentrated within the incised and expanded channels. Relatively high stream power and bedload transport capacities have increased the erosivity of flows. In many reaches, this severely limits the ability of channels to store and lock up materials, inhibiting the potential for geomorphic recovery.

6.3.2.3 Changes to riparian vegetation cover and wood loading in Bega catchment

With the exclusion of the escarpment and upland rivers, most river courses in Bega catchment have scattered or no riparian or instream vegetation. Where present, vegetation consists largely of exotic species and/or native vegetation has been retained in narrow corridors of one tree width. Vegetation structure has also been dramatically altered since European settlement, with the removal of ground cover and shrub layers. The existing tall tree stratum is ageing with limited regeneration due to grazing pressure. Links with terrestrial vegetation have been significantly diminished.

The establishment of appropriate riparian and within-channel vegetation is imperative for the retention of sediments and continued recovery. The secondary impacts associated with shading and water quality improvement are essential for maintenance and improvement of viable aquatic habitats. In addition, increased wood loadings are required to enhance recovery process along some River Styles. However, given the limited riparian vegetation, physical reintroduction of wood is necessary.

While seed sources are available for reaches close to National Parks, and adjoining reaches in good condition, it will take considerable time for appropriate species to recolonise these settings. However, most river courses in Bega catchment are isolated from appropriate seed sources and continue to support land uses that extend to channel banks (or into the channel, e.g. cattle grazing). Hence, natural recolonisation is limited. Physical intervention through fencing, direct planting, and stock management is required in most instances. Strategic plantings, weed management and the reintroduction of wood would provide focal points from which either natural regeneration or plantings could be extended into neighbouring reaches.

Willow management is a significant issue in Bega catchment. In 1997, almost two million willows of six main varieties were recorded in Bega catchment (Riddell, 1997). Currently, the largest concentration occurs along the Bega River where the majority of plants have become established since 1993. The removal of all willows is neither desirable nor practical, but propagation is continuing with only 10% of the ideal willow habitat in Bega catchment currently colonised (HRC, 2000). Willows are primary colonisers and are more opportunistic than natives in Bega catchment (except in the Brogo system where *Casuarina Cunninghamiana* competes vigorously with willow). Hence, willow spread and establishment will continue to extert a significant impact on geomorphic river recovery throughout the catchment. Indeed, this is likely to be a severe future pressure if young plants and seeding adults are not eradicated and replaced.

6.3.3 Pressures on river recovery in Bega catchment

6.3.3.1 Population dynamics and changes in land use

As noted in **Chapter 4**, the population of the Bega Valley has fluctuated over time. In the last few decades there has been a shift in the occupation structure of the work force. With the deregulation of the dairy industry and with continual increases in mechanisation, on-farm labour needs have decreased. However, this has been offset by an expansion in the Bega Co-op business through value-adding and product expansion. This has lead to an expansion in the labour market in Bega township. All indications suggest that this will continue into the future.

Given the improvements in techniques, and the less intense use of the land (in terms of stocking rates etc.), the potential for river recovery and prospects for more environmentally sound use of the land is encouraging. The trend in the dairy industry has been offset to some degree by the subdivision of large acreages and a rise in the number of cottage industries and hobby farms in the Valley. However, a perceptible change towards increased vegetation cover in the catchment has occurred. This is due to a number of factors including the introduction of the Native Vegetation Conservation Act in 1997.

A significant trend over the last few decades has been the increase in the seasonal population of the Bega Valley. This trend has accompanied the formation of small lots which are being used as holiday or recreational properties. In addition, the promotion of the Bega Valley as a holiday destination has greatly increased the seasonal (summer) influx of tourists, particularly to Tathra.

6.3.2.2 River management and river rehabilitation strategies

River management on the Far South Coast region incorporates issues such as riparian vegetation, sedimentation and water quality planning. This approach includes the Total Catchment Management ethos (now the South-East Catchment Management Board), the NSW Water and Vegetation Reforms, Estuary Management, Landcare and Rivercare initiatives.

The Bega Catchment Integrated River Health Package (NSW DLWC, 2002) outlines the future directions for river management in the catchment. It is framed around the South East Catchment Management Board Blueprint and the Healthy Rivers Commission recommendations (HRC 2000), and is being used as a principle tool for setting DNR priorities in river and wetland management. **Table 6.1** summarises some of the short term (10 year) priorities that are being emplaced. These programs will dictate the future direction of geomorphic river recovery in the Bega catchment. For example, the benefits of stock access control to creeks under the Bega-Towamba Catchments Stream Rehabilitation Incentive Program, and the Bega Integrated Sediment Management Project will have quick, visible effects that will trigger responses throughout the system. The key is that these are an integrated approach that spans geomorphology, ecology, flow regimes, water quality and vegetation management.

Table 6.1 Draft Bega Catchment Integrated River Health Package (NSW DLWC, 2002).

Program	Catchment Blueprint and Bega specific Program Targets (Draft)	Work and actions
Wetland program	By 2012, 100 top priority wetlands fenced, rehabilitated and managed for conservation and limited production. By 2007 and 2012 all wetlands along Bemboka and Bega Rivers (respectively) fenced and managed. The hydraulic function of 5 key wetlands on Bega River restored and a wetland centre established.	Assessment of wetland condition, restore eroded swamps, fencing, weed control, farm planning.
Dairy laneway program	By 2012, faecal coliform inputs to rivers will be reduced by 10%. By 2005, all dairy laneways in Bega catchment upgraded to best standard. The number of swimming days in Lower Brogo River to increase by 50%.	Model and monitor dairy effluent, assessment of laneway condition, farm planning, re-fence and realign laneways.
River fencing rehabilitation program	By 2012, 80% of river frontages in Bemboka and Tantawangalo subcatchments to be fenced and managed for conservation and limited production. This includes 100% of dairy farm river frontages and 40% of remaining river frontages. Erosion and sediment sources to be stabilised.	Farm planning, incentive contracts, fencing, weed control, stock management, erosion and sediment stabilisation.
Strategic weed and vegetation management rehabilitation program	By 2012, 100 strategic reaches under long term vegetation and weed management regimes for conservation outcomes (with limited stock access as part of the management regime). This includes 50 reaches in Bemboka and Tantawangalo, and the remainder from other areas in Bega catchment.	Farm planning for weed and vegetation management, weed removal, revegetation, fencing.
Complete recovery of strategic reaches rehabilitation program	By 2012, 20 strategic reaches rehabilitated to complete recovery, including in-stream habitat, ecological processes, environmental flows, ongoing vegetation and weed management. This includes 10 reaches in Bemboka and Tantawangalo subcatchments, 5 in the rest of the catchment, and 5 Crown Land frontages.	Farm and river reach coordinated works, fencing, weed control, revegetation, sediment stabilisation, wood emplacement, water sharing and environmental flows plans.
Water efficiency program	By 2012, south coast irrigation industry to show a 10% improvement in water efficiency indicators. By 2005, all Bemboka, Tantawangalo dairy irrigators and Water Users Association members to have Irrigation and Drainage Management Plans and water efficiency indicators at industry best practice standards. By 2007, 50% of remaining irrigators to have fulfilled the same requirements.	Design Irrigation and Drainage Management Plans, install efficient monitoring equipment, invest in water efficient technology.
Water Sharing and environmental flows program	By end 2003, whole of Bega catchment to complete an unregulated water sharing plan with environmental flow protection and extraction management rules.	Consultation with stakeholders.
Sediment reduction program	By 2012 reduce sediment inputs to waterways by 10% in priority streams. Seal approaches to 50 road stream crossings in Bega catchment and stabilise severe gully and stream erosion.	Seal roads, river rehabilitation that enhances sediment storage along river courses.

6.3.3.3 Water resources and implementation of flow management plans

The varied population trends have shifted water requirements and needs. While irrigation remains the primary water user in the catchment, the need for guaranteed domestic supply to an increasing number of smaller properties has increased (NSW DLWC, 1999). In addition, the need for minimum environmental flow allocation will place significant pressure on water planning agencies to satisfy a wide range of stakeholders. Through the Bega Valley Water Management Plan these allocations are being addressed.

The Bega-Bemboka River Flow Plan has been coordinated through the Bega Valley Water Management Committee since late 1998, and includes the area along the trunk stream upstream of the Brogo River confluence. The plan will eventually be extended to other subcatchments in the Bega valley. This plan has incorporated a range of environmental, socio-economic and practical applications. In 1998 water allocation was converted from a calculation based on area to volume with a series of access share rules developed between active irrigators, dam filling and power generation at Cochrane Dam (in upper Bemboka River) and sleepers and dozer irrigators (respectively inactive irrigators, and those who hold licenses but do not have irrigation capacity).

In 1998, Pacific Power and the Bega Valley Water Users Association negotiated an agreement whereby water can be stored in Cochrane Dam for irrigation purposes. DNR is currently considering a license for operation of the dam, and environmental flow which may be included in the license (HRC, 2000). However, Cochrane Dam is small relative to its inflows (annual inflows are about 9 times the capacity of the dam). Thus, except in drought years, water retention in the dam has little effect on the flow regime of the Bemboka system.

Water extraction guidelines are based on seasonal flow along the Bega-Bemboka River. Metering, environmental benchmarking management plans (including macroinvertebrate ecology, habitat assessment, wetland surveys, water quality, riparian vegetation, sediment movement and storage), socio-economic riparian water demands and aboriginal cultural significance have all been incorporated into the water management plan. The bottom line is based on environmental requirements and states that:

"While the flow duration figures provide guides for management, there is an absolute commitment to keep refuge pools in the river full and to recharge and connect pools with visible surface flow to the Kanoona nickpoint (bedrock step just upstream of Wolumla-Bega confluence). These criteria will be monitored closely" (NSW DLWC, 1999).

The goals of the flow management plan are to (NSW DLWC, 1999):

- Maintain and improve existing levels of river health, biodiversity and ecosystem function by protecting water levels in pools, protecting natural low flows, restoring a proportion of high flows that maintain floodplain and wetland inundation patterns, mimic natural flow variability (by manipulating water flows from Cochrane Dam), and protect and enhance estuarine environments and processes.
- Maximise the economic benefit to the community at large from the use of water resources.
- Improve the efficiency of water use.

The plan has been trialled since 1999. Currently, irrigators along the Bemboka-Bega River are using these informal flow sharing arrangements. This plan is being revised to include greater water use efficiency, equitable flow sharing arrangements and recommendations of the Healthy Rivers Commission report into the Bega River system (HRC, 2000). A water sharing plan under the Water Management Act (2000) will become formalised within the State's water reform planning framework. This will include the entire Bega catchment minus the Brogo regulated river. The incorporation of environmental flows into these plans will have significant effects on river system recovery in the future.

There is currently no water sharing plan for the Brogo Catchment or requirement to make environmental releases from Brogo Dam. Reiterating what was described in Chapter 4, water release from Brogo Dam does not follow a 'natural' regime. In the absence of the dam, the lower section of the Brogo River sometimes dried up in summer. 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. Irrigation use is relatively high, but because of the provision of regulated flows, the future hydrologic stress has been considered to be low (HRC, 2000). Below Brogo Dam, the river flows through a confined valley in which occasional floodplain pockets have been cleared for agricultural use. These reaches are located in forested country for some distance before reaching the wide lowland plain valley which has been cleared for farming. Given the confined valley in which it is located, the effect of Brogo Dam on the geomorphic structure of the river has been localised with reaches immediately downstream of the dam wall being affected. However, Brogo Dam has modified flow patterns throughout the Brogo Valley. The lack of flow variability has reduced aquatic habitat diversity (HRC, 2000). However, the reliability of flows of satisfactory water quality, and the presence of a relatively good riparian vegetation strip along the river (which provides leaf litter, wood, organic carbon, etc.) has allowed a reasonable diversity of aquatic fauna to be maintained (HRC, 2000).

6.3.4 The linkages of geomorphic processes along river courses and the recovery potential of reaches in Bega catchment

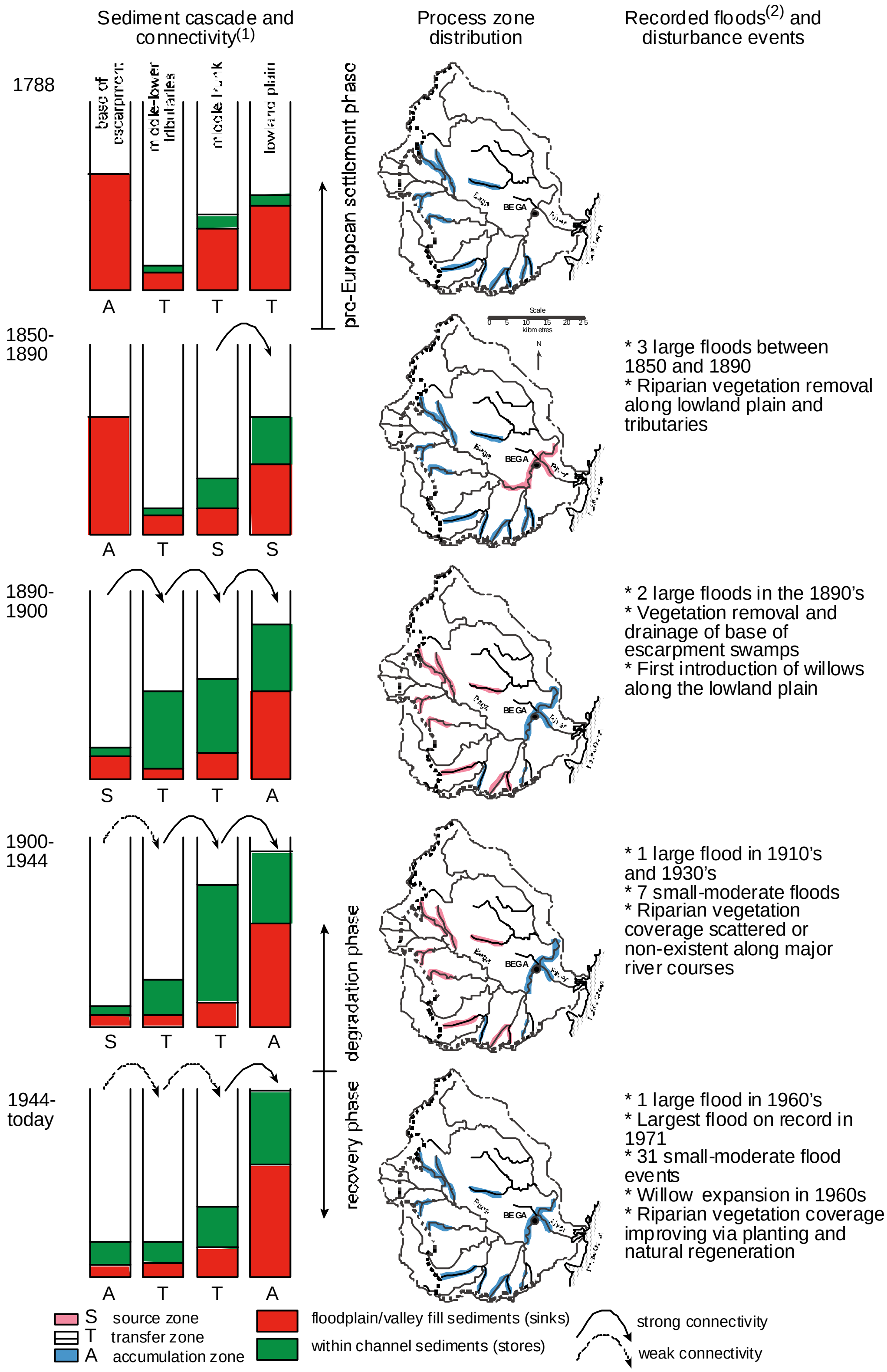
Whether a reach recovers along a creation or restoration trajectory is dependent on its current condition and the sets of circumstances that affect future changes. The relative impact of these influences is fashioned by the position of the reach in the catchment, the linkage of geomorphic processes along the river course, and the off-site impacts experienced by the reach (i.e. responses to the pressures and limiting factors that operate in the catchment). The nature and rate of responses to future flood events, sediment availability and vegetation interactions are River Style specific.

As different reaches of each River Style sit at different positions on the degradation/recovery diagram and are in different geomorphic condition, the recovery potential of each reach must be assessed individually, based on the character of each reach and the pressures and limiting factors operating in each subcatchment. The same driver of change can have a positive or negative affect on different reaches of different River Styles. For example, impacts of depend on the nature and character of the reach. In Bega catchment, small to moderate flood events since the largest flood on record in 1971 have lead to the infilling of a number of pools along bedrock-controlled reaches reflecting deterioration of reach condition along this River Style. In contrast, the accumulation of sediment along channel margins of the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style is leading to the formation of benches and a reduction in channel capacity, improving geomorphic condition along these reaches.

6.3.4.1 The changing nature of linkages between reaches in Bega catchment: The cascade of geomorphic response

Building on the alluvial sediment budget, and analysis of the flood record presented in **Figure 4.17**, phases of geomorphic river recovery can be related to sediment cascades through the process zone configuration of Bega catchment, and events triggering change, as shown in **Figure 6.10**. The discontinuous nature of erosion and deposition has resulted in several pulses of sediment transportation that have induced dramatic geomorphic changes at different times throughout the catchment.

Figure 6.10 The alluvial sediment budget of Bega catchment: Assessing the changing nature of sediment source, transfer and accumulation zones post-European settlement (from Fryirs, 2001). Note (1) volumes are relative only and (2) the flood record is incomplete.

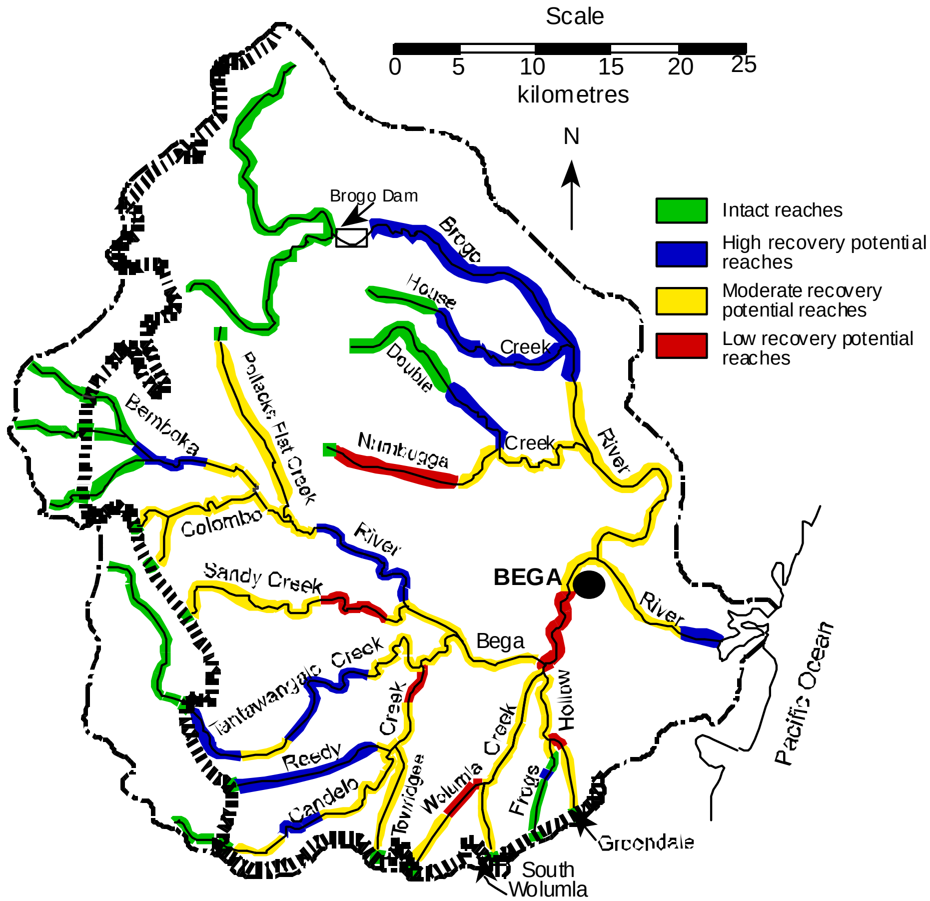


The timing of sediment release and exhaustion in Bega catchment demonstrates how limiting factors act as filters between initiating processes and subsequent responses (Fryirs and Brierley, 2001). **Figure 6.10** demonstrates for a 150 year period how discontinuities in sediment movement, and the resulting cascade (i.e. sediment release and transfer), dictated the timing and magnitude of geomorphic change along Pattern 2 rivers and the lowland plain. Disturbance to highly sensitive River Styles along these river courses drove geomorphic changes throughout the catchment. Relating this sequence of sediment movement to the timing of flood events, periods of event resistance and event sensitivity can be defined (i.e. phases in which the landscape can either absorb change or be prone to change, respectively) reflecting geomorphic condition, the magnitude of the initiating event and the limiting factors operating in the catchment.

At the time of European settlement reaches at the base of the escarpment and along the lowland plain were 'primed for change', inducing a period of event sensitivity. Enhanced geomorphic effectiveness was induced by large flood events in the 1850s along the lowland plain, and in the 1890s at the base of the escarpment. In both locations, but at different times, catastrophic geomorphic changes were triggered (Brooks and Brierley, 1997; Fryirs and Brierley, 1998 a). By the 1960s, signs of geomorphic river recovery were manifest in the system (Brooks and Brierley, 2000; Fryirs and Brierley, 2001). The largest flood on record, in 1971, induced relatively minor changes to river morphology. Wholesale changes in river character and behaviour did not occur. The lowland plain accumulated large sand sheets in both the channel and floodplain, and localised reworking of materials occurred in the contributing catchment. However, by 1971, the sediment slug had moved to the lowland plain and the contributing catchment was effectively exhausted of sediment. As a consequence, the system demonstrated event resistance during the 1971 flood. No large floods have occurred since 1971, but around 17 small-moderate floods have been recorded (see **Figure 6.10**). These smaller magnitude events have aided geomorphic river recovery via the building of recovery features such as benches and bars, and the scouring and re-emergence of bedrock pools.

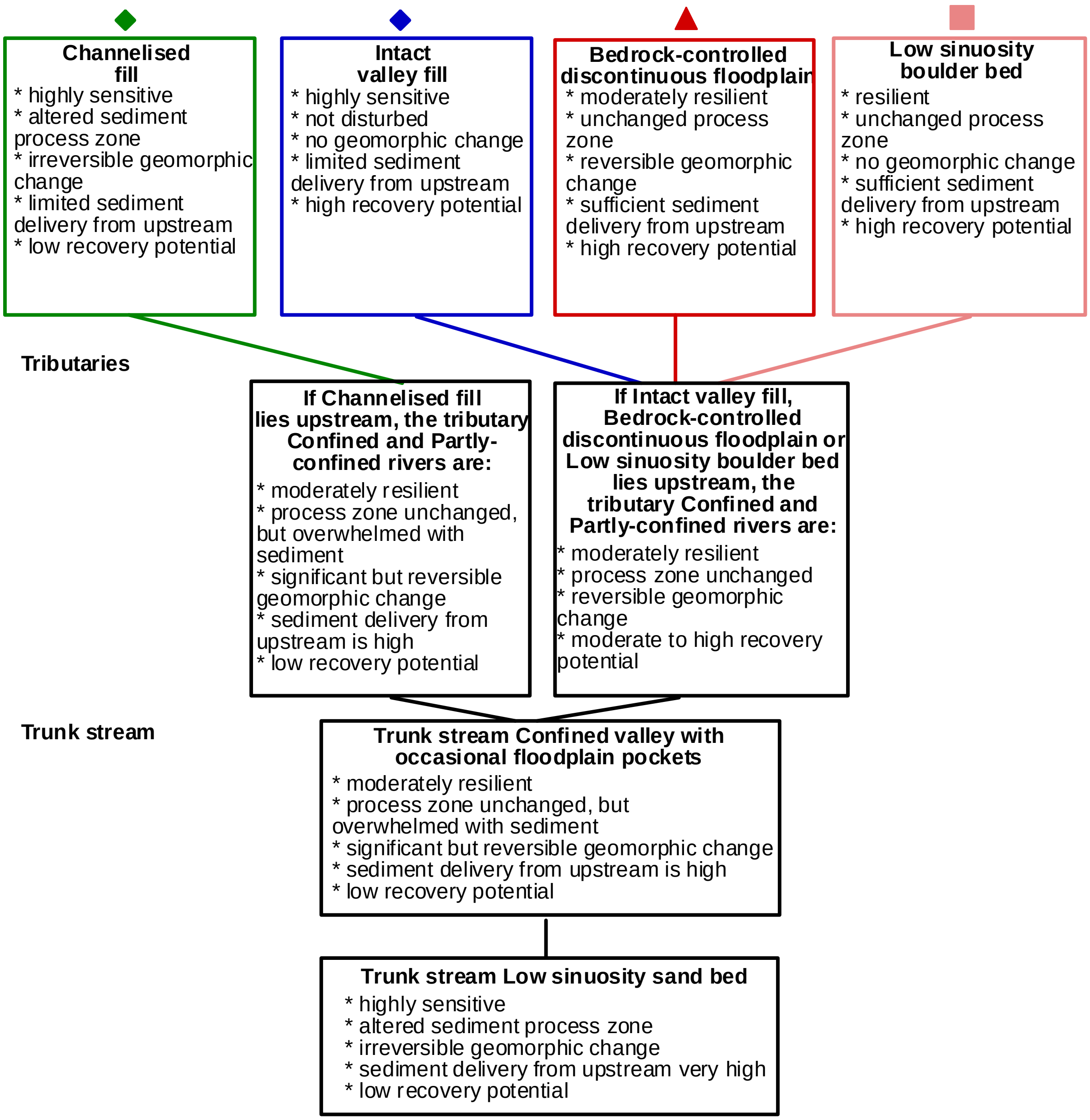
Given the extent of landscape change since European settlement of Bega catchment, the primary sediment sources in the contributing catchment have been exhausted. As rates of material production and sediment transfer from slopes are low (Fryirs and Brierley, 1999), most of the river system will remain sediment starved for thousands of years, resulting in an extended timeframe for geomorphic recovery. In addition, the shift in character of sediment storage units towards more transient forms (i.e. from floodplains which lock up sediment to within-channel bars that are readily reworked), together with the increased capacity of the system to move sediment (and associated difficulties for sediment storage), have ensured that the residence times for sediment stored in the catchment have been shortened dramatically (i.e. to the order of years or decades). When combined with limited sediment supply, this severely limits the likelihood for future river recovery at both the reach and the catchment scales. However, this assertion masks significant variability in the recovery potential of reaches in the catchment (**Figure 6.11**). **Figure 6.12**, modified from Fryirs and Brierley (2001), summarises how the catchment-scale linkage of geomorphic processes along different patterns of River Styles dictates the recovery potential of rivers in the catchment. In the following section, these relationships are explained for different parts of the catchment.

Figure 6.11 The geomorphic recovery potential of reaches in Bega catchment



The potential for future adjustments to river morphology and the associated alluvial sediment budget in Bega catchment are dependent, in large part, on the relative balance between sediment availability and the transport capacity of the river. Estimates of bedload transport capacity were compared with the actual volumes of material that are available to be reworked at given cross-sections. This provides a realistic sense of the potential volumes of sediment that are able to be transported under flood events of differing recurrence intervals. When summary comparisons of bedload transport capacity are related to the availability of sediment in different valley settings at the base of the escarpment (the source zone), and differing locations within the catchment (i.e. transfer and accumulation zones), distinct trends for sediment conveyance are noted. The presence of different River Styles at the base of the escarpment, and the distribution of Intact valley fill and Channelised fill River Styles, dictate the patterns of downstream sediment transfer and associated geomorphic responses.

Figure 6.12 Catchment scale linkages and their impact on the recovery potential of rivers along different river courses that display different downstream patterns of River Styles. Symbols ascribed to the downstream pattern of River Styles refer back to Figure 5.1.



- *In the uplands and gorge country*

Given the relatively undisturbed character and behaviour of Steep Headwater and Gorge River Styles, they have little geomorphic impact on downstream reaches.

- *At the base of the escarpment*

The Channelised fill River Style at the base of escarpment has been irreversibly altered (**Figure 6.12**). Large volumes of material have been removed from Holocene valley fills. As upstream sediment supply is limited, these 'holes in the landscape' will take thousands of years to fill. Hence, there is little potential for geomorphic river recovery over management timeframes. The rate of recovery will depend on the ability of these reaches to reform discontinuous watercourses and retain fine grained materials along their incised channel beds. Fryirs and Brierley (2001) show that while the potential for bedload transport is low for floods of small magnitude, the concentration of flows within the incised trenches produces high bedload transport rates for events of 1 in 10 year recurrence and above (from ~15,000 m^3/day for the 1 in 10 year event to ~101,000 m^3/day for the 1 in 100 year event). This factor, together with high availability of sediment stores (averaging >60,000 m^3/km) means that the potential off-site impacts of sediment delivery from these reaches remains high, dependent on the nature of future flood events.

At the base of the escarpment in other subcatchments, Partly-confined valley with bedrock-controlled discontinuous floodplain and Low sinuosity boulder bed River Styles have not experienced significant geomorphic change. While bedload transport capacities are high along these reaches (up to 175,000 m^3/day for a 1 in 100 year event; Fryirs and Brierley (2001)), the availability of sediment is relatively low. These reaches have either shallow, narrow floodplains that store <50,000 m^3/km, or are boulder dominated. Hence, they are sediment supply limited (i.e. sediment availability < bedload transport capacity) and potential off-site impacts of sediment release are relatively small. Upstream reaches are near-intact. This factor, together with their moderate-good geomorphic condition, ensures that recovery potential is high along these river courses.

Subcatchments that are characterised by the Intact valley fill River Style at the base of the escarpment are considered to have little geomorphic impact on downstream reaches. These settings have maintained their pre-disturbance role in terms of sediment accumulation. While these reaches are under threat of degradation, their recovery potential remains high.

- *Along middle reaches of tributaries*

Alternating sequences of Partly-confined and Confined River Styles are found along middle-lower tributaries before they reach the trunk stream (**Figure 6.12**). Those reaches located downstream of the Channelised fill River Style have experienced significant geomorphic change as a result of sediment release from upstream and their potential for recovery is low. The reaches located downstream of the Intact valley fill, Partly-confined valley with bedrock-controlled discontinuous floodplain and Low sinuosity boulder bed River Styles have experienced limited geomorphic change and their potential for recovery is moderate to high.

The rate of recovery along middle tributary river courses reflects the degree of bed material reorganisation and sediment transfer through these reaches, and the building and stabilisation of benches and floodplains which narrow channel dimensions. These reaches have amongst the highest bedload transport capacities for small catchment areas. This is because of their bedrock-controlled character and narrow valleys. Given that these reaches typically have within-channel sediment stores of < 50,000 m^3/km or between 50,000-100,000 m^3/km (**Figure 6.8 A**), there is significant potential for sediments to be flushed through these reaches. Unless significant supplies of material are maintained from upstream, and this is not possible along most tributary river courses of Bega catchment (as noted on **Figure 6.8 A**), sediment stores along the river course are likely to be quickly exhausted. Hence, the residence time for sediment storage along most of these bedrock-controlled reaches is likely to be very short. This has significant implications for the potential of the river to readjust its morphology along a creation or restoration trajectory. For example, the Partly-confined valley with bedrock-controlled discontinuous floodplain River Style along Tantawangalo Creek, which drains a catchment area of just 204 km^2, has the capacity to transport over 71,000 m^3/day in a 1 in 10 year event. The volume of within channel stores available to build recovery features is only 68,000 m^3 along this reach. Hence, the challenge for river rehabilitation lies in retaining sediments along this reach to build benches that will reduce channel capacity and enhance geomorphic recovery. A similar scenario is repeated for all the confined and partly-confined river courses in Bega catchment (Fryirs and Brierley, 2001). Given that available sediment stores along these reaches are low, sediment is required from upstream to instigate recovery. However, several questions must be asked if realistic sediment management plans are to be developed, such as: is there sediment available upstream; from where should it be released, and what effect will this have on the recovery potential of upstream reaches?

- *Along the lowland plain*

Along the lowland plain irreversible geomorphic change has occurred and the cumulative effects of disturbance prevent the river from regaining a pre-disturbance condition. The potential for recovery towards a created condition depends on the degree to which material reorganisation occurs, island and bench building results, and the rate at which the sediment slug is removed from this part of the catchment. Unlike most of the catchment, lowland plain reaches are sediment transport limited (i.e. sediment availability > bedload transport capacity). Over 8 million m^3 of sediment is stored in the channel zone and is available for reworking. A further 4 million m^3 is stored on the floodplain (Fryirs and Brierley, 2001). Bedload transport capacities for these lowland plain reaches are amongst the highest in the catchment (around 300,000 m^3/day for the 1 in 100 year event), presenting significant potential for material redistribution. The formation of benches and within-channel islands will enhance river recovery. However, the challenge lies in stabilising these stores to ensure that large volumes of sediment released during moderate-large flood events do not induce off-site impacts in the estuary.

6.4 Catchment-wide assessment of the geomorphic recovery potential of rivers

Figure 6.11 shows the catchment-wide distribution of recovery potential for each reach in Bega catchment. In **Table 6.2** reovery potential is summarised in terms of the length of streams and the percentage of river courses in the catchment in each category. Intact reaches make up around 27 % of all river courses in Bega catchment, primarily along the Steep headwater (around 6 %) and Gorge around 16 %) River Styles in the uplands and escarpment zones respectively. The remainder of intact reaches occur in isolated sections at the base of the escarpment. These reaches are the last remaining intact remnants of these River Styles, and in all cases are the only examples of these River Styles in the catchment. The Intact valley fill River Style makes up 2 % or 10 km of river course in Bega catchment. The last two remaining swamps occur at the base of the escarpment in Frogs Hollow and Towridgee subcatchments. The last remaining example of a Floodout River Style makes up < 1 % or 2 km of river courses in Bega catchment and occurs along middle Frogs Hollow Creek. The only example of a Low sinuosity boulder bed River Style occurs along Bemboka River at the base of the escarpment and makes up around 3 % or 13 km of river courses in Bega catchment. These isolated sections of river that display Intact conditions have high conservation value.

Table 6.2 Stream lengths for each reach of each River Style with different recovery potential

RIVER STYLE	RECOVERY POTENTIAL	Length (km)	% of total stream length in catchment
Channelised fill	High recovery potential reaches	9	1.8
	Moderate recovery potential reaches	45	9.1
	Low recovery potential reaches	10	2.0
Confined valley with occasional floodplain pockets	High recovery potential reaches	103	20.7
	Moderate recovery potential reaches	92	18.5
Floodout	Intact reaches	2	0.4
Gorge	Intact reaches	80	16.1
Intact valley fill	Intact reaches	10	2.0
Low sinuosity boulder bed	Intact reaches	13	2.7
Low sinuosity sand bed	Moderate recovery potential reaches	39	7.8

	Low recovery potential reaches	7	1.5
Partly-confined valley with bedrock controlled discontinuous floodplain	High recovery potential reaches	17	3.3
	Moderate recovery potential reaches	19	3.8
	Low recovery potential reaches	21	4.1
Steep headwater	Intact reaches	28	5.5
Brogo Dam		4	0.8
RECOVERY POTENTIAL		Total stream length in catchment (km)	% of total stream length in catchment
Intact reaches		133	26.9
High recovery potential reaches		129	26.0
Moderate recovery potential reaches		195	39.4
Low recovery potential reaches		38	7.6

High recovery potential reaches occur along 26 % of river courses in Bega catchment. Their location is restricted largely to areas at the base of the escarpment or along isolated reaches in the rounded foothills where upstream off-site impacts have been negligible. These reaches tend to be in good geomorphic condition. Only three of the nine River Styles have reaches with high recovery potential, namely the Channelised fill, Confined valley with occasional floodplain pockets, and Partly-confined valley with bedrock-controlled discontinuous floodplain.

The Confined valley with occasional floodplain pockets River Style with high recovery potential accounts for around 21 % or 103 km of river course in the catchment. Interestingly, no reaches of the Confined valley with occasional floodplain pockets River Style have low recovery potential. This is surprising because a significant percentage of these reaches are in poor geomorphic condition, and they have often experienced the cumulative effects of upstream disturbance (e.g. along the Bega River). The relatively high recovery potential of reaches of this River Style is due to the inherent resilience of this River Style to change, and the ability to readily recover from disturbance.

Of the other reaches with high recovery potential, reaches of the Channelised fill and Partly-confined valley with bedrock-controlled discontinuous floodplain River Styles are located at the base of the escarpment downstream of reaches that are Intact. Hence, off-site impacts to recovery are minimal. These reaches make up 2 % or 9 km and around 3 % or 17 km of river course in the catchment respectively.

Reaches with moderate recovery potential make up 39 % of all river courses in the catchment. Other than those River Styles that are Intact, all River Styles have reaches with moderate recovery potential. Around 18 % of moderate recovery potential reaches are within the Confined valley with occasional floodplain pockets River Style (around 92 km of river course).

Reaches with low recovery potential occur along two laterally-unconfined River Styles, the Channelised fill and Low sinuosity sand bed River Style. Pronounced geomorphic changes have occurred along these rivers, irreversibly altering their geomorphic structure and function. The location of reaches of the Channelised fill River Style at the base of the escarpment means that sediment supply to these rivers has been exhausted and it will take thousands of years for the incised trenches to refill. Conversely, along the Low sinuosity sand bed River Style, the cumulative effects of disturbance have been manifest. This reach is sediment transport limited and recovery will be slow. Reaches with low recovery potential only make up around 8 % or 38 km of all river courses in the catchment. As these reaches are located in parts of the catchment where limiting factors to recovery are severe, recovery time will be slow, and the impacts on neighbouring reaches will be significant. All reaches with low recovery potential are in poor geomorphic condition.

Overall, the subcatchments with the highest recovery potential are in the Brogo system (including House, Double and Numbugga Creeks) (**Figure 6.11** and **Table 6.3**), where around 74 % of all river courses (around 110 km) of river length are either Intact or have high recovery potential. Other than the Channelised fill reach along Numbugga Creek, all low recovery potential reaches are found in the Bemboka-Bega system and its tributaries. High recovery potential reaches in the Bega-Bemboka system are resticted largely to Bemboka River, Tantawangalo and Reedy Creeks, making up only 17 % of all river courses in the catchment. The small remnant Intact reaches of the Intact valley fill and Floodout River Styles are located exclusively in the south-east of the catchment in Frogs Hollow and Towridgee subcatchments. Unfortunately, the remainder of river courses in these subcatchments have moderate or low recovery potential. This has serious implications for the prioritisation of river conservation and rehabilitation strategies in the catchment, as outlined in the following chapter.

Table 6.3 Stream lengths for each reach in each subcatchment with different recovery potential

Subcatchment/ River Style	Recovery potential	Stream length (km)
Greendale		
Gorge	Intact	0.24
Channelised fill	Moderate	3.93
Bedrock controlled discontinuous floodplain	Low	0.89
Frogs Hollow		
Gorge	Intact	0.30
Intact valley fill	Intact	4.04
Confined with occasional floodplain pockets	High	1.17
Floodout	Intact	1.96
Confined with occasional floodplain pockets	Moderate	6.64
South Wolumla		
Gorge	Intact	0.25
Channelised fill	Moderate	6.05
Bedrock controlled discontinuous floodplain	Moderate	2.90
Confined with occasional floodplain pockets	Moderate	1.13
Wolumla		
Gorge	Intact	0.28
Channelised fill	Moderate	6.36
Bedrock controlled discontinuous floodplain	Low	5.15
Confined with occasional floodplain pockets	Moderate	9.03
Towridgee		
Gorge	Intact	0.25
Intact valley fill	Intact	5.72
Confined with occasional floodplain pockets	Moderate	1.00
Candelo		2.30
Steep headwater	Intact	0.73
Gorge	Intact	4.04
Bedrock controlled discontinuous floodplain	Moderate	3.38
Confined with occasional floodplain pockets	High	16.50
	Moderate	4.00
Bedrock controlled discontinuous floodplain	Low	
Reedy		
Gorge	Intact	0.38
Channelised fill	High	8.74
Bedrock controlled discontinuous floodplain	Moderate	0.83
Tantawangalo		
Steep headwater	Intact	15.62
Gorge	Intact	1.33

Bedrock controlled discontinuous floodplain	High	6.79
Confined with occasional floodplain pockets	Moderate	7.12
	High	12.82
Bedrock controlled discontinuous floodplain	Moderate	8.29
Confined with occasional floodplain pockets	Moderate	8.30
Sandy		
Gorge	Intact	0.58
Channelised fill	Moderate	8.45
Confined with occasional floodplain pockets	Moderate	4.79
Bedrock controlled discontinuous floodplain	Low	9.11
Confined with occasional floodplain pockets	Moderate	2.94
Colombo		
Gorge	Intact	0.75
Channelised fill	Moderate	7.33
Bedrock controlled discontinuous floodplain	Moderate	3.94
Confined with occasional floodplain pockets	Moderate	0.84
Pollacks Flat		
Gorge	Intact	0.27
Channelised fill	Moderate	9.98
Confined with occasional floodplain pockets	Moderate	1.01
Bemboka/Bega		
Steep headwater	Intact	3.63
Gorge	Intact	0.59
Low sinuosity boulder bed	Intact	4.05
Confined with occasional floodplain pockets	High	11.56
	Moderate	12.46
	High	12.53
	Moderate	15.08
Low sinuosity sand bed	Low	7.42
	Moderate	3.04
Low sinuosity sand bed (below Brogo River confl.)	High	10.70
Confined with occasional floodplain pockets (Bottleneck reach)	High	9.24
Brogo		
Gorge	Intact	32.15
Confined with occasional floodplain pockets	High	31.58
Low sinuosity sand bed	Moderate	25.14
House		
Gorge	Intact	3.52
Bedrock controlled discontinuous floodplain	High	4.05
Confined with occasional floodplain pockets	High	5.45

Double		
Gorge	Intact	11.77
Bedrock controlled discontinuous floodplain	High	5.85
Confined with occasional floodplain pockets	High	15.77
Numbugga		
Gorge	Intact	0.29
Channelised fill	Low	7.13
Confined with occasional floodplain pockets	Moderate	6.95