CHAPTER 3: PRACTICAL CONSIDERATIONS IN APPLICATION OF THE RIVER STYLES FRAMEWORK IN BEGA CATCHMENT

3.1 Introduction

Findings presented here summarise detailed research undertaken in Bega Catchment from 1995-2001, providing a coherent platform for application of the River Styles framework in its entirety.

3.2 Stage One: Catchment-wide baseline survey of river character and behaviour

Methods used to undertake Stage One of the River Styles framework in Bega catchment are summarised in **Figure 3.1**.

3.2.1 Historical analyses and assessment of regional setting

In the River Styles framework, landscape units are readily identifiable topographic features with a characteristic pattern of landforms. Identification and mapping of landscape units is undertaken on the basis of physiographic character, landscape position, geology and relief. Examples of landscape units include: tablelands, uplands, mountains, escarpment, rounded foothills, low lying hillslopes and lowland plain. A map showing the distribution of landscape units in the catchment is produced. Elevation, longitudinal valley slope and valley width are tabulated to characterise each landscape unit. These attributes represent fundamental controls on river character and behaviour.

Longitudinal profiles record the downstream changes in elevation, and hence slope, along a river course. Given that slope is a primary control on river character and behaviour, changes in slope along a longitudinal profile often coincide with landscape unit and/or River Styles boundaries. Overlaying longitudinal profiles from different subcatchments can be used to compare downstream changes in slope and assess the importance of tributary-trunk relationships as determinants of the downstream patterns of River Styles (Stage One Step Three). In the River Styles framework, contributing area is superimposed onto the longitudinal profiles. The area draining into each section of the river course presents a fundamental control on downstream changes in discharge. It also defines the relative contributions of area from different parts of the catchment, and provides a quick, visual overview of changes in catchment area (and hence discharge) at tributary confluences. It is often instructive to note (and explain) whether the character and behaviour of the trunk stream changes downstream of tributaries.

Figure 3.1
STAGE ONE: Catchment-wide baseline survey of river character and behaviour

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

(1) Review background information and available literature on the catchment, including, academic papers and reports.
⇓
(2) Derive catchment-framed maps including streamlines, geology, rainfall distribution, land use etc. and analyse catchment morphometric parameters, using GIS where available.
⇓
(3) Designate landscape units and produce longitudinal profiles with contributing area plots.
⇓
(4) Analyse subcatchment morphometric parameters.
⇓
(5) Analyse discharge data and hydrological regimes.
⇓
(6) Summarise regional setting information.

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

(1) Analyse the catchment-wide distribution of river character and behaviour.
⇓
(2) Designate River Styles using air photographs and produce a River Styles tree.
⇓
(3) Produce a catchment-specific River Styles tree based on the valley-setting in which a river operates.
⇓
(4) Select representative reaches of each River Style, planform maps using air photograph interpretation, and draft proformas.
⇓
(5) Ratify River Styles boundaries in the field.
⇓
(6) Complete field analyses to finalise proformas and amend planform maps for each representative field reach.
⇓
(7) Characterise and explain river behaviour for each River Style through interpretation of reach-scale assemblages of geomorphic units.

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

(1) Determine downstream patterns of River Styles. Group the tributaries and trunk stream according to the patterns identified.
⇓
(2) Determine the imposed boundary condition controls on river character and behaviour along longitudinal profiles.
⇓
(3) Determine the flux boundary condition controls on river character and behaviour along longitudinal profiles.
⇓
(4) For representative examples of each downstream pattern of River Styles, produce a summary longitudinal profile that synthesises the relationship between patterns of River Styles and relevant controlling parameters.
⇓
(5) Produce a summary table that synthesises catchment-wide understanding of controls on river character and behaviour.

The timing and frequency of flows dictate the capacity of a river to adjust its morphology, while the sequencing of floods affects the geomorphic effectiveness of the flow (i.e. the capacity of a given flood to perform geomorphic work, that is, transport sediment). The hydrological analyses undertaken in the

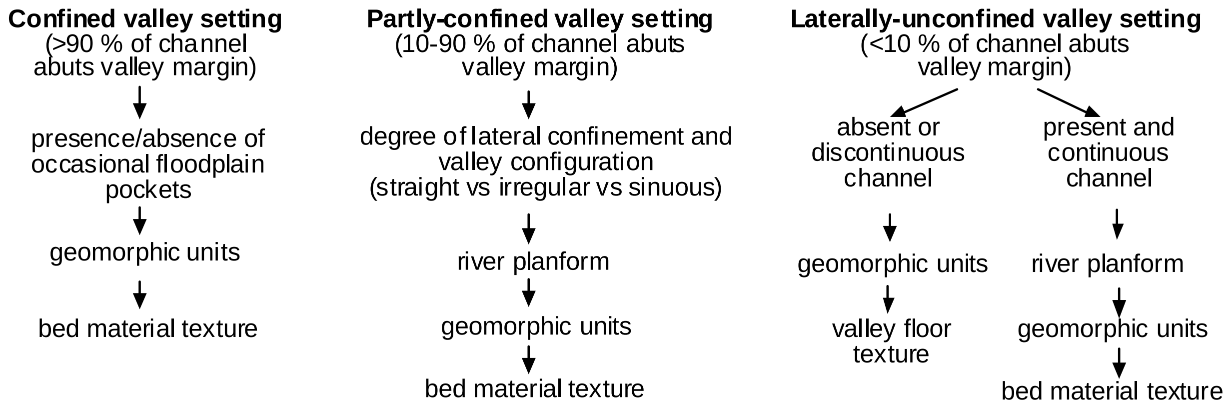
River Styles procedure are used to gain an appreciation of what scale of event is the dominant control on river morphology, and how frequently that type of flood occurs.

For Bega catchment, regional setting analyses involved compilation of historical and archival information sourced from the Mitchell Library in Sydney, the National Library in Canberra, the State Archives in Sydney, the Bega Historical Museum and the Bega Office of the Department of Land and Water Conservation. These historical records proved invaluable in assessment of river changes since European settlement. Flood records and discharge data were analysed using the Pinneena database compiled by NSW DNR. A 25 m digital elevation model (DEM) was used to designate landscape units and construct the longitudinal profiles for each primary river course in the catchment. GIS databases were also used to review maps of vegetation cover, geology etc. Local anecdotal evidence was compiled from various sources including landowners and local historians. A range of other catchment morphometric parameters (such as stream density, stream length, catchment area etc.) was calculated either manually using 1:100,000 and 1:25,000 topographic maps or from the 25 m DEM.

3.2.2 Air photograph interpretation and mapping of River Styles

The definition and interpretation of River Styles is initially undertaken as a desk top exercise. Fieldwork is then undertaken to collect relevant information on river character and behaviour for each River Style in the catchment and ratify boundaries between River Styles. The primary trunk streams in each subcatchment are systematically analysed, identifying the distribution of floodplains along river courses to determine the range and pattern of valley-settings. Within each valley-setting, River Styles are identified on the basis of river planform and the assemblage of geomorphic units. Bed material texture provides a finer level differentiation that is completed in the field. Dependent on whether the reach falls into a confined, partly confined or laterally-unconfined valley setting, differing sets of procedures are used to identify the River Style (**Figure 3.2**). The importance of each parameter for assessing river character and behaviour depends on the valley-setting. A River Styles tree is constructed that outlines the specific identification criteria for each River Style. Each River Style is given a diagnostic name and a draft catchment wide map is produced showing the distribution of River Styles. Geomorphic planform maps are produced for representative reaches of each River Style.

Figure 3.2 Procedures used to identify River Styles in different valley settings



The identification of River Styles in Bega catchment was undertaken using the 1994 1:25,000 Bega-Goalen air photograph set and accompanying topographic maps. Each River Style was identified on the basis of its valley-setting, assemblage of geomorphic units, river planform and bed material texture. Given the fine scale resolution of the exercise, a splitting approach was adopted, and near uniform river character and behaviour was identified for reaches that were as short as 1 km in length. Planform maps were constructed at the scale of 1:6,000 by enlarging the aerial photographs. Representative reach maps were rectified in the field.

Each River Style boundary was checked in the field. In general, River Styles boundaries were distinct, marked by significant constrictions in valley morphology or a change in valley alignment. Numerous boundaries coincided with bedrock steps along longitudinal profiles and tributary confluences. In cases where a transition between River Styles occurred, say, over a kilometre, the boundary was simply placed in the middle of the transition zone.

3.2.3 Field analysis

Given the pilot nature of this study, each reach of each River Style was visited to rectify and finalise the geomorphic unit distribution and complete proformas for each River Style. Valley-scale cross sections were surveyed and sedimentological and vegetation analyses performed for differing geomorphic units. Representative photographs were also taken. The presented River Styles proformas contain a summary of the character and behaviour of each River Style across the catchment. This entails synthesis of the range of geomorphic conditions found in each River Style. The best examples of planform maps, photographs and cross-sections are presented. Most of this fieldwork was conducted in 1996 and 1997.

3.2.4 Assessing controls on river character and behaviour

One of the key components of the River Styles framework is the desire to understand how and why each reach looks and behaves in the manner that it does. To further this understanding a summary assessment of controls on the distribution of River Styles is developed. Critical controls on river behaviour may vary from reach to reach. Initial insights into the array of controls on any given reach may be gained by plotting downstream patterns of River Styles onto longitudinal profiles. Analyses of slope and contributing area are combined with catchment area-discharge relationships to estimate gross stream power, from which stream power ranges are determined for each River Style. The critical role of downstream changes in valley confinement is explained at this stage, generally in terms of the geological imprint (structure and lithology) along with interpretations of long-term landscape history.

To assess controls on the character and behaviour of each River Style in Bega catchment, river courses were grouped according to their downstream pattern of River Styles. A representative example of each downstream pattern was chosen and River Styles and landscape unit boundaries placed on the longitudinal profile-contributing area plots. Gross stream power was calculated and overlayed on this plot. Slopes were derived for the length of the River Style using 10 m contour interval data on topographic maps. An interpretation was made of the contemporary process zones (source, transfer, accumulation) and sediment transport regime (bedload, mixed load, suspended load) of the river course. A visual diagram demonstrating downstream changes in valley and channel width was compiled from air photographs and the valley-scale cross-sections.

3.3 Stage Two: Catchment-framed assessment of river evolution and geomorphic river condition

Assessment of geomorphic river condition was conducted for each reach of each River Style in the catchment. In some cases, this required breaking River Styles into smaller reaches. In all, 73 reaches were assessed in Bega catchment (**Figure 3.3**). Methods used to undertake Stage Two of the River Styles framework in Bega catchment are documented in **Figure 3.4**.

Figure 3.3 Reaches used to assess the geomorphic condition of rivers in Bega catchment

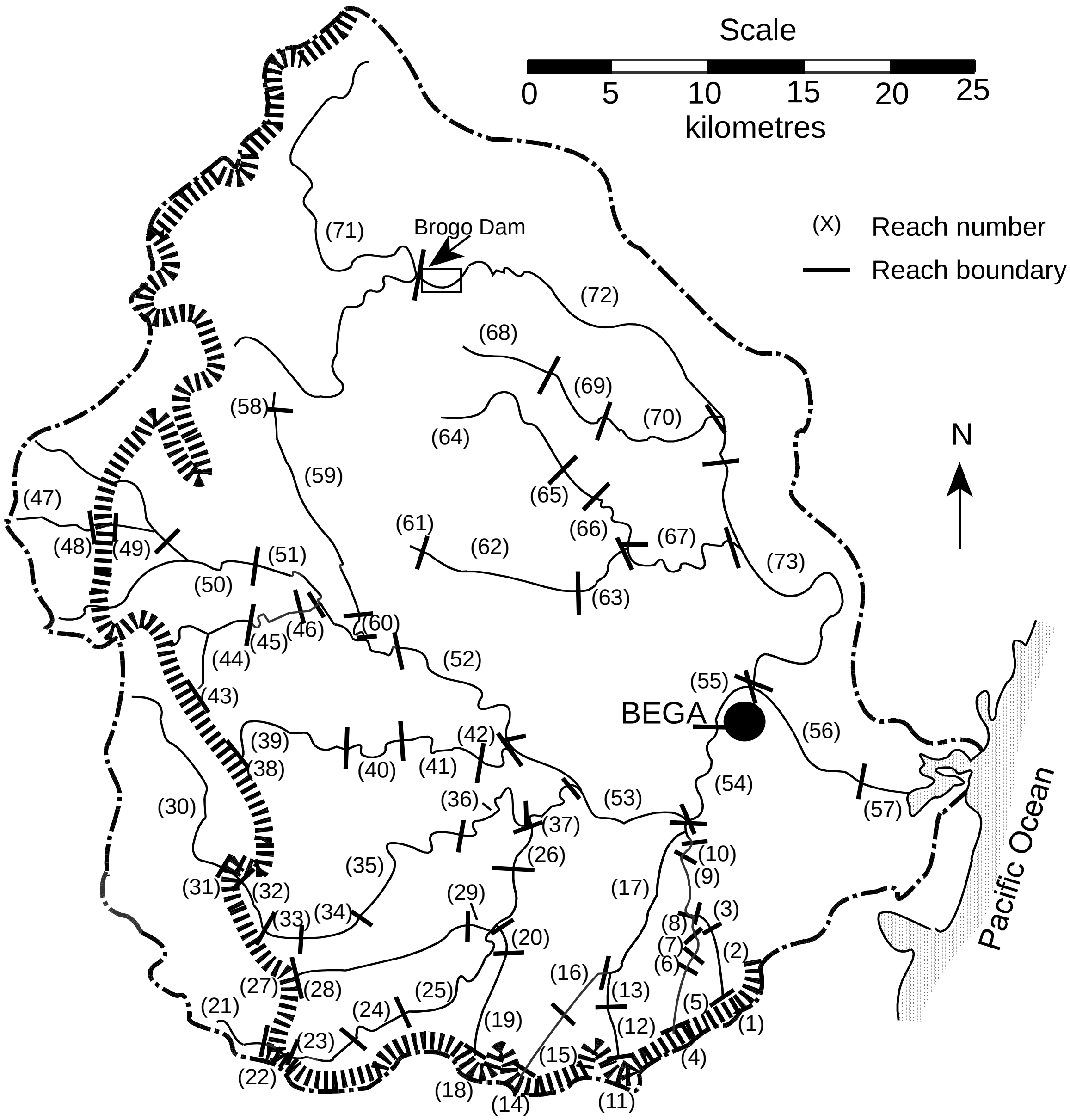


Figure 3.4
STAGE TWO: Catchment-framed assessment of river evolution and geomorphic river condition

Stage Two, Step One: Determine the capacity for adjustment of the River Style

(1) Interpret how each River Style can adjust under the prevailing flux boundary conditions (i.e. sediment, flow and vegetation characteristics).
⇓
(2) Assess the ability of each degree of freedom to adjust for each River Style by determining which geoindicators within each degree of freedom are relevant for each River Style.
⇓
(3) Construct a table noting relevant geoindicators that will be used to identify a reference condition and assess the geomorphic condition of reaches.

Stage Two, Step Two: Assess river evolution as a basis for identifying irreversible geomorphic change and a reference condition

(1) Identify the timeframe over which environmental conditions in the catchment/region have been relatively uniform.
⇓
(2) Construct an evolutionary sequence for each River Style in the catchment.
⇓
(3) Draw planform maps and schematic cross-sections for each timeslice in the evolutionary sequence.
⇓
(4) Determine whether irreversible geomorphic change has occurred for each reach.
⇓
(5) Derive desirability criteria for river character and behaviour based on relevant geoindicators for each River Style.
⇓
(6) Identify reference conditions for each River Style.
⇓
(7) Select the most appropriate reference reach using the 'relevant geoindicators' and asking the question: What would be the expected character and behaviour of the river given its position in the catchment, and the prevailing water, sediment and vegetation regimes?

Stage Two, Step Three: Determine and explain the geomorphic condition of the reach

(1) Determine the geomorphic condition of each reach using the degrees of freedom and good, moderate and poor condition matrix.
⇓
(2) Interpret and explain the geomorphic condition of the reach.

3.3.1 Determining the capacity for adjustment

To determine the capacity for adjustment of each River Style in a catchment, the question is asked: In what ways can this type of river adjust within its valley-setting under the prevailing set of flow and sediment characteristics? Ways in which the channel adjusts its position on the valley floor, and how the reach delivers sediment downstream should be considered. In asking this question, three degrees of freedom are considered in the River Styles framework, namely, channel attributes, river planform and bed character. An example of how the capacity for adjustment has been assessed for a range of River Styles in Bega catchment is shown in **Figure 3.5**.

Figure 3.5 Determining the capacity for adjustment for a range of River Styles. (Note: Intact valley fill rivers may be highly sensitive to change if a threshold of slope or surface resistance is breached and the river is transformed to a Channelised fill river)

Channelised fill River Style

* channel geometry can adjust significantly
* river planform can adjust significantly
* bed character can adjust significantly

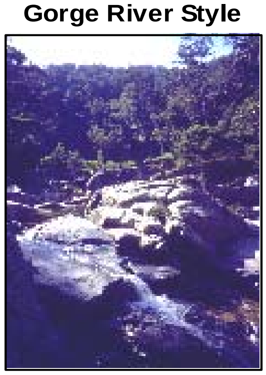
River Style has significant capacity to adjust and is considered sensitive to change

Intact valley fill River Style

* bed character can locally adjust

River Style has limited capacity to adjust and is considered resilient to change

Gorge River Style



* bed character can locally adjust

River Style has limited capacity to adjust and is considered resilient to change

Partly confined valley with bedrock-controlled discontinuous floodplain River Style

* channel geometry can locally adjust
* river planform can locally adjust
* bed character can adjust significantly

River Style has limited capacity to adjust and is considered relatively resilient to change

Within each degree of freedom, a series of geoindicators is measured or assessed to determine the ability of each reach to adjust within its valley-setting (**Table 3.1**). In this framework, channel attributes are assessed in terms of the size and shape of a channel, bank morphology and vegetation and loading of wood. River planform is assessed in terms of the number, sinuosity and lateral stability of channels, the assemblage of instream and floodplain geomorphic units, and riparian vegetation structure and composition. Bed character is assessed in terms of grain size, bed configuration (i.e. sorting, bed stability, hydraulic diversity) and sediment regime (i.e. whether the reach acts as a sediment source, transfer or accumulation zone). Only those geoindicators that provide direct insight into how that river adjusts are assessed for each River Style. **Figure 3.6** shows how to identify relevant geoindicators for the Channelised fill River Style in Bega catchment. This type of analysis is used as a simplified measure of the ***sensitivity of a River Style*** to change. Those reaches with significant adjustment potential are considered sensitive to change, while those with localised adjustment potential are considered resilient to change.

Figure 3.6 Identifying relevant geoindicators for the Channelised fill River Style

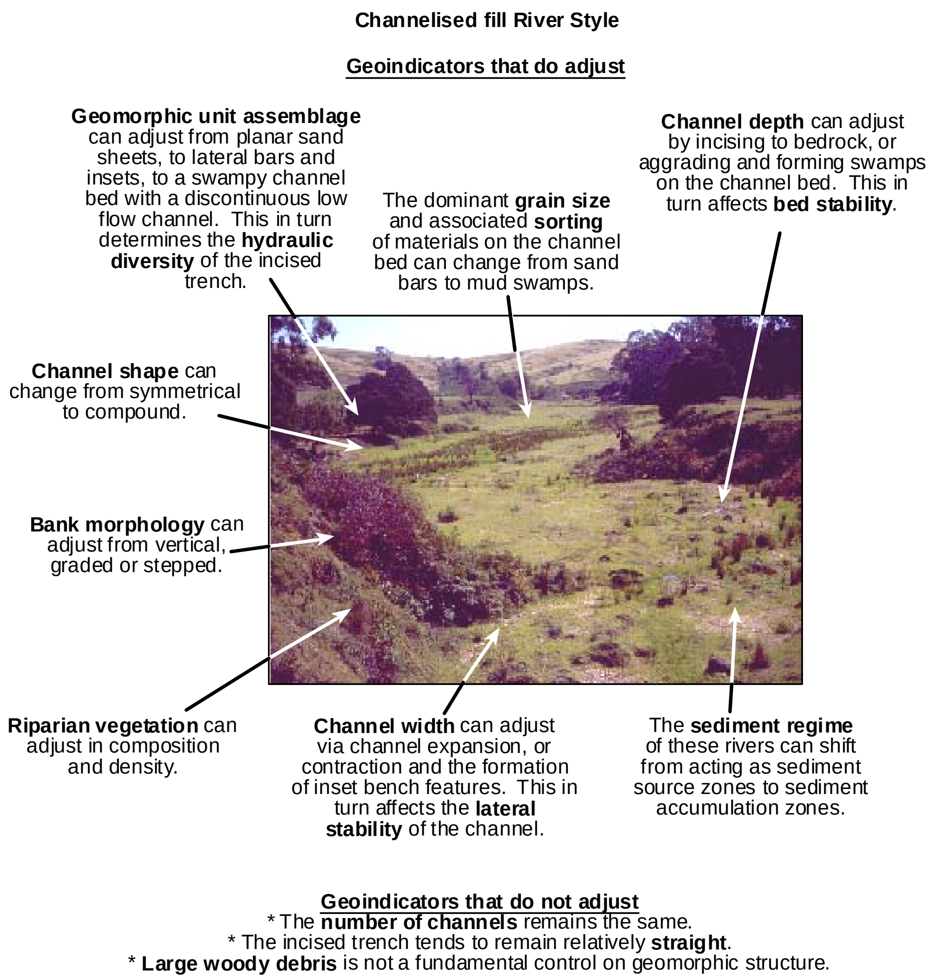


Table 3.1 Methods for measuring each geoindicator used to assess the capacity for adjustment and geomorphic river condition. These measures are summarised over a reach (From Brierley and Fryirs, 2005; Fryirs, 2003).

Degree of freedom / Parameter	Definition	Some geomorphic tools used to measure/assess each geoindicator
Channel attributes – Channel structure is a function of bed and bank material texture, vegetation cover, bed slope and discharge.		
Size	The width and depth of the channel	• Width:depth ratio and cross-sectional area of the channel relative to the catchment area it drains.
Shape	The cross-sectional form of the channel	• Identification of irregular, compound, symmetrical or asymmetrical channels
Bank morphology	The shape and character of each bank	• Identification of uniform vertical, uniform graded, faceted, undercut banks • Characterisation of bank texture using grain size analyses
Instream vegetation structure	The character and density of aquatic and terrestrial vegetation. Linked to the geomorphic structure and flow regime.	• Qualitative rating of the composition (native vs exotic) and coverage of vegetation on instream geomorphic surfaces using Specht (1999).
Wood loading	The character and density of wood. Linked to the geomorphic structure and flow regime.	• Qualitative rating of the type, alignment and abundance of wood in the channel
River planform – The outline of a river from above is a function of material texture, valley slope, valley-setting and vegetation structure.		
Number of channels	Count of the number of channels across a valley transect	• Identification of absent, discontinuous, single or multi-channel variants
Sinuosity of channels	The degree of channel curvature along the length of a river	• The ratio between channel length along the thalweg and valley length along its axis
Lateral stability	The degree to which the channel can move on the valley floor	• Identification of channel expansion processes, concave bank erosion and avulsion processes
Geomorphic unit assemblage	The building blocks of rivers. Each geomorphic unit has a distinct form-process association. Assemblages of geomorphic units are used to interpret river behaviour.	• Analysis of form and sedimentology is used to interpret processes responsible for formation of geomorphic unit • Assessment of the juxtaposition and assemblage of geomorphic units • Assessment of channel-floodplain connectivity and unit condition (e.g. is there signs of reworking, dissection etc.).
Riparian vegetation	The character and density of vegetation along the river banks. Linked to the geomorphic structure and flow regime.	• Qualitative rating of the composition (native vs exotic), continuity, and structure of vegetation assemblages in the riparian zone using Specht (1999)
Bed character– Is a function of flow regime, sediment availability and the capacity of the reach to transfer materials.		
Grain size and sorting	The size, distribution and arrangement of materials stored on the channel bed	• Visual estimates of the percent of channel bed comprising different grain size fractions • Analysis of sediment distributions on different geomorphic units.
Bed stability	Capacity of channel bed to adjust vertically	• Interpretation of vertical bed activity via incision/aggradation.
Hydraulic diversity	The character of flow over the channel bed	• Visual water surface flow estimates using Thomson et al. (2001)
Sediment regime	The storage, transfer and delivery capacity of the reach. Measures the capacity and/or competence of the reach to transport sediment.	• Identifying sediment process zone (i.e. source, transfer, accumulation) (Schumm 1977) • Quantitative measure of sediment transport capacity vs sediment availability to interpret supply vs transport limited reaches.

Relevant geoindicators were then used to construct a set of 'desirability criteria' for each River Style. Based on these criteria, and the evolutionary sequence, a reference condition is identified for each River Style. This is then used as a benchmark against which to assess the geomorphic condition of each reach.

3.3.2 Assess river evolution as a basis to identify irreversible geomorphic change and a reference condition

Analysis of Holocene river evolution in Bega catchment built on significant research completed for River Styles at the base of escarpment (Fryirs and Brierley, 1998 a, Brierley and Fryirs, 1998) and along the lowland plain (Brooks and Brierley, 1997, 2000). Additional analyses were based on extensive field, historical and appraisal of academic literature completed as part of a PhD thesis by Kirstie Fryirs (Fryirs, 2001; Fryirs and Brierley, 2000; Fryirs 2003; 2002). Assessment of differing phases of geomorphic adjustment evident for the same River Style at differing positions across Bega catchment formed the basis for an appraisal of evolutionary timeslices using ergodic reasoning. Whenever possible, these differing forms of analysis were cross-checked.

Stages of geomorphic river evolution were appraised for each River Style over timeframes of decades to centuries, extending from the pre-European settlement period (i.e. around 1788) to the present. Detailed analyses were conducted along one representative reach of a River Style using a range of historical information (**Table 3.2**). Timeslices were constrained by the dates of air photographs, historical information, anecdotal and archival data sources. In general, timeslices included 1788 (pre-European settlement), around 1900 (the first photographs), 1944 (the first set of air photographs), and today (the 1994 air photographs and field analyses). Additional timeslices were used where significant historical data were available. For example, along the lowland plain, settlement occurred around the 1850's and hence a timeslice has been constructed for that time.

Table 3.2 Archival and historical data collection in Bega catchment

Location	Information held	Comments
Lands Department of NSW	Portion plans	Contains vegetation information and comments on available surface water. Occasionally nothing is noted other than types of trees used as portion markers.
	Bridge surveys	Invaluable for assessing changes in channel dimensions.
	Surveyors field books	Commonly contain notes on topography and landscape condition.
	Parish maps	Show portion numbers, boundaries and first property owner.

	Historical and recent air photographs	Record the changing structure of river courses, including channel width and alignment, vegetation cover, etc.
National Library, Canberra	Early air photographs, books, journals, maps, oral histories, newspapers, rehabilitation or river work plans.	Date from the 1890s, but often a difficult resource to use because of poor indexing.
Mitchell Library, State Library of New South Wales, Sydney	Old maps, correspondences, books, journals, small picture file, laser disk storage of photographs, some newspapers.	Considerable information kept here on flood histories, photographs of reaches etc.
State Government offices (DNR), local councils, local museums and libraries	Rainfall data, flood histories, photographs, old paintings, river rehabilitation plans, river surveys, reports, etc.	A lot of information, but can be difficult to find due to poor archiving and indexing. All sorts of oddities available.

To extend the record into the pre-European settlement period, floodplain geomorphology and sedimentology were analysed in the field. Conventional and Accelerated Mass Spectrometer (AMS) ^{14}C dating was used to determine the age of some floodplain features, placing time constraints on the nature, magnitude and rate of change.

In those settings that retain little evidence of evolutionary change, ergodic reasoning was used to complete an evolutionary sequence. Reaches used for ergodic reasoning were of the same River Style, operated under similar catchment boundary conditions, and sat at a similar position in the catchment. In this way, future scenarios were added where examples existed (i.e. along reaches that showed an additional evolutionary slice than along the selected representative example). Schematic representations of channel cross section and planform were produced for each timeslice. From this, each reach in the catchment was placed onto the relevant evolutionary sequence for the River Style.

The evolutionary sequence of each reach is used to identify if, how and when irreversible geomorphic change occurred and identify a reference condition. The ability to identify whether a reach has experienced irreversible geomorphic change requires evidence of major shifts in the catchment boundary conditions under which the river operates and associated irreversible responses in the structure and function of the river.

If a reach has experienced irreversible geomorphic change, it's condition must be assessed in terms of the River Style to which it has shifted. In this instance, comparing the contemporary reach with a pre-disturbance reference condition is irrelevant in setting realistic management goals. If a river still operates within the process regime of its pre-disturbance River Style, and reversible change has occurred, the condition of that reach is assessed in light of that River Style. These insights are used to frame subsequent management actions.

Four types of natural reference conditions can be identified, based on the irreversibility/permanency of geomorphic change, and the prevailing catchment boundary conditions (Brierley and Fryirs, 2005):

1) Remnant reaches that have been minimally disturbed by humans, such that geomorphic changes to river character and behaviour remain reversible.
2) Reaches where human-disturbance has occurred, but geomorphic changes to river character and behaviour remain reversible.
3) Reaches where change has been induced by indirect human-disturbance and irreversible change has resulted.
4) Reaches where change has been induced by direct human-disturbance and irreversible geomorphic change has resulted.

A reference reach of a River Style is identified by asking the question: What would be the expected character and behaviour of the river given its position in the catchment, and the prevailing water, sediment and vegetation regimes? A reference reach should fit the desirability criteria constructed for each River Style. These reaches are either available in the catchment and can be used as direct analogues or are identified from the evolutionary sequence for the River Style under examination.

3.3.3 Determine and explain the geomorphic condition of each reach

Geomorphic condition was assessed for each reach of each River Style in Bega catchment. Using the evolutionary sequences, irreversible change was identified when a wholesale change in river structure and function occurs. Each reach in the catchment was compared to its relevant reference condition (identified from the desirability criteria) to assess its condition (see Brierley and Fryirs, 2005; Fryirs, 2003). Field analyses to perform this assessment were completed from 1998-2000, and included detailed sedimentary, vegetation, channel planform and geomorphic unit analyses.

To assess the condition of a reach a matrix is developed whereby the practitioner assigns ticks or crosses in answer to the 'desirability questions' table constructed for each River Style. Depending on the number of Yes/No responses to questions asked about the 'desirability' of reach character and behaviour, a tick is assigned for each degree of freedom (Brierley and Fryirs, 2005).

Three ticks for a reach places it in a good geomorphic condition (**Table 3.3**). Reaches in good geomorphic condition are defined as those in which river character and behaviour are appropriate for the River Style in that valley-setting and that position in the catchment. Geomorphic structures are in the right place and operating as expected for a 'natural' or 'near-natural' version of that River Style. This reach should cross-compare closely with the reference condition.

Table 3.3 Determining the geomorphic condition of a reach of a River Style

Channel attributes	River planform	Bed character	Geomorphic river condition
√	√	√	Good
√	**X**	√	Moderate
X	√	**X**	Moderate
X	**X**	**X**	Poor

Three crosses places a reach in the poor condition category (**Table 3.3**). Poor condition reaches are defined as those in which river character is divergent from the reference condition and abnormal or accelerated geomorphic behaviour/change occurs. Key geomorphic units are absent or located inappropriately along the reach, and processes are out-of-balance with the geomorphic structure of the reach.

Moderate condition reaches sit between these two extremes (with either two crosses, or two ticks for any of the degrees of freedom; **Table 3.3**). There are certain characteristics of the reach that are out-of-balance or inappropriate for that River Style.

Once the condition of each reach has been determined, a table is constructed for good, moderate and poor condition reaches of each River Style in the catchment that details and explains how each degree of freedom has adjusted. These tables provide the template for repeat surveys, where the geomorphology of the reach can be monitored to determine if improvement has taken place. They also outline the geomorphic parameters that require manipulation to improve the condition of the reach.

3.4 Stage Three: Assessment of the future trajectory of change and geomorphic river recovery potential

Assessment of limiting factors and pressures that constrain the recovery of landforms and ecosystems enables the adoption of appropriate measures to minimise the impacts of these constraints. Application of this kind of thinking enables management strategies to address underlying causes rather than the symptoms of problems relating to factors such as sediment exhaustion, flow management; nutrient fluxes, weed dispersion, depleted seed sources etc.. These considerations must be assessed on a catchment-by-catchment and reach-by-reach basis. In the River Styles framework, within-catchment linkages of physical processes are examined, such that disturbances in one part of the catchment can be related to river responses elsewhere. In this way, both off-site impacts and lag effects can be appraised.

The first step in assessment of geomorphic river recovery is to identify stages of adjustment to disturbance of each reach of each River Style. In this case study, these assessments are framed in light of disturbance events since European settlement of the area in the 19th century. Each reach is placed on pathways of degradation or recovery and predictions are made about the likely direction of future changes. Assessment of the connectivity of biophysical processes in the catchment, and interpretation of limiting factors to recovery, are used to determine the geomorphic *recovery potential* of each reach. Factors considered in these assessments include human-imposed constraints on water and sediment transfer, vegetation patterns (including the loading of wood), and other pressures that may constrain river recovery. Methods used to undertake Stage Three of the River Styles framework in Bega catchment are summarised in **Figure 3.7**.

Figure 3.7
STAGE THREE: Assessment of the future trajectory of change and geomorphic river recovery potential

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

(1) Position each reach on its evolutionary sequence for the River Style.
⇓
(2) Translate each timeslice of the evolutionary sequence of the River Style onto the recovery diagram using the decision tree.
⇓
(3) Determine the trajectory of change of each reach in the catchment (i.e. either degradation, restoration or creation).

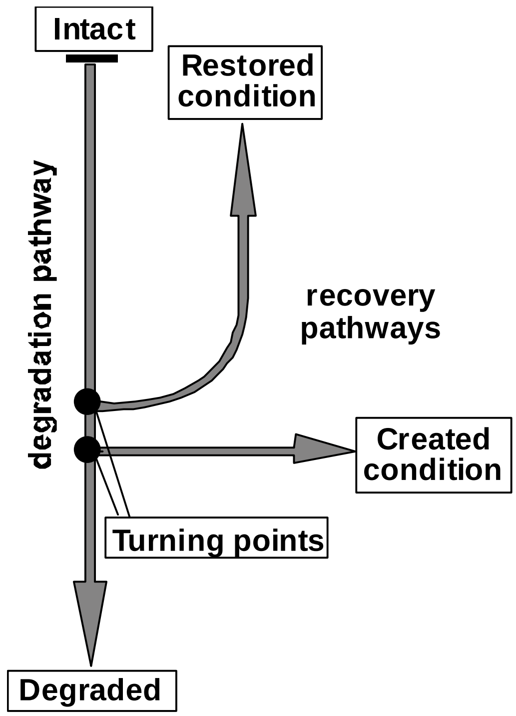
Stage Three, Step Two: Assess river recovery potential: Place reaches in their catchment context and assess limiting factors to recovery

(1) Determine the sensitivity of the reach (completed in Stage Two, Step One).
⇓
(2) Note the geomorphic condition of the reach (completed in Stage Two, Step Three).
⇓
(3) Assess limiting factors and pressures in the catchment.
⇓
(4) Place each reach in relation to ongoing (and prospective) catchment dynamics.
⇓
(5) Determine the recovery potential of each reach using the decision tree.

3.4.1 Determine the future trajectory of change

The trajectory of change a reach will take is determined by placing each reach in the catchment on the recovery diagram (Brierley and Fryirs, 2005). This diagram comprises three pathways, the degradation scale on the left and two recovery pathways, restoration and creation on the right (**Figure 3.8**).

Figure 3.8 The recovery diagram used in the River Styles framework (from Brierley and Fryirs, 2005)



Assessment of the trajectory of change of a reach is based initially on analysis of the evolutionary sequences constructed in Stage Two, Step Two of the River Styles framework. With the evolutionary framework of river changes in-hand, the position of each reach on the recovery diagram is determined using a decision-tree (Brierley and Fryirs, 2005). The position of the reach relates directly to its geomorphic condition assessed in Stage Two of the River Styles framework. Based on this analysis, stages of adjustment for each reach (i.e. the trajectory of change) are identified and interpreted (see Brierley and Fryirs, 2005; Fryirs and Brierley, 2000.

3.4.2 Assess the recovery potential of each reach

Given that rivers are evolving, adjusting entities, a reach can sit at any position on the degradation pathway and, given favourable conditions, may move onto a recovery pathway at any point. However, even though a reach may sit on a recovery trajectory and show signs of recovering towards a restored or created condition, the river may not have the 'potential' to recover. To assess the likelihood of geomorphic recovery for each reach of each River Style, limiting factors and pressures to recovery must be examined. Each reach must be placed within its catchment context and appraised in terms of physical linkages between reaches. In this context, the *recovery potential* of each reach is assessed individually, based on a combined assessment of its *sensitivity* to change, its *geomorphic condition*, its *position in the catchment* and the *limiting factors* and *pressures* operating upstream and downstream of it.

As sediment availability is the primary limiting factor to geomorphic recovery in Bega catchment, a post-European settlement alluvial sediment budget was constructed for the catchment. Once all evolutionary sequences were in-hand, it took around six months of primary research to construct this sediment budget (see Fryirs and Brierley, 2001). 1:6,000 aerial photograph trace maps were completed for every water course and lower order drainage line in the catchment. These maps, which formed the basis to assess geomorphic condition and recovery, recorded the dimensions of each floodplain and instream geomorphic unit in the catchment. Over 2,000 measurements of the surface area of sediment storage units were taken and over 50 channel cross sections were surveyed. Depth to bedrock was analysed for each geomorphic unit via drilling of floodplain surfaces or probing of channel bed materials. The planform maps and cross-sections were used to calculate the volumes of material stored along each river course. Based on the evolutionary timeslices, volumes of material removed since European settlement were determined. This allowed temporal changes in sediment release, storage and transfer to be calculated for each reach in the catchment spanning the post-European settlement timeframe. Bedload transport modelling and stream power analyses were completed to determine how sediment availability 'limited' the potential for geomorphic river recovery throughout the catchment.

Additional recovery assessments could have been performed for changes to the hydrological regime across the catchment, and analysis of seed sources (native/exotic) along river courses. Specific catchment-wide assessments of this ilk were not completed in this study, but related analyses completed within the Bega Office of DNR were used to complement the sediment budget work. Of particular assistance here were reports on the Bega-Bemboka Flow Management Plan (NSW DNR, 1999), the Bega Catchment Integrated River Health Package designed to meet priorities set within the South East Catchment Management Board Blueprint (NSW DNR, 2002) and the Healthy Rivers Commission inquiry into the Bega River system (HRC, 2000).

In Bega catchment, those reaches that sit higher in the catchment, close to intact and good condition reaches, have been assigned a high recovery potential rating. The proximity of reaches to those in good geomorphic condition means that impacts of disturbance are likely to be limited, providing an opportunity to recover relatively quickly. Those reaches that remain in good condition but are isolated in the catchment are generally resilient to change and will absorb off-site impacts. Hence, they are also given a high recovery potential rating. The position of poor condition reaches in the catchment then dictates the recovery potential of the remaining reaches in the catchment. These poor condition reaches are often sensitive to change, and tend to propagate degradation throughout a catchment with significant off-site impact (e.g. Fryirs and Brierley, 2001). Moderate and low recovery potential ratings are assigned according to the sequencing of reaches along a river course and their resilience or sensitivity to change (see Brierley and Fryirs, 2005).

3.5 Stage Four: River management applications and implications: Catchment based vision building, identification of target conditions and prioritisation of management efforts

Methods used to undertake Stage Four of the River Styles framework in Bega catchment are documented in **Figure 3.9**.

Figure 3.9
STAGE FOUR: River management applications and implications: Catchment based vision building, identification of target conditions and prioritisation of management efforts

Stage Four, Step One: Develop a catchment framed physical vision

(1) Collaborate with local community groups, council, state water and land conservation agency, landowners and other stakeholders to determine a physical catchment-framed vision for river courses over a timeframe of 50-100 years.

Stage Four, Step Two: Identify target conditions for river rehabilitation and determine the level of intervention required

(1) Use information derived through application of Stage Two to determine the types of manipulation required along a reach and the types of geomorphic structures that must be enhanced. Appraisal of geomorphic *condition* provides information on the types of manipulation needed and level of intervention required. Good, moderate and poor condition reaches of each River Style can be used as short-medium term *target conditions*.

⇓

(2) Use information from application of Stage Three to determine the likelihood that each reach will recover along a creation or restoration pathway. Assessment of *recovery potential* provides a surrogate for the time it will take a reach to recover given its catchment position and response to limiting factors operating within the catchment.

Stage Four, Step Three: Prioritise management efforts based on geomorphic condition and recovery potential

(1) Based on the condition and the recovery potential of each reach, prioritise each reach according to its conservation/rehabilitation status.

⇓

(2) Develop a catchment-wide plan of attack (a program/schedule of works) for tackling the river conservation/rehabilitation issues in the catchment.

Stage Four, Step Four: Monitor and audit adjustments to geomorphic river condition

3.5.1 Create a catchment-framed physical vision

An over-arching catchment-framed *vision* outlines the goals and objectives for river rehabilitation over a 50-100 year timeframe. This provides a basis to develop an achievable and realistic plan of attack. Derivation of a realistic vision must consider ongoing and likely future 'pressures' that will be experienced in the catchment, and associated appraisals of prospective environmental changes.

Generation of a vision presents an overarching statement on the desired future state of the catchment. Scoping or foresighting exercises undertaken with a range of stakeholders must build on the geomorphic template created through application of Stages 1-3 of the framework. When information is limited, or uncertainties and limitations are encountered the precautionary principle should be applied. In articulating how this vision will be achieved one of three scenarios is adopted:

1) ***Do nothing***. In this case, stakeholders must accept the current condition of the river system. In Bega catchment this includes accepting the incursion of exotic vegetation (e.g. willows), accelerated rates of geomorphic change and many river courses in poor condition. Adoption of this option means that the remaining sections of river that retain a good geomorphic condition may be placed under threat of deterioration.
2) ***Work with natural processes in a realistic way***. This involves identifying what is realistically achievable. Rehabilitation of target reaches that have a high likelihood of inducing positive outcomes in neighbouring and downstream reaches is vital. Ideally, rehabilitation strategies entail minimal impacts, endeavouring to promote progressive change over time while minimizing social and economic disruption. In many cases, recovery is already underway. In these situations, management strategies should aim to enhance 'natural' processes while conserving and maintaining rare, unique or good condition reaches. Wherever possible, strategies aim to allow the river to adjust naturally and function in an ecologically sustainable manner, working with the inherent adjustments and connectivity for that particular system. For example, whenever pertinent a continuous riparian corridor should be sought and channel-floodplain linkages should be maintained.
3) ***Invasive improvement***. This involves high cost, high maintenance measures that strive to 'improve' the condition of the system. While ecologically possible these options are often unrealistic in social and economic terms.

To articulate the vision and determine which of these options is viable a series of questions are asked, including:

- What are we trying to achieve?
- What do we want the river to be like?

- What are we managing for?
- How do we intend to achieve our goals?

The vision statement must incorporate considerations that link initiatives relating to:

- Sediment supply and storage
- Water transfer, storage and quality
- Vegetation coverage, composition and succession
- Habitat availability, viability and variability
- Measures of ecological functioning, such as food web processes, nutrient flux, organic matter processing, etc.

While all endeavours are made to determine the best overall outcome at the catchment-scale, some reaches may have to be compromised to achieve the vision. In other words, collective enhancement of rivers in broad-scale terms is unlikely to be achieved without some short-term losses. Maximising the potential for long-term success requires that reaches are prioritised in terms of the greatest likelihood of success. By effectively prioritising efforts, tangible success can be achieved in a strategic manner rather than spreading efforts so thin that very little is achieved.

To facilitate adoption of the River Styles framework, ensuring that a suitable communication tool is provided for end users, the creation of the physical vision for Bega catchment was undertaken in collaboration with technical officers in the Bega Office of NSW DNR. Community-based workshops and field days were used to increase understanding of issues, scope views and define achievable goals within a specified timeframe. This has ensured that potential benefits <u>and</u> limitations of available data and understanding are fully appreciated, enhancing the opportunity for adoption of findings (see Chapters 7 and 8).

3.5.2 Identify target conditions for river rehabilitation

Nested within an over-arching vision are a suite of short-medium term target conditions which are used as stepping stones along a creation or restoration pathway. These target conditions are defined for particular time periods for each reach of each River Style in the catchment. As target conditions are achieved, the catchment vision is reappraised in an iterative process.

If target conditions for each River Style are to be sustainable over the long term they must be framed in light of the character, behaviour, condition and recovery potential of a reach, recognising how these interactions operate at the catchment-scale and related concerns for the overarching vision. Due regard must be given to potential off-site impacts. River rehabilitation strategies undertaken in each reach must not compromise the catchment-framed goal.

Determining *target conditions* involves assessing what is realistically achievable for each reach in the catchment over a short-medium timeframe (i.e. over years to decades). The assessment of river condition and recovery potential undertaken in Stages Two and Three of the River Styles framework provides the tools and scientific information needed to identify target conditions for river rehabilitation. Creation and restoration goals equate to the natural or expected condition of a River Style operating in a sustainable manner under the prevailing boundary conditions. Information on minimally impacted reaches of each River Style is used to guide the target conditions for channel alignment, geomorphic structures, vegetation character, sediment distributions and channel-floodplain relationships for reaches in poorer condition. Hence, reaches in good geomorphic condition are used to design the target conditions for river structure and function of reaches in moderate or poor geomorphic condition.

Information on the condition and recovery potential of each reach in the catchment is used to determine the level of intervention and the type of manipulation required to attain a sustainable river structure and function, and the level of risk associated with applied rehabilitation measures. The *timeframe of recovery* is related to the recovery potential of the reach, and the *level of intervention* required is directly related to the condition of the reach. Reaches in good condition with high recovery potential will require minimal intervention, with visible results occurring relatively quickly. As the condition and recovery potential of reaches deteriorates the required level of intervention increases and the rate of recovery decreases. In poor condition reaches, direct intervention and manipulation may be required. The scientific insight provided through application of the condition and recovery potential framework is used to define, for each reach, the parameters that require manipulation to enhance recovery towards the target condition. These analyses are used as a benchmark against which to assess whether improvement has occurred.

3.5.3 Prioritise efforts at river conservation and rehabilitation

A prioritisation framework determines the sequencing of actions that can be applied to achieve the catchment-based vision. Prioritisation frameworks for river rehabilitation and conservation programs can be used to ensure that the most cost-effective and efficient reach based strategies are employed that work towards the catchment vision. Indeed, prioritisation frameworks will only be effective if placed within a catchment vision. It is not until we know what we are striving to achieve in big-picture terms that prioritisation frameworks for river conservation and rehabilitation programs can be effectively applied.

In developing catchment-wide river rehabilitation programs, critical decisions must be made on where in the catchment to start and the associated plan of activities. Procedures used to make such decisions should be logical, testable and transparent. While economic, cultural and social values place obvious constraints on how this is undertaken, a physical template forms a critical basis for decision-making. Application of a physically-based prioritisation framework, can be used to identify where the greatest likelihood of success is likely to be attained within the catchment. In many cases, the rehabilitation of strategic reaches triggers a positive feedback whereby enhanced recovery is achievable throughout the catchment. Identifying those reaches where 'tweaking' is required is an underlying premise of the prioritisation framework developed in the River Styles framework.

Given limited resources, any rehabilitation strategy must concentrate efforts, rather than spreading them too thinly and recognising the imperative to not confuse activity with effectiveness. Increased awareness does NOT necessarily equate to success in bringing about effective change. The greatest environmental benefits are likely to emerge from carefully targetted management activities. Endeavours need to be rational, credible and scientifically sound, expressed within a clear sense of what we are trying to achieve. Broad community support is required, so that ownership of outcomes is attained. Efforts must be realistically achievable, or we risk losing the good will of the community who are committed to these initiatives.

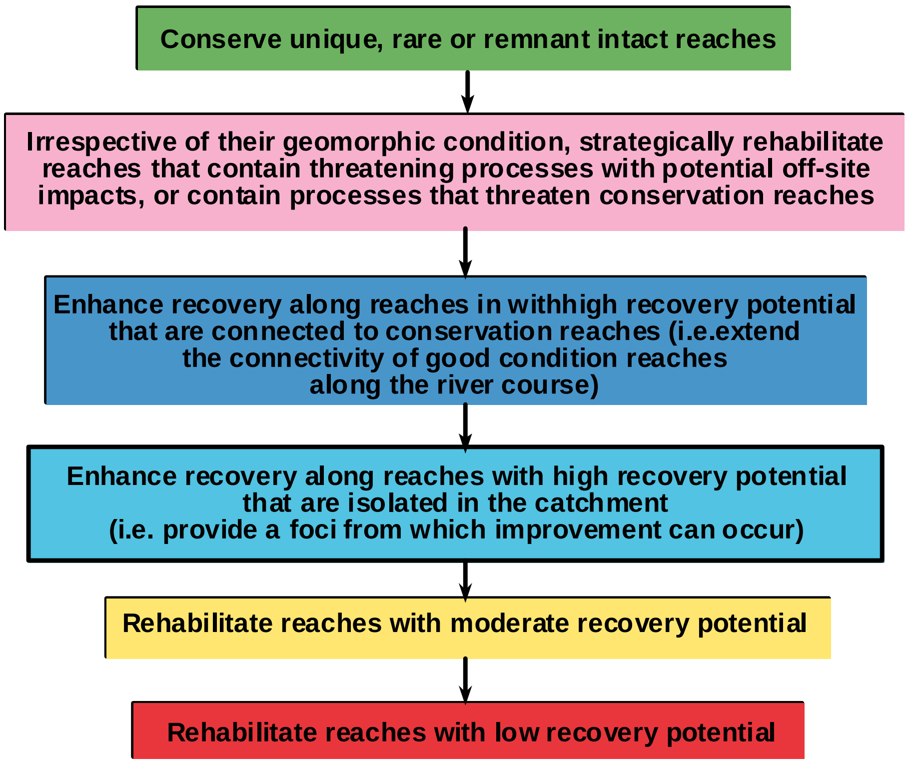
We must recognise that some of our efforts will not be successful, and we must learn from these failures. We must be able to demonstrate the benefits of land repair practices if we are to successfully invest in such initiatives. In some instances, the costs of repair will be less than the costs for prevention. We must create an appropriate awareness of the real cost to fix things, and what is actually required to implement the broad-scale changes that are needed.

Within this context, the philosophical perspective which underpins the prioritisation strategy for management efforts in the River Styles framework is as follows (see Brierley and Fryirs, 2005):

1) Conservation precedes rehabilitation.
2) Tackle strategic reaches irrespective of their geomorphic condition.
3) Work in those sections of the catchment with high natural recovery potential.
4) Consider more difficult tasks.

The flow diagram in **Figure 3.10** highlights how an understanding of river condition and recovery potential has been merged to provide a scientifically based framework for prioritising efforts at river rehabilitation in the River Styles framework.

Figure 3.10 Prioritisation of river reaches based on their geomorphic condition and recovery potential



3.5.4 Achieving target conditions and the catchment-based vision: Deriving a meaningful and realistic plan of attack

This stage involves selecting appropriate techniques for river rehabilitation problems faced in the catchment. The most suitable treatment will vary markedly for different problems and for different river types. Adopted techniques must fit the character, behaviour and condition of the river if they are to minimise offsite impacts (Fryirs and Brierley, 1998 b). By determining the target condition of a reach, and the required treatment, the rehabilitation group must match resources with actions to initiate on-the-ground implementation.

Significant attention has been placed on developing appropriate tools for river rehabilitation practice in Australia (e.g. the River Rehabilitation Manual for Australian Streams developed by Rutherfurd et al. (2000)). Developing these tools and techniques for each reach in a catchment is generally beyond the scope of what is realistically achievable in a River Styles report, but has been presented here to demonstrate how information can be used to develop rehabilitation programs within a catchment frame.

As management strategies are implemented and the operation of biophysical processes adjust, it may be necessary to revise the target conditions and priorities for conservation and rehabilitation. The vision/goals must be reappraised once a certain target condition is achieved, and as pressures such as climate change, major flood/drought events or other unexpected consequences arise. Adoption of adaptive management principles is vital if flexibility is to be achieved in the rehabilitation process. Ongoing monitoring and maintenance programs allow the rehabilitation group to learn from mistakes and document successes, enabling continual progress towards the vision to be made, thereby maintaining momentum within the community.