MARY RIVER & TRIBUTARIES REHABILITATION PLAN

APPENDIX 2

CHANNEL FORMING, DEGRADATION, RECOVERY & RESTORATION

PROCESSES, PRESSURES, INDICATORS & STRATEGIES

A LITERATURE REVIEW

Brian Stockwell
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1.0 CHANNEL FORMING PROCESSES

As briefly discussed above, several factors govern the physical processes in rivers and hence their morphology. The primary factors influencing river morphology are:

- the volume and time distribution of water supplied from upstream;
- the volume, timing and character of sediment delivered to the channel;
- the nature of the materials through which the river flows; and
- the local geological history of the riverine landscape.

Secondary factors that can be important determinants of channel morphology include local climate, the nature of riparian vegetation and the land-use of the drainage basin (Church 1996). River morphology in turn influences the nature and function of stream ecosystems. An overview of how these factors are observed in the landscape is essential for understanding riverine process and restoration.

1.1 Channel Shape

The shape of the cross section of a river channel at any location is a function of the flow, the quantity and character of sediment in movement through the section, the character or composition of materials making up the bed and banks of the channel and instream and riparian vegetation. A natural channel not only carries sediment but migrates laterally by erosion of one bank, maintaining on the average a constant channel cross section by deposition at the opposite bank. In an alluvial channel, an equilibrium between erosion and deposition can be maintained so that the form of cross section is “stable” but the position of the channel is not (Leopold et al. 1964).

For a given roughness and slope, the size of the channel is a function of the flow. Increasing discharge alters the overall size, but the shape of the channel margins tends to remain constant. Because the banks of non-cohesive sand are unable to withstand an increase in shear stress associated with an increase in depth resulting from increased discharge, the banks give way and the central portion of the channel simply enlarges.

1.2 Effective Discharge

The size of a natural alluvial channel is highly variable depending, amongst other things, on the characteristics of its flow regime. The size of the river channel may alter in response to changes in magnitude, duration or hydraulic characteristics of the flows (Tilleard 1999). The most meaningful discharge for any discussion of channel morphology is that which forms or maintains channels which has often be approximated by bankfull discharge (Leopold et al. 1964). The "effective discharge" concept proposes that an alluvial channel will adjust in it size and shape such that its bankfull capacity corresponds to the discharge which, through time, is responsible for moving the most sediment.

Schaffernak (1922, cited in Tilleard 1999) was the first to propose that the size and shape of a river channel reflects the discharge at which most of the formative work is done. He further proposed that this discharge corresponds to that stage at which the bulk of the bed load is carried. Wolman and Miller (1960) subsequently demonstrated that the largest proportion of total sediment load is carried by flows occurring on average once or twice each year rather than by more extreme but less frequent events. They also observed that the dimensions determining channel shape and planform are related to flows at or near the bankfull stage. This led to the conclusion that frequently recurring events of moderate intensity rather than rare floods of unusual magnitude are the effective events in forming significant alluvial landforms. Outhet et al. (1999) however, have challenged this concept in the Australian environment on the basis that Australia's highly variable rainfall, runoff patterns result in significantly different responses. Generally, mean peak annual floods of Australian streams are an order of magnitude larger and are more variable than they are for world average streams (Lake et al 1986).

Smelser and Schmidt (1998) argue that whereas flood discharges that exceed bankfull levels in large alluvial streams flow onto floodplains where flood energy is dissipated, narrow mountain valleys concentrated flood energy down the axis of the valley. Consequently, they suggest that infrequent large floods with recurrence intervals between 50 and 200 years form macro-bedforms such as boulder steps in mountain streams. Further hillslope processes associated with large rainfall events such as landslides, rockfalls, and debris flows are important geomorphic agents affecting mountain streams because they supply coarse sediment and woody debris to the stream, which blocks or re-routes flowing water (Smelser and Schmidt 1998).

1.3 Meander Geometry

> '*The striking geometric regularity of a winding river is no accident. Meanders appear to the form in which a river does the least work in turning, hence they are the most probable form a river can take.'* (Leopold and Langbein 1966, p.60)

Meander length is empirically related to the dominant discharge. Leopold et al. (1964) postulated that there is a fundamental relation between width and meander length in alluvial rivers. They suggest meander length varies from 7-10 times channel width and that a large proportion of bends have a value for the ratio of radius of curvature to width in the range of 2-3, with a median value of 2.7. Newbury and Gaboury (1993 (a)) agree stating that a full meander wavelength occurs between 7 and 15 times the bankfull width for rivers ranging from 0.3 to 300 m wide. In all open channels regardless of their pattern, secondary currents occur that cause the flow to rotate as it moves downstream. In meandering reaches, rotation of the flow is accentuated as the water flows around a bend (Newbury and Gaboury 1993(a) - Figure 1.1).

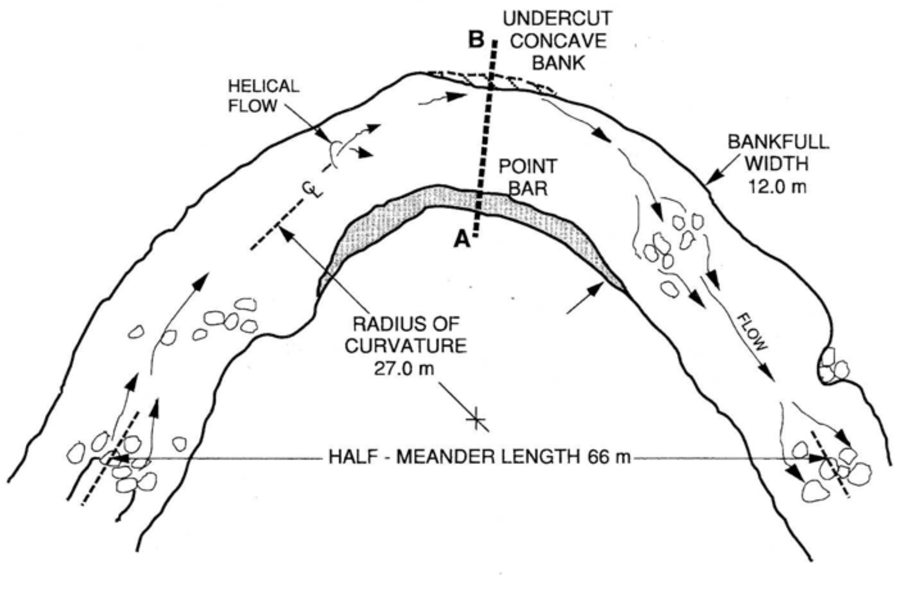

Figure 1.1
Flow patterns and stream geometry of a meander bend on the North Pine River. The radius of curvature is 2.3 times the bankfull width, similar to meanders in many rivers (Source: Newbury and Gaboury 1993 (a)).

1.4 Meander Migration Rates

The bends of alluvial meandering rivers migrate laterally by eroding their banks in a process known as meander migration. Meandering streams naturally erode the outer bank of stream beds and deposit sediment on the inner bank. This leads to lateral movement of stream channels known as meander migration. Based on a comprehensive analysis of world wide, data Walker and Rutherfurd (1999) have quantified a global median migration rate of 0.9 m/yr, or 1.6% of bankfull width per annum.

A natural alluvial stream rarely stays straight for more than about 10 channel widths due to the combination of downstream and cross channel flows. Upon entering a bend, momentum forces the central core of flow, known as the high velocity filament, toward the outer (concave) bank. The rate of fluvial scour, and hence meander migration, has been shown to increase with the proximity to the high velocity filament to the outer bank. The high velocity filament then moves back across the channel due to the change in channel direction, but lags behind the change in channel direction. The meander which results is a product of erosion on concave banks and sediment deposition on convex banks (Walker and Rutherfurd 1999 - Figure 1.2).

The rate of meander migration is a function of the balance between the force of the flow and the resistance of the banks. The relative force of the flow is determined by slope, discharge and how effectively the high velocity filament is deflected toward the outer bank. Bend curvature, and the length and shape of the upstream bend are factors that influence the degree of deflection (Walker and Rutherfurd 1999). Resistance to erosion is composed of the resistance of sediments to fluvial scour, and the work required to remove the sediment. Work required is dependent on vegetative protection and bank height. The higher the bank, the greater the amount of sediment that has to be eroded for the same amount of lateral channel shift.

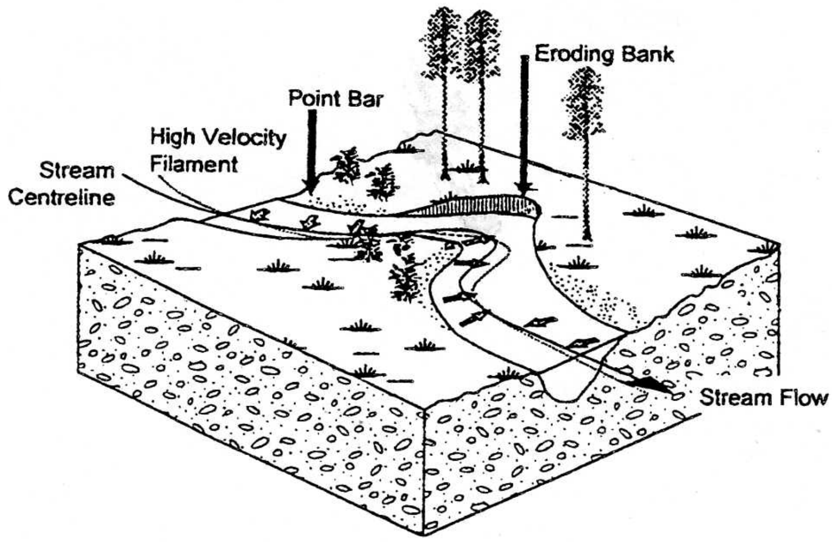

Figure 1.2 Flow and channel form in a meandering stream
(Source: Walker and Rutherfurd 1999).

1.5 Long Profile

As it moves downstream a river channel's width and depth increase, while there is a tendency for bed-particle size to decrease and the gradient to generally flatten. The longitudinal profile of a stream is concave to the sky, but they are rarely smooth curves, nor composites of smooth curves. Variations in discharge and in lithologic and structural controls often produce irregularities of a larger scale and pools, bars and riffles create a vertical wave pattern along the profile (Leopold et al. 1964).

The River Continuum Concept (RCC) developed in the Northern Hemisphere by Vannote et al. (1980), suggest that the geomorphological–hydrological characteristics of an intact river form the fundamental template upon which biological communities become adapted. The concept suggests that as this template changes from headwaters to mouth the biological attributes of the associated communities change in a predictable fashion. Lake et al. (1986), however, argue that Northern hemisphere based schemes of longitudinal river zonation do not apply to the more stochastic and less predictable Australian streams. Townsend (1989) has queried the idealised downstream changing pattern proposed by the RCC and suggests a conceptual framework based on patch dynamics will provide a basis for comprehending river community structure and dynamics

Gravel bar and associated pool and riffle sequence are the most common geometric features seen in many river channels. Like meanders, the geometry of pool and riffle profile for all river patterns in erodible materials may be related to the bankfull width. The mean spacing of pools is half the meander wavelength, or about 5.6 to 6.7 times the bankfull width for alluvial and bedrock streams (Newbury and Gaboury 1993 (a) - Figure 1.3).

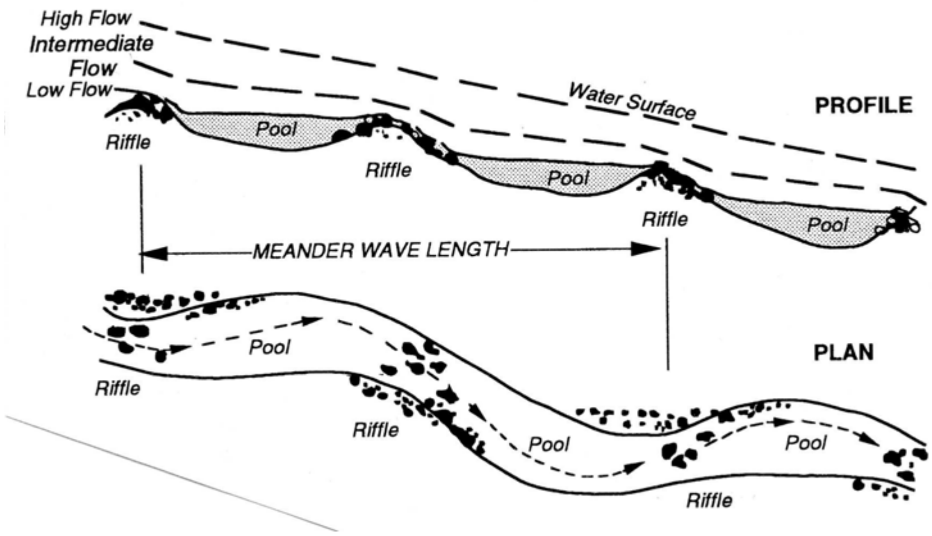

Figure 1.3
Schematic of a long profile and associated channel pattern
(Source: Newbury and Gaboury 1993(a)).

Observations extending up to 7 years found no indication that the bars comprising riffles move downstream with time and any movement of gravel bars or riffles appears to be relatively slow (Leopold et al. 1964). Gravel bars or riffles consist of a concentration of cobble or pebbles - which are replaced during periods of high flow. Thus the riffle is made up of particles that lodge on the bar temporarily, yet the bar is an entity that may change shape or position.

Experiments in flumes have shown that any initial grouping of rocks, as in a gravel bar, tends to preserve the concentration of rocks and thus promotes formulation of a gravel bar (Leopold et al 1964), although this is influenced by particle shape and density. In the field this is evidenced by the formation of pool and riffle profiles in channelised streams, despite their uniformly constructed gradients (Newbury and Gaboury 1993(a)). The gravel bar can be regarded as a kind of kinematic wave in the traffic of clastic debris (Leopold et al. 1964).

1.6 Role of Large Woody Debris

Brooks (1999b) considers it is likely that Australian floodplains could not have evolved as they did without the influence of Large Woody Debris (LWD) on in-stream processes. LWD can impart significant hydraulic resistance within river channels, which can reduce mean stream power, reducing bank shear stresses, bank erosion rates (on reach averaged basis), bed shear stresses and bedload transport rates (Brooks 1999b).

Considering the combined influence of the hydraulic resistance factors and the bed stabilisation, Brooks (1999b) suggests the role of LWD can be more significant on overall channel morphology than riparian vegetation. Similar to riparian vegetation, the extent to which LWD affects flow resistance and bed stability diminishes with increasing channel size as:

- a greater proportion of channel cross section will be occupied by LWD in low order channels;
- very often trees in low order streams fall in perpendicular to the flow, causing maximum blockage to the flow;
- LWD in low order channels also tends to have a fairly random longitudinal distribution and it is under these circumstances that hydraulic resistance and bed load stabilisation are maximised; and
- In lower order channels the height of the trees falling into channels will be greater than channel width. In these circumstances the logs are often tied into both banks and will remain as they fell. Such LWD can remain *in situ* for considerable periods of time - up to several thousands of years in some circumstances (Brooks 1999b).

Log jams and single large snags in small heavily vegetated streams may result in:

a high proportion of local lateral channel migration;

- local bank erosion;
- the triggering of channel avulsion or cut offs; and
- bank scalloping and channel widening.

However, when these effects are averaged over a reach the overall influence can be positive (Brooks 1999b). Similarly, on a channel scale, Marsh et al. (1999) have identified that LWD has several positive morphological effects including: scour under LWD, downstream bar formation, downstream scour, reinforcement of channel bank, sorting of bed material (coarsening), expansion of channel at the LWD and deposition over the LWD (Figure 1.4).

In reaches containing large amounts of organic debris, steps may be common over individual, transversely oriented logs, or through debris accumulations up to several metres in height. Church (1996) has found that the formation and decay of log jams regulates the transfer of bed material downstream. The upstream side of a jam typically consists of sediment-filled backwater reach while downstream, an extended, sediment-starved riffle or rapid may form.

LWD is also an important source of terrestrial carbon which drives instream production in forested streams. Microbial flora and fauna and macroinvertebrates (shredders) quickly colonise snags, commencing a gradual decomposition process. LWD serves as stable host for the growth of algae and provides a location for nitrogen fixation (D'Aoust and Millar 1999). Considerable evidence has accumulated indicating a nutritional dependence by the shredders on the microbial flora of the LWD rather than the substrate itself (Cummins 1974). Harris (1987) observes that fish often depend on the specific features of a particular habitat type. Freshwater cod, for example, are reliant on snags for shade, breeding hollows and a shelter to hide from predators and from which to launch attacks on prey. Habitat diversity is increased by LWD which can facilitate fish migration through maintenance of a stepped profile as well as resting and shelter from predators during migration.

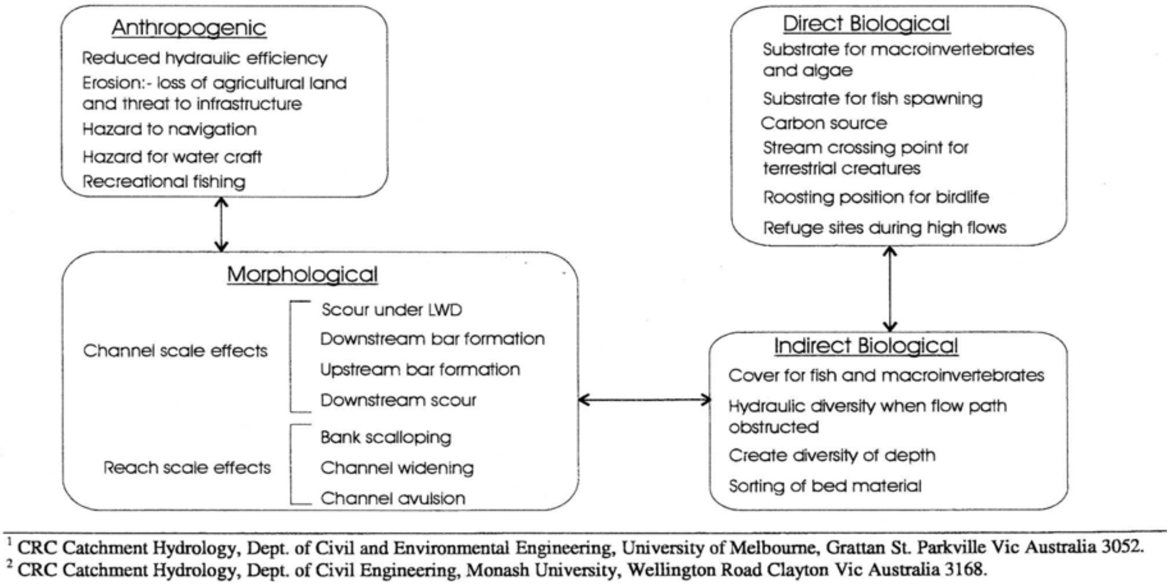

Figure 1.4
The functions of large woody debris and the interactions between them
(Source: Marsh et al. 1999).

1.7 River Corridor Formation

Large and Petts (1996) used the term river corridor to describe a zone encompassing active and abandoned channels, the aquatic margins of these channels, the riparian zones along the channel banks and any floodplains. In their natural states, river margins consist of a complex mosaic of patches of different type, size and age that reflect the geomorphological setting. "*The development of riparian systems through time is part of a directional sequence known as the reversible process concept ..., within which the directional sequences are rejuvenated by erosion, deposition and flood disturbance*" (Large and Petts 1996, p 108). Variability of flow has been suggested as an influencing factor in the life cycles of stream macroinvertebrates in Australia (Lake et al. 1986). The flood pulse concept links this hypothesis to the role of the riverine corridor and suggests that the cycle and extent of inundation may be viewed as a fundamental community organiser that overrides longitudinal patterns (Junk et al. 1989).

Riparian plants increase catchment friction through their physical effects on flow and play a geomorphic role through the binding effects of their root systems on stream banks. Roots of woody vegetation increase the shear resistance of soils by providing an additional apparent soil cohesion. Abernathy and Rutherfurd (1999) modelled the effect of Swamp Paperbark (*Melaleuca ericifolia*) and River Red Gum (*Eucalyptus cumaldulensis*) roots to otherwise degraded bank profiles and found that the addition of roots increased stability by up to 132% and 175% respectively. Riparian zones also buffer the impacts of contaminants in surface and throughflow and can prevent sediment and nutrient pollution of streams in the right conditions (Prosser, 1999).

Riparian vegetation is known to have a controlling influence on forested stream ecosystems as a source of allocthonous energy inputs. Davies and Bunn (1999) have demonstrated that riparian vegetation provides the overwhelming majority of carbon driving instream primary production in forested upland streams. They also found that riparian shade can regulate the growth of species of algae which are unpalatable to macroinvertebrates. Riparian vegetation also harbours arthropods that can fall into the stream. These creatures can be a seasonally important source of nutrition for certain fish species (Lake and Marchant, 1990). Cummins et al. (1995) also argue that the riparian zone can exert a major influence that may override physical river based predictions of biological responses. Patches of riparian vegetation, they suggest, can be strong modifiers and early successional stages may have significantly higher rates of primary production.

Alluvial wetlands store 29-93% of sediment reaching streams (Large and Petts 1996). Progressive sedimentation eventually leads to the loss of wetland habitat, new 'wet' habitat is created by channel cut-off and lateral migration elsewhere along the river corridor. In this dynamic ecosystem periodic replacement of older soil-vegetation complexes by pioneer patches (eg gravel or sand deposits) leads to an increase in both biodiversity and primary biological productivity (Large and Petts 1996). Shiel (1995) emphasizes the importance of the high natural biodiversity in billabongs and their role as critical refugia for aquatic and terrestrial life in dry times, as well as breeding habitats for fish, birds and a myriad of smaller creatures when the billabongs are reunited with their parent river systems in times of flood. The diversity of micro-fauna (Protozoa, Rotifera, Cladocera) in billabongs is relatively high and they are therefore an important source of food when flooding triggers breeding cycles of larger vertebrate inhabitants of floodplain waters (Shiel 1995).

1.8 Geomorphological Influences

Unlike the Northern Hemisphere, from whence most of the above theory emanates, the rivers of Australia flow through a landscape that has largely been tectonically inactive for tens of millions of years and has undergone only gradual hydrological change as a result of climate changes during the Quaternary (the last 2Ma) (Nanson and Doyle 1999). Earlier in the last glacial cycle (125ka to 25ka), the coastal rivers of southeastern Australia were relatively high energy, laterally active systems transporting coarse sediment. In low-gradient large valleys where these older coarser deposits remain as terraces, these rivers are not especially responsive to European impact. In contrast, during the late Holocene (the last 5 ka) and in smaller steeper-gradient valleys, low energy, fine grained, small channelled, systems have formed, becoming stabilised by riparian vegetation in the last 2ka. These systems have been particularly responsive to European land clearance and, due to local stream power conditions, the middle reaches of these valleys are the most vulnerable (Nanson and Doyle 1999).

In this previously stable setting, European land use practices have, in less than a century, wrought widespread channel degradation. The effective rehabilitation of these rivers and floodplains requires a sound understanding of their genesis. River management practices will not be effective if imposed counter to natural environmental trends or in the absence of an analysis of the pressures and processes leading to their current condition.

2.0 CHANNEL DEGRADATION PRESSURES AND PROCESSES

Theoretically under equilibrium, channels tend to be morphologically stable, transporting the water and sediment load imposed from the catchment upstream without enlarging or aggrading. It is important to understand that a channel which is described as stable may naturally erode its bed and banks. However there are few intact equilibrium streams to be found in Australia, most having been subject to human disturbance.

Degrading processes can occur in a river as a result of a number of direct and indirect pressures. Direct pressures on river systems include flow regulation, water storage and diversion, channelisation, river works, aggregate extraction and mining, encroachments from agriculture, desnagging, channel realignment, urbanisation and infrastructure, recreation and boating, introduction of feral animals, exotic fish and plant species. Indirect pressures can result from modified water and sediment flow regimes from the catchment, pollution with organic matter, biocides, heavy metals, nutrients and rubbish (Kapitzke et al. 1998, Brooks 1999a).

When the influences exerted by such pressure become extreme, stream behaviour can exceed threshold levels that results in the degradation of the stream through abrupt as opposed to gradual changes (Kapitzke et al. 1998). A threshold change is one in which there is an abrupt change from one state to another (Lucas et al. 1999). This may occur when a critical value for a particular process is exceeded. For example, progressive in-channel sedimentation that continues until the gradient at the downstream end of the deposit exceeds a critical limit and initiates incisions, is indicative of a river's response to exceeding natural thresholds.

Natural forces, however, can also induce threshold changes through the influence of external factors such as tectonic or climatic change as well as riverine factors (eg when meanders develop and sinuosity increases until meander bends overlap and meander cut-off occurs). A movement across a threshold may be intrinsic to a landform or may be induced by progressive change of an external variable. For example, flow causes the lower section of a bank to erode; the upper section is left overhanging, eventually this upper section will collapse (Lucas et al. 1999).

2.1 Natural Variation or Accelerated Degradation?

There are those who have postulated that that some extreme channel changes in Australia over the last 100-200 years fall within the natural range of variability of these systems, or are part of a 'natural cycle' (eg Erskine 1986; Erskine 1996; Tilleard et al. 1996). They argue that because we have a highly variable climatic regime in Australia with extreme inter-annual flood variability, that the sort of channel response to extreme events commonly seen over the last century or so, are no more extreme than some of the natural responses to large events over the preceding millennia. This hypothesis however has been criticised as being based on an inaccurate portrayal of base line data (Brierley pers. comm., Seminar Brisbane 1999), without any convincing evidence of river behaviour prior to disturbance and contrary to findings based on measured changes in sedimentology (Brooks 1999a).

The dominant body of opinion is that when the controlling variables of a river that have evolved over thousands of years are suddenly removed or altered, the river will start behaving in a different way. Studies in the Cann and Thurra River, for example, have shown that post-disturbance channel behaviour is outside the realm of that indicated by recent geological history. Brooks (1999a) suggests from this study that it appears likely that post-European channel changes in many locations may have been significantly underestimated. Unless we recognise that a range of disturbances (Table 2.1) have ushered in a new set of conditions within which our rivers are now functioning, we could make a new set of river management mistakes of equivalent magnitude to some of those in the past.

TABLE 2.1

Human Influences on Channel Change

INDIRECT CHANGE	DIRECT CHANGE
Land Use Change:	***Regulation:***
❑ Deforestation	❑ Impoundment of Water
❑ Afforestation	❑ Water Diversions (eg. for irrigation)
❑ Agricultural (eg. grazing to intensive use)	***Channel Management:***
❑ Urbanisation	❑ Gravel Extraction
❑ Mining	❑ Straightening
Land Drainage:	❑ Flood Control
❑ Agricultural Drainage	❑ Bank Erosion Protection
❑ Surface Water Drainage	❑ Dredging

2.2 Floods - Catalysts not Causes

Degradation of our waterways inevitably gains popular public attention after major flooding events. Frequently the flood itself is attributed a causal role in the long-term decline of the integrity of river systems. Geomorphological investigations provide an alternate view.

Bank failures are the most obvious symptoms of flood damage and normally occur following a sharp fall in the river, especially when river stages drop quickly. Water trapped in the soaked beds tends to trigger bank failures in certain soils due to liquefaction, slumping and unbalanced pore water pressure (Noble 1976; Abernathy and Rutherfurd 1999). Failure usually occurs when bank material strength is minimised and weight is maximised associated with periods of prolonged rainfall and drawdown of river stage on the falling limb of a flood hydrograph (Abernathy and Rutherfurd 1999). During the 1973 flood, seven Mississippi River bank failures occurred in Louisiana. The Montz bank failure was a typical flow failure caused by liquefaction of fine sands in point bar materials comprising the bank (Noble 1976 - Figure 2.1).

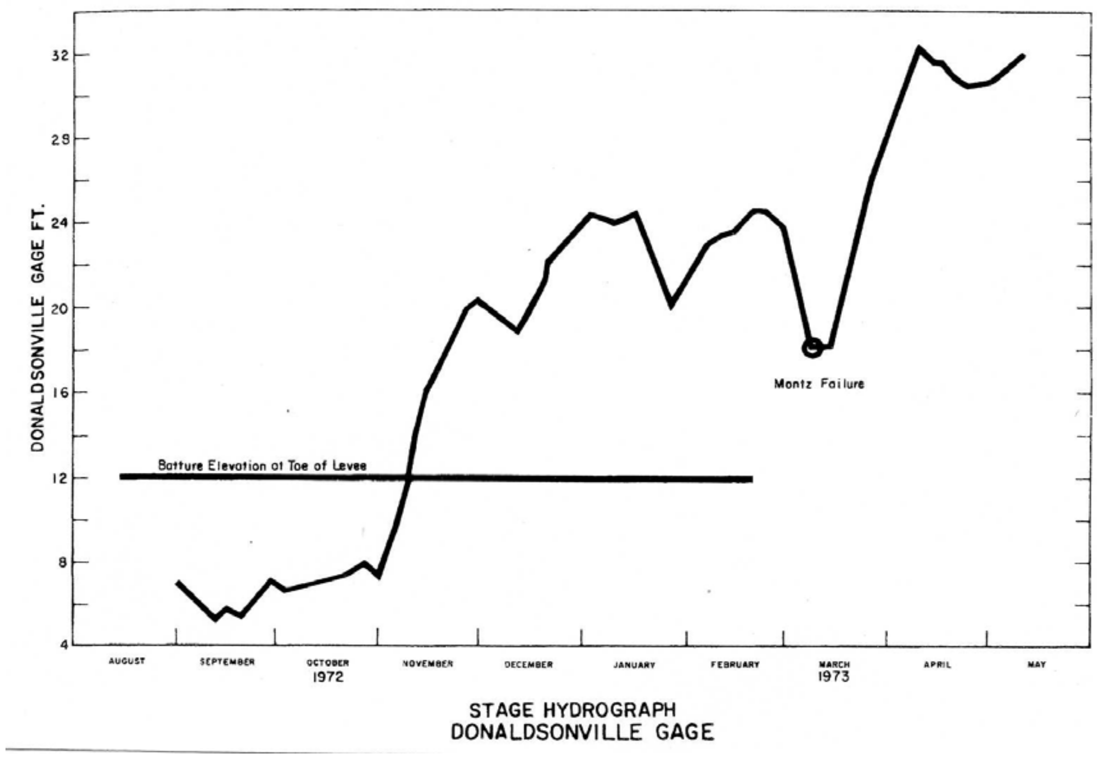

Figure 2.1
Hydrograph at Donaldsville on Mississippi river showing pronounced drop in river level prior to the river bank failure at Montz, just downstream (Source: Noble 1976).

Groups of large floods and climatic periods of above average rainfall have been linked to river channel changes. The gravel bed channels of the Nambucca River catchment on the mid-north coast of New South Wales, for example, have continued to undergo severe degradation since catastrophic floods of the late 1940s and early 1950s. A detailed study of the Nambucca catchment has shown river changes can be separated into four phases, largely dictated by flood frequency, with the two dominant phases in the 1890s and the several decades following 1948 (Nanson and Doyle 1999). The study, however, suggests that while clusters of large floods are the triggering mechanism for channel erosion in disturbed catchments such as Nambucca it is clear that recent channel degradation was caused by European land clearance.

The human disturbance which led to disastrous channel incision and upstream bed lowering is typical of many Australian streams. Scouring of the channel formed head cuts that retreated through the Nambucca system (nickpoint erosion) and emptied masses of gravel from the floodplains, previously stored for 1500-2000 years, into the channel. Research indicates that the current state of the channels is a result of a combination of factors. These factors include the removal of riparian vegetation, artificial channel straightening, removal of large woody debris, dredging of tidal reaches, and gravel extraction. The clustering of flood events has been the catalyst for revealing the effect of these practices, rather than the cause of the degradation (Doyle et al. 1999). The removal of riparian vegetation and the clustering of flood events seem to cause much more severe channel erosion than does any recognisable sequence of flood dominated regime (FDR) and drought dominated regime (DDR) cycles (Erskine and Warner 1988).

A study in Ashley Creek in the USA, which evaluated records from 1926-1995 and made a comparison of minimum streambed elevations to annual peak discharges, further questions the assertion of large floods being the primary agents of degradation. An analysis of this data indicated that changes in streambed may be related to changes in the hydrologic regime, but that peak flood events were not directly responsible for streambed elevation changes (Smelser and Schmidt 1998 - Figure 2.2).

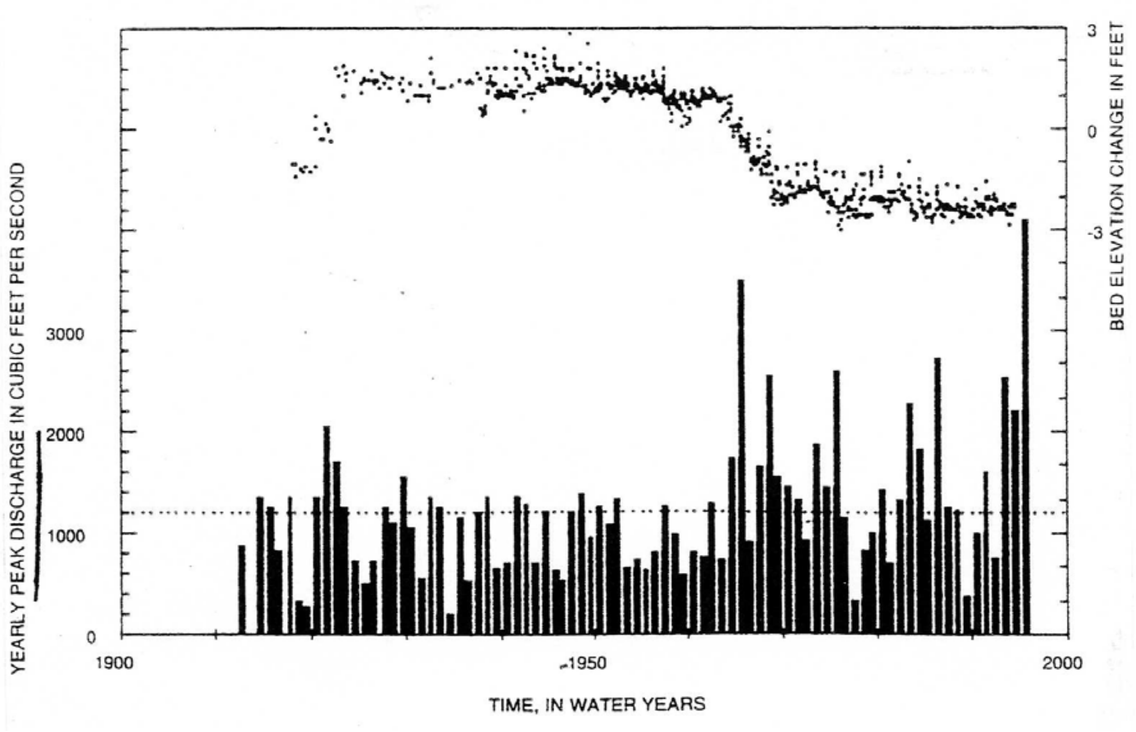

Figure 2.2.
Comparison of minimum streambed elevations to annual peak discharges.
The dashed horizontal line delineates the mean annual flood of 100 ft^3/sec (sic)
(Source: Smelser and Schmidt 1998).

The role of human disturbance in triggering flood damage was highlighted by an investigation following major flooding in southern British Columbia in 1990 which resulted in widespread bank erosion. A total of 748 bends in four stream reaches were assessed by comparing pre- and post- flood aerial photography. Bends without riparian vegetation were found to be nearly five times as likely as vegetated bends to have undergone detectable erosion during the flood events. Major bank erosion was 30 times more prevalent on non-vegetated bends as on vegetated bends (Beeson and Doyle 1995).

These examples not only illustrate the need to separate cause from effect but also the importance of data collection prior to rehabilitation. Measuring geomorphic indicators as well as researching historical records can lead to a greater understanding of the requirements of rehabilitation of the channels.

2.3 Catchment Clearance vs Riparian Zone Clearance

The most extensive changes affecting streams are land-use changes attributable to agriculture, forestry, mining, grazing and urbanisation. A major impact of deforestation associated with these land-use changes is accelerated erosion on hillslopes, together with gully erosion and increased sediment supply to the streams. Any change that eliminates or reduces vegetative cover is likely to increase sediment discharge proportionately more than the water discharge. This can lead to channel bed aggradation and overbank deposition on floodplains to depths in excess of 1 m. Channels have tended to become wider, shallower, and less sinuous and much of the eroded sediment is still stored in the channel and flood plain (Brooks 1996).

It is also likely that catchment clearance has altered flood hydrographs, and hence channels, but this is a more contentious issue and is almost impossible to test because no baseline data exist for large catchments (Brooks 1999a). Clearing the forest from the floodplains and lower hillslopes reduces flow transmission times by increasing channel and floodplain velocities, and thereby increases peak flood-discharges. Forest removal also temporarily increases valley-side erosion and slope wash, however a study by Nanson and Doyle in South Eastern Australian Streams (1999 - Figure 2.3) suggests that by far the most important source of silt, sand and gravel for the channels is the widespread enlargement of the channels themselves.

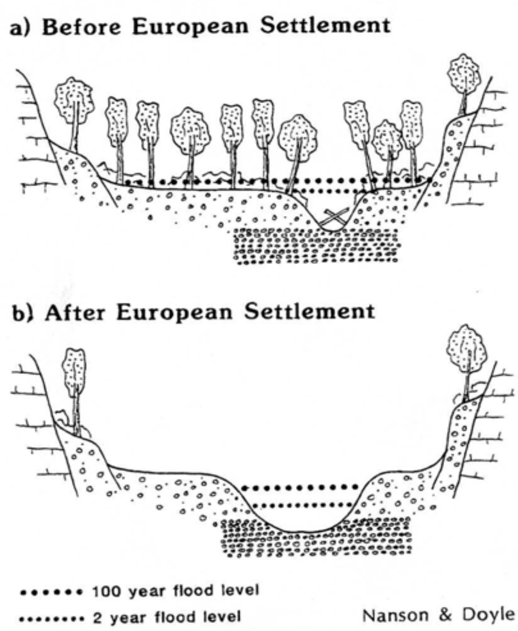

Figure 2.3
Channel enlargement due to European land clearance (Source: Nanson and Doyle 1999).

There is growing appreciation of the extent to which Europeans have caused dramatic changes to the geomorphic function and processes within rivers and streams (Eyles 1977, Brooks and Brierley 1977, Fryirs and Brierley 1999, Gale et al 1999). It is interesting to note that all but one of the above studies (Gale et al. 1999) identified channel erosion rather than overall hillslope erosion as the primary mechanism for enhanced sediment yields. Livestock access to channels and riparian land due to soil trampling and vegetation destruction has further accelerated erosion (Outhet et al 1999). Seawords and Vallett (1995) suggest uncontrolled grazing along streams will reduce the rate of recovery following disturbance by flooding resulting in long term cumulative impacts (Figure 2.4). There seems little doubt that in many catchments, European deforestation, and in particular clearance of vegetation from streambanks, has caused channel incision and bank erosion that has led to serious channel degradation.

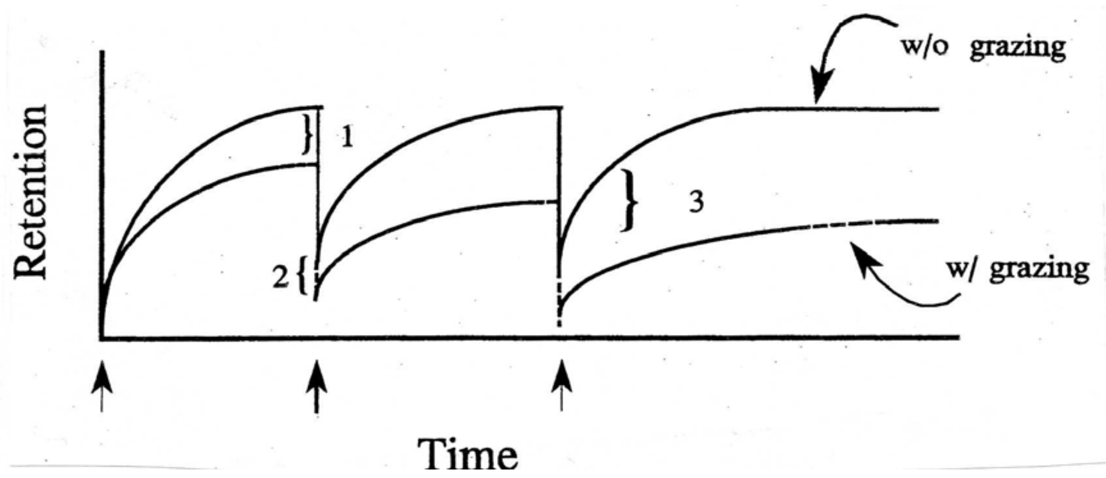

Figure 2.4
Conceptual model of disturbance interaction for streams impacted by floods and livestock grazing. Retention (of biological and physical integrity) is plotted against time and flood events are depicted as arrows along the X-axis. **1** - At any time grazed reaches are less retentive than reaches without grazing. **2** – Because of pressure on biological and physical agents which assist retention, grazed plots will be less resistant to flooding, and **3** – rate of recovery (i.e. resilience) will be lower in grazed plots following disturbance of flash floods (Source: Seawords and Vallet 1995).

Clearing riparian vegetation triggers stream bank erosion and also deprives the channel of replacement reserves of large woody debris for instream habitat and morphology. Under these conditions channels become too wide to re-form substantial debris dams. This can trigger channel erosion involving widening, deepening and straightening, infilling of pools and loss of land from the adjacent floodplain. Nickpoint erosion is a primary mechanism. In such channels which are straighter and many times larger and less cluttered by debris, a far greater proportion of a flood discharge is transported in the channel than occupied prior to clearing. This increases stream power during flood events and exacerbates impacts of flood events (Nanson and Doyle 1999 – Figure 2.5).

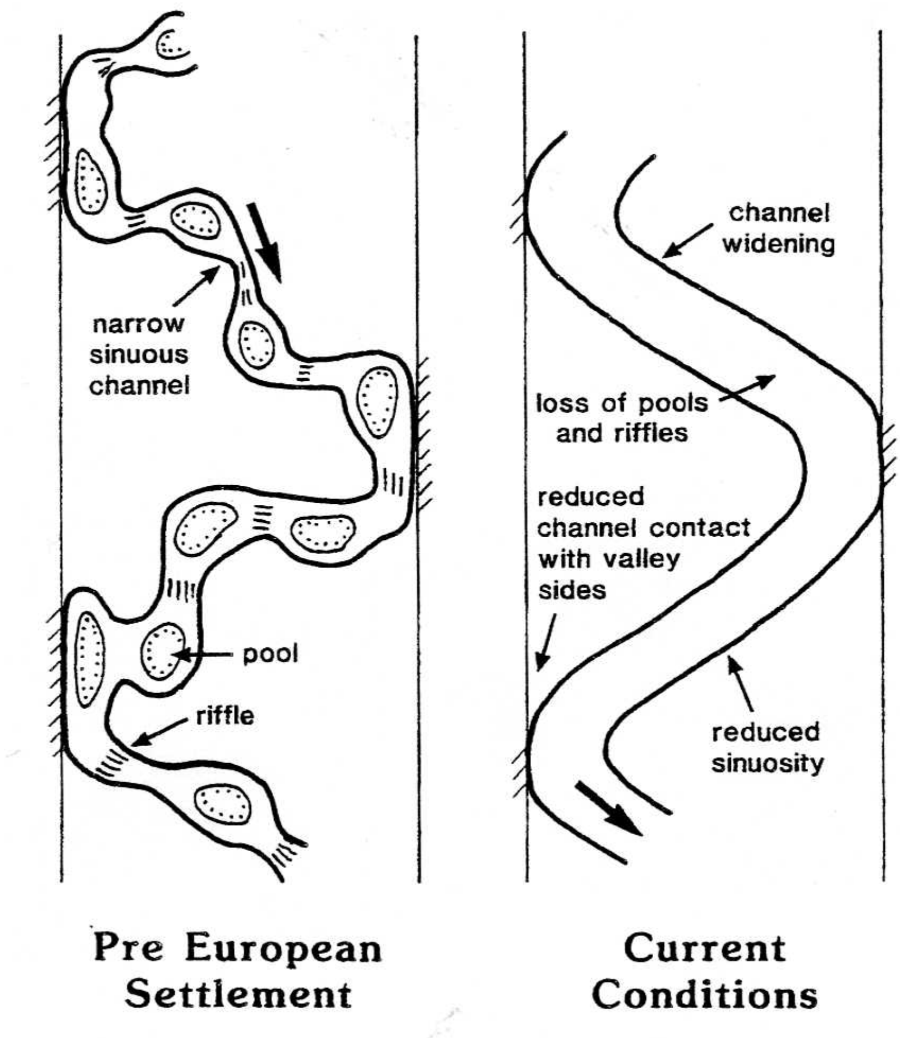

Figure 2.5
Planform of Pre-European and Post-European stream channels
(Source: Nanson and Doyle 1999).

A paired catchment study of the Thurra and Cann Rivers in Victoria by Brooks (1999a) demonstrates the fundamental role of riparian clearance in channel degradation as compared to broader catchment clearance. Both catchments have been subject to logging in the upper catchment, and have experienced major wildfires - most notably the Ash Wednesday fires in 1983 which burnt out the entire Thurra catchment, and about 60% of the Cann catchment. From the available evidence, the Thurra catchment appears to have been affected more severely by both logging and fire. The defining difference between the two catchments is the nature of riparian zone disturbance. The Thurra's riparian zone is relatively intact while the Cann has suffered from riparian vegetation clearance, desnagging and stock impacts.

The most profound post-disturbance changes occur in the Cann River as demonstrated in the modelled hydraulic parameters. Velocity at bankfull (U_{bf}) increased by a factor of 6.1, bankfull discharge (Q_{bf}) increased 45 fold, which means that Q_{bf} has increased from a recurrence interval of less than Q1.5 to greater than Q 20 (in the reached surveyed). Mean unit stream power (w) has increased by a factor of 35 (Brooks 1999a). Hydraulic changes are reflected in altered channel form with the width increasing 3.7 fold, mean depth doubling, channel area increasing by a factor of 7.3 and slope steepening by up to 2.6 times. Mean sand size has increased, indicating that all the finer sand fractions are being winnowed from the bed load. There also appears to be a large increase in the calibre of the largest grain size being transported which cannot be found in bedload from paleo-channels, dating to 26,900 years BP. A further critical change is associated with bank stability parameters which show a shift from a channel which was formerly dominated by fluvial erosion to one which is now controlled by mass failure (Brooks 1999a).

The combined impact of all of these parameters is evidenced in modelled bedload transport rates which indicate an increase of about three orders of magnitude in the contemporary channel compared with the pre-European channel. The channel now has the capacity to transport the vast amounts of sediment that have been supplied to the channel as a result of recent channel incision and expansion, thereby exporting it from this reach altogether. Evidence from the dated paleo-channel and floodplain deposits indicates that the material eroded from the Cann River channel this century and exported from the floodplain reach represents a minimum of 1500 years of floodplain accretion (Brooks 1999a).

It is clear from the above review that riparian clearance plays a more significant role than broader catchment clearance on the morphological characteristics of most rivers. In terms of ecological functions the relative importance of catchment disturbance versus riparian zone clearance is less clear. It is difficult for the riparian zone to completely buffer waterways from the ubiquitous problems of salinity, nutrient enrichment and eutrophication. Davies and Nelson (1994) however, found that the impacts of logging were not significant when riparian buffers in excess of 30m were retained. Below this width however, macroinvertebrates decreased in abundance and brown trout populations decreased by around 50%. Reduction of riparian shade, however, can substantially increase water temperatures resulting in decreased dissolved oxygen levels. In upland streams reducing shade cover below 40-50% can lead to an increase in primary production, but this is associated with a major decline in stream health as a result of filamentous algae growth (Davies and Bunn, 1999).

2.4 Desnagging

Removing snags from rivers was common throughout the 19th Century and is still occurring in streams today. The desire to clear navigable channels and the belief that removal of large woody debris helps to mitigate against the impacts of floods are the main factors leading to this practice. Brooks (1999b) argues that large woody debris (LWD or snags) was probably one of the dominant geomorphic controls in many Australian rivers prior to European settlement. He suggests that the widespread removal of LWD from channels in desnagging operations was a dominant factor leading to the extensively altered channels common throughout the continent today. His analysis shows that full desnagging of the pre-disturbance Cann River channel results in a 120 fold increase in bedload transport (Brooks 1999b). Channel roughness conditions have also been fundamentally altered. The pre-disturbance state modelled on the Thurra channel is dominated by form roughness (roughness associated with pools and riffles) and LWD roughness, and indications are that the two are inextricably linked. In the Cann, the relationship between mean log (LWD) length and channel width has been altered. Formerly the majority of large logs tended to straddle the entire channel and thus were anchored into both banks and hence seldom moved from where they fell (Brooks 1999a).

River Red Gums (*Eucalyptus cumaldulensis*), for example, are thought to remain in lowland streams for decades, if not centuries, and comprised a major habitat for invertebrates (Lake, 1995). The degradation of habitat as a result of de-snagging and the issues raised above, has been recognised as the greatest factor leading to generalised declines in fish abundance and distribution (Harris, 1987). While such diffuse broad-scale forms of habitat degradation undoubtedly increase the vulnerability of many threatened species, only occasionally (freshwater cod or swamp galaxis) were they seen as the most immediate primary threat (Harris 1987). D'Aoust and Millar (1999) provide extensive evidence that the river systems with LWD are significantly different from those devoid of debris. Desnagging can lead to loss of low-velocity refuges for fish and invertebrates during both baseflows and flood flow conditions, as well as loss of habitat for terrestrial and avian fauna who use snags for resting, crossing and hunting locations (D'Aoust and Millar 1999).

2.5 Channelisation

Long term channel adjustment is triggered by channelisation, which generally involves widening, deepening, or straightening of a channel. Impacts associated with channelisation include:

- Increased slope by providing a shorter channel path that enables the transport of more sediment than was supplied at the upstream end of the channelised reach with the balance being obtained from the bed, which triggers channel scour that works its way up the channel. An excess load is then supplied to the downstream part of the channelised reach and because the flatter natural reach downstream could not transport this sediment it was deposited on the bed;
- Bed lowering in the channelised reach can then initiate considerable bank erosion and/or collapse, which may locally enlarge the width of the channel by two or three times its constructed width;
- Deepening of the channel effectively lowers the local base level of tributary channels which may initiate a cycle of erosion in the tributaries as they adjust to new conditions. The erosion may work its way up the tributaries as a series of knickpoints in response to changes in the mainstream. Disturbance of aquatic biota with the time

for biological recovery on an unmaintained modified stream varying from 50-100 years; and

- Artificially straightened channels below specific slope thresholds can develop more sinuous channel patterns over time, however, morphological recovery of a modified channel including the return to a more natural distribution of bed forms such as pools and riffles, is likely to be more rapid than biological recovery (Keller 1976; Brookes 1996; Brizga et al. 1999b - Figure 2.6).

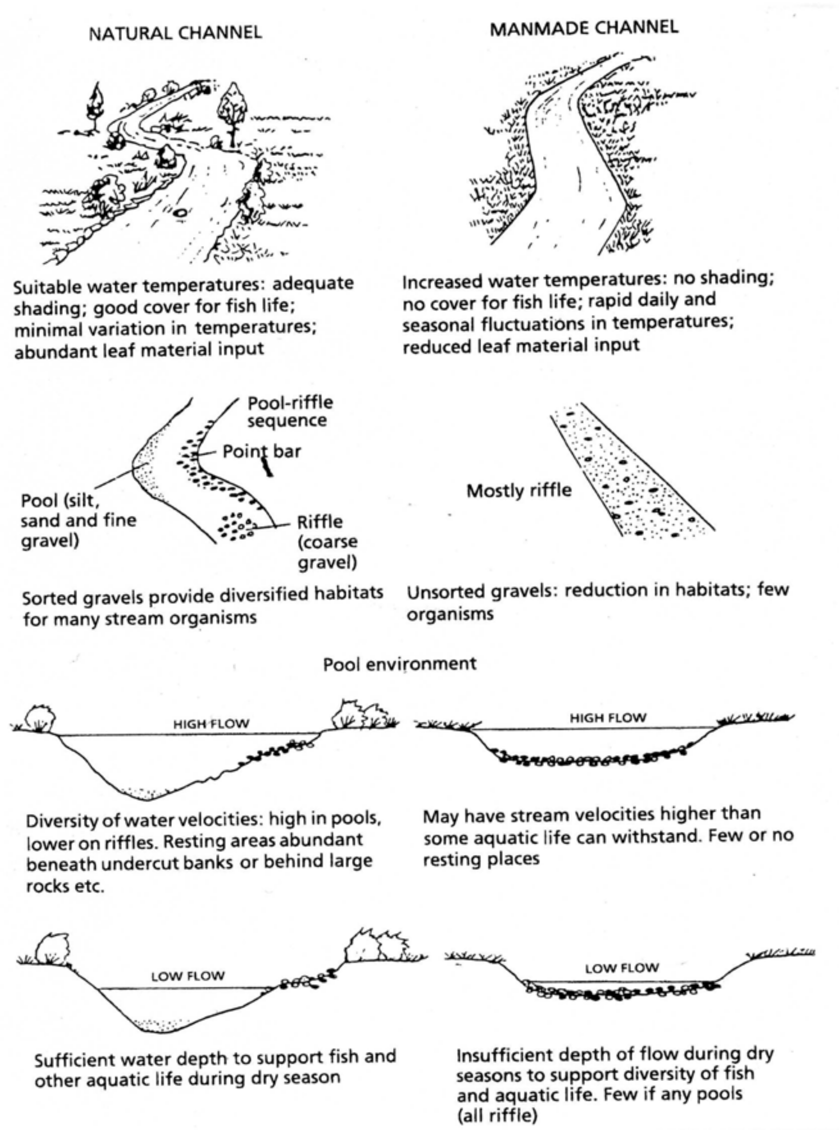

Figure 2.6
Comparison of Channel morphology and hydrology of a natural stream with a channelised watercourse (Source: Keller 1976).

Brizga et al. (1999b) exemplify the practical implications of the above processes in their work in the Bunyip River. In the late 19th and early 20th century the Bunyip River was formed into a straight drain through a swamp and roads were constructed on the spoil banks immediately adjacent to both sides of the drain. The Bunyip Main Drain (as it is now called) has been subject to significant incision and this incision has subsequently migrated many kilometres further upstream through alluvial reaches of Bunyip River and its tributaries. Aggradation has occurred in the lower reaches of the Bunyip Main Drain and downstream in Western Port Bay. Historical bed incision and natural re-meandering processes have resulted in the sides of the drain becoming steeper than a stable batter slope and over steepening threatens infrastructure in many places.

Reducing the natural spatial heterogeneity of streams also removes the patches in which flood-related increases in shear stress are not so great; such as behind boulders, in riffles, near the banks and in deadwater zones associated with meanders. Natural bed interstices (the hyporheic zone) also act as a refuge for stream invertebrates during high discharge (Townsend 1989). As a result, channelisation threatens recolonisation and natural recovery of ecosystem processes after spates. In addition, Hortle and Lake (1983) found that channelised sections of the Bunyip River had distinctive fish assemblages as a result of reduced amounts of submerged cover.

2.6 Regulation of River Flows

In the discussion of channel forming processes above, the fundamental role of the hydraulic characteristics of a waterway on its morphology were identified. It is therefore obvious that altering flow regimes through the construction of dams, weirs and diversions can have a degrading influence on channel form and processes. Increasing flow through storage releases will decrease channel stability, which will decrease substrate stability, increasing the size of particles moved and hence increasing erosion, sedimentation and depth, while decreasing channel capacity (Mitchell et al. 1999). As cross sectional size and meander wavelength are related to stream discharge (Schumm 1977), a reduction in flow through impoundment and diversion can be expected to lead to reductions in these parameters, provided that sufficient sediment is available to allow for channel adjustment (Brizga et al. 1999a). Deposition can occur behind or below dams as sediment supplied by tributaries is unaffected or increased, but large magnitude floods to transport the sediment are regulated (Brookes 1996). Reduction in channel width and depth as a result of these influences leads to de-watering of the substrate and encroachment of terrestrial vegetation. Encroachment of vegetation into former channel area may lead to a reduction in the flood capacity and a rise in flood levels.

In the absence of any significant change in channel morphology, hydraulic roughness or gradient, the reduction in flows would lead to a reduction in stream power and therefore reduced erosion rates. However, channel contraction and vegetation encroachment confine flows within the channel, leading to increased unit stream power at a given flow. Many overseas studies have found that this has lead to incision of tributaries entering regulated streams downstream of major dams (Brizga et al. 1999a).

It is not unusual for disturbance during the construction phase to lead to short term downstream sedimentation. The construction of the Thomson Dam in southern Victoria, for example, initially caused siltation of the channel substrate for a distance of 25 km downstream (Brookes 1996). However, following construction the magnitude and frequency of peak discharges generally decreases below dams reducing the occurrence of flushing flows. Further, a reservoir traps up to 95% of bed load and suspended sediment carried by the river. These factors combined can initiate scour immediately below the dam. Bed degradation can continue and migrate downstream for several decades at rates up to 50 km per year (Brookes 1996). However, variations in the rate of migration of the zone of bed degradation are dependent on numerous factors, including the nature of the bed and bank materials and the discharge regime.

Large quantities of water are harvested from the Yarra catchment, a system with a long history of water resource development. Changes to the Yarra hydrological regime have affected bank erosion in several ways. Lowered base levels resulting from lower water levels may have contributed to historical and recent incision in some tributaries of the Yarra. While the regulated sections of the river have been subject to channel contraction and vegetation (particularly exotic) encroachment, a number of tributaries have incised streams that extend upward from the confluence with the Yarra (Brizga et al. 1999a). With time, the extent of contraction is expected to increase which will have implications for floodplain inundation, which is expected to increase in frequency as channel contraction occurs. In the absence of management intervention, channel contraction processes in the Yarra River are expected to continue until channel size is reduced to dimensions that are in equilibrium with the modified flow regime. However, this may be a long-term process (many decades to centuries) due to the limited availability of sediment to facilitate aggradation (Brizga et al. 1999a).

In the Snowy River NSW, hydraulic diversity and river bed variations are significantly reduced and riverine conditions are environmentally less favourable due to limited habitat for aquatic fauna (fish and macroinvertebrates), increased water temperatures and decreased dissolved oxygen levels (Bain and Tilleard 1999). Under natural flow conditions, the floodplain reach of the Snowy River exhibited a favourable pool riffle morphology in the first half of the century. This was associated with regular alternating side-attached bars. However, since the late 1960s (after regulation) the bars have deteriorated and the pools have infilled to the point where they are practically non-existent today. In their place is a more uniform, featureless river bed characterised by longitudinal bars (Erskine and Tilleard 1997; Bain and Tilleard 1999). Alternate bar and associated pool-riffle sequences are thought to have formed during extended periods of high flow that occurred prior to regulation when snow melted (Erskine and Tilleard 1997). The loss of pools is associated with a reduced presence of alternate bars. Possible contributors to the loss of bars include reduced flows in the post-regulation period and an increase in the size of bed sediment (Stewardson et al. 1999b).

In ecological terms, river regulation that prevents the flooding of the areas outside the main channel precludes the processes linked to periodic inundation on the floodplain and exchange of biota between channel and floodplain wetlands (Larsen 1996). Bunn and Arthington (1997) have identified a range of ecological impacts associated with river regulation summarised in Table 2.2.

2.7 Fish Barriers

Fluvial-geomorphic processes form and control fish habitat which require multiple in-channel and out-of-channel flows to maintain productive and reproductive processes (Hill et al. 1991). From a broader perspective fish habitats rely on linkages between the stream, floodplain, riparian and upland zones and watershed geography. One of the largest impediments to fish habitats is the severance of these linkages. Construction of in-stream barriers such as weirs, or hydraulic jumps associated with road crossings therefore degrade the integrity of the river system. Compared to their overseas salmonoid relatives, Australian native freshwater fish species are less able to pass through barriers as they generally, cannot swim as fast, do not tolerate the same levels of disturbance and are reluctant to leap (White and O'Brien 1999).

TABLE 2.2
Downstream Impacts of Dams and Flow Regulation

TYPE OF IMPACT	EFFECT ON ECOLOGY
Dam construction	Even small dams and weirs have a barrier effect that impedes the movement of aquatic animals.
	Dams are not operated at a constant water level, so the productive littoral areas are rarely sustained.
	Water released from the bottom of the dam is much colder than normal river water. Rapid changes in temperature can disrupt fish spawning and kill their eggs.
Flow Regulation	Pulses of cold water released from a dam at times when the stream or river has normal low flows can disrupt life-cycles of biota.
	Increasing the frequency and duration of low flows compounds just about every potential water quality problem in the catchment.
	Flow is the primary determinant of blue-green algae growth.
	Regulation disrupts the relationship between the river and its flood plain, which is critical to the health of the system.
Water Harvesting	The cumulative effects of small scale water harvesting are not sufficiently taken into account, particularly in respect to requirements of the marine fishery.

(Source: Bunn and Arthington 1997)

A number of studies have quantified barriers to fish movement which suggest that there are:

- 4000 known barriers in NSW (Leader and Smit 1997);
- 2500 potential barriers throughout Victoria with about 150 dams, fords, culverts and erosion control structures being constructed in Victorian streams annually (Bennett 1997);
- 6000 artificial barriers in the Queensland section of the Darling River alone (Jackson 1997) and over 1500 dams and weirs in the Murray Darling Basin without fishways;

- on average 32% of the total valley length in Eastern Australia from the Mary River in Queensland to the Gippsland Lakes System in Victoria, is blocked to fish migration due to physical barriers; and
- few native fish are able to pass through most of the fishways built prior to mid 1980s.

Artificial barriers to fish movement have been identified as a threatening process in the Australian Fish Action Plan (Jackson, 1993). However, rarely is one factor alone responsible for species decline. For example, biological interactions including predation and competition between exotic species (more adapted to regulated conditions) and native fish have been identified as causing the threatened status of various fish species (Harris, 1987).

2.8 Urbanisation

Developing an urban area increases the area of low or zero infiltration capacity and increases the speed of water transmission in channels and surface water sewers. The impacts of urbanisation on channel processes and form typically include:

- erosion of the catchment surface during construction, which can cause large amounts of sediment to be released initially into the channel, which must subsequently be carried out of the system;
- increased storm runoff which may increase velocities, leading to erosion of the channel bed and/or banks;
- enlargement of natural channels downstream in both temperate and tropical environments due to increased discharges arising from paved urban areas; and
- changes to substrate composition (Brookes 1996).

Wolman and Shick (1967) have noted that sediment which had accumulated within a channel was still present seven years after construction activities had ended. It is only after the phase of temporary aggradation that the channel itself begins to enlarge in response to increased runoff from paved areas. As soon as a catchment is completely urbanised or development is stable, it is possible that the stream may become adjusted to the changed hydrological state (Brookes 1996). The urbanisation process also has downstream impacts on biological communities. Hogg and Norris (1991) found that deposition of fine inorganic sediments following storm events, below recent urban development was a major cause of low invertebrate numbers in the downstream pools of Tuggeranong Creek in the ACT.

2.9 Sand and Gravel Extraction

To the untrained eye the presence of sediment deposits within degrading rivers are perceived to be factors which accelerate their demise. Point bar deposits may be viewed as causal agents for erosion on the outside bend, longitudinal bars formed from material scoured from eroding banks are thought responsible for the loss of deep holes. These attitudes, combined with rapid growth in demand for construction materials, has resulted in significant sand and gravel extraction from Australian rivers. When extraction of bedload material exceeds the amount being transported into it from upstream, there is a net sediment loss to the system (Erskine et al. 1985). The river then responds by eroding its bed or banks, or both depending upon sediment type and composition. Even in British Columbia in Canada where their major problem is aggradation commercial sand and gravel extraction has not been permitted since the 1970s, except for navigation purposes (Babakaif 1999).

Gravel extraction from the channel bed has been identified as one of the contributing factors resulting in the extensive bed lowering in the Nambucca catchment (Doyle et al. 1999). Gravel extraction has also contributed to increased flow velocities, channel expansion and excessive sediment transport (Nanson and Doyle 1999). Field work has indicated that the source of much of the in-stream gravel is from an emptying of floodplain gravels into the system and not gravel derived from the headwaters. A combination of nickpoint retreat following extraction and the loss of LWD has led to pools infilling, resulting in more uniform bed profile, although overall bed was lowered. A wider and less sinuous channel is formed after a nickpoint, or series of nickpoints, have retreated (Doyle et al. 1999).

Kondolf (1997) suggests that not only will channels incise after extraction, but this can also lead to bed coarsening, undermining of structures and channel instability and a drop in water level. The loss of sand into the scour hole can also trigger downstream erosion of the bed (Galay 1983, Rutherfurd and Budahzy 1996). In an area of South Australia the mining of just 6,700 m^3 in one year led to catastrophic erosion upstream and severe aggradation downstream. In less than two years, a 2m nickpoint had migrated 4.2 km upstream (Burston and Good, 1996). It was estimated that the resultant bed lowering released some 101,000m^3 of sediment (Burston and Good, 1996).

If extraction is below the river bed level, groundwater recharge from rivers to floodplain aquifers may be severely reduced. Extraction below the waterline will disturb fine grain sediments and nutrients stored in the hyporheic zone, increasing suspended solids downstream adversely affecting both water users and ecosystems. Extraction of this type can also directly destroy instream habitats of fish, platypus and other aquatic fauna (particular benthic communities) resulting in dramatic declines in populations (Pearson and Jones, 1975). Removing gravel bars above low flow water level can significantly effect fish spawning and feeding areas during high flows.

2.10 Sedimentation and Substrate Degradation.

Many of the human activities already mentioned can restrict the exchange of water and nutrients between the fluvial and parafluvial zones through sedimentation from bank erosion, gravel extraction, or poorly-managed catchment land uses. Newbury and Gaboury (1993(a)) discuss the "hidden" habitat that exists in porous streams in the interstital flow through the substrate. Too often our analysis of stream condition and resultant rehabilitation programs focus on riverbanks, channel forms, and plan rehabilitation based on the state of the visible parts of the stream. Few strategies specifically target the importance of the maintenance of water exchange between the surface stream and the subsurface hyporheic zone (Boulton 1999). Sedimentation from bank erosion, gravel extraction, or poorly managed catchment land uses can restrict this exchange. In their natural state, gravel beds of the hyporheic zone act like biological filters, a role that is compromised by sedimentation (Boulton 1999).

Sedimentation is often as common as bed lowering and is often only realised if catchment-wide historical information is obtained (Outhet et al. 1999). Flow regulation can prevent natural flushing flows that periodically cleanse the biological filters of silt and fine sediments. Significant catchment disturbances can lead to sedimentation at a very obvious scale, with the formation of 'sand slugs' in the waterway. Sand (and gravel) slugs are large pulses of sediment moving through a system. A sand slug moves through a channel as an attenuating wave (ie. it gets longer and lower as it proceeds). As their fine sediment fills in undercuts, backwater zones, edgewater habitats, pools and riffles, sand slugs degrade a river by reducing their geomorphic complexity. In general, channels may aggrade and widen, pools can infill, the bed material can become finer, and channel roughness decrease. Sediment slugs can also cover important habitat, for feeding and lifestyle requirements for numerous organisms (eg woody debris and bed-rock outcrops - Bartley and Rutherfurd 1999). Stream rehabilitation programs should consider ways to address sedimentation both to prevent clogging of the upper sediments of gravel-bed rivers and bars and to ensure they take a catchment wide view to identify sources of sediments, passage of sand slugs and, importantly, natural recovery mechanisms.

Increased sedimentation and siltation have contributed to population decline of fish such as the Australian bass (*Macquaria novemaculeata)* and can disrupt litter decomposition, inhibiting the build up of invertebrates and micro-organisms (Lake and Marchant 1990). Macroinvertebrate fauna populations were less abundant and structurally different in a creek subsequent to clearfelling of adjacent forests as a result of sediment input (Richardson, 1985).

3.0 CHANNEL RECOVERY - PROCESSES AND INDICATORS

As discussed in section 1.2 above, Brierley (1999) and Bartley and Rutherfurd (1999) have stressed the importance of identifying the stage of recovery of a stream following disturbance to assist in the prioritisation of rehabilitation works. Outhet et al. (1999) also consider it necessary to assess the stage of bed lowering and channel adjustment before rehabilitation can be designed. Knowledge of the trajectory and processes of recovery following disturbance will be important to rehabilitation planning not only for utilisation of existing models, such as those by Brierley (1999) and Rutherfurd et al. (1999), but also because:

- understanding the limited variables related to the recovery process will allow stream managers to accelerate the process of stream recovery; and
- determining the recovery trajectory of streams will allow more informative decisions about the distribution of rehabilitation money (Bartley and Rutherfurd 1999).

As most rivers are still in the adjustment phase, understanding relative channel condition pre- and post-disturbance assists in identifying the point at which individual rivers are in the post-disturbance adjustment spectrum. This is a crucial part of the process in helping to establish management priorities, and identifying the recovery potential of the whole system, or different reaches within the system (Brooks 1999a). The following sections summarise indicators of channel recovery after various perturbations and from a range of degrading processes. There are, however, a number of general recovery indicators for streams including:

- re-development of pools and riffles;
- bench formation and terrace development;
- redevelopment of a meandering thalweg;
- slope re-grading;
- cross sectional adjustment;
- re-working of previously eroded material;
- variable flow patterns;

- armouring and heterogeneous sediment; and
- vegetation colonisation.

Bartley and Rutherfurd (1999) consider these features to be generally indicative of equilibrium channels and therefore constitute the end-point of the recovery spectrum. Cohen (1999), however, suggests that long-term channel recovery is dependent on the reduction of stream power, the increase in sinuosity (within a wider channel), the decrease in channel width, and subsequent reconnection of the channel to its floodplain, so that floodplain inundation results.

3.1 Recovery from Channelisation

Brookes and Sear (1996) described channel recovery from channelisation in terms of mean stream power. They identified that at mean stream powers less than 15 W/m^2, deposition of sediment results in the smothering of instream features, including pools and riffles. However, above a threshold of 35 W/m^2, straightened channels tend to recover naturally, and it is only channels with very high energies which regain some or all of their original sinuosity.

3.2 Recovery from Sand Slugs

Bartley and Rutherfurd (1999) tested a temporal method for determining if a stream has recovered. They hypothesised that the amount of recovery in the stream is a function of the time since the slug passed, and the range of flows experienced in that time. They also identified an alternative if assessing times proves to be difficult suggesting the use of a 'space for time' substitution. This method is based in the argument that the reaches furthest upstream from the end of the sand slug should be the most recovered. Their preliminary investigation into the recovery of geomorphic complexity following disturbance by sand slugs, however, has shown that the recovery pathway is non-linear. In addition, the recovery process will vary between streams and even between reaches (eg between incised and non-incised streams - Bartley and Rutherfurd 1999).

3.3 Recovery Path of Bed Degradation

The nature of the recovery pathway from bed degradation will vary depending on the scale of, and context in which the degradation occurred. For example, recovery from a nickpoint that starts as a small waterfall-like scarp followed by a plunge will migrate upstream until it eventually is dampened out into a series of small rapids (Keller 1976). However, bed degradation in many coastal catchments is significantly larger in scale with channels up to five times the width of pre-European channels and able to contain floods up to a 1:100 year event, as a result of cycles of bed lowering and bank readjustment (Cohen 1999). Many of these systems have lost a range of natural recovery mechanisms, as they no longer have a supply of large woody debris from the floodplain or riparian vegetation, nor is there a seed source to allow within channel colonisation. This results in sediments that are continually reworked and a prolonged period of channel instability (Cohen 1999). In such systems, the retention of sediment through colonising vegetated geomorphic units is an essential part of channel recovery in geomorphic and ecological terms (Doyle et al. 1999).

Doyle et al. (1999) argue that subsequent to substantial bed degradation, the channel will adjust to similar dimensions whether it is grass or a fully forested floodplain. They suggest, however, that the recovery process after these two scenarios is substantially different. Under the forested scenario, the channel becomes filled with LWD which is a necessary part of the channel recovery following instability. As discussed earlier, LWD may cause local scour but overall a large volume of LWD aides bed stabilisation and aggradation, leading to restabilisation of the fluvial system (Doyle et al. 1999).

In many situations in Australia, over-widened channels are colonised by within-channel vegetation. The occurrence of this in-channel vegetation will increase the roughness of these channels, increase sedimentation, and in the long-term reduce channel capacity as has occurred in Jones Creek, a forested sub-catchment of the Genoa River in Victoria. The Creek has undergone channel metamorphosis triggered by a series of floods between 1971 and 1978. Channel widening of the trunk stream by up to 200% at the confluence resulted in a lagged tributary response resulting in significant changes to channel form. With phases of incision, followed by channel widening with a reduction in sinuosity (Cohen 1999). Rates of colonisation of recent sediment deposits are extremely high in Jones Creek with Black Wattle (*Acacia mearnsii*) being the dominant early successional species. The rapid rate of colonisation increases the volume of sediment locked up and will ultimately reduce the long-term sediment supply to the incised channel, thus promoting further channel recovery. It also enhances channel recovery by reducing channel cross-sectional area, and inhibits downstream changes in channel geometry associated with the passage of sediment slugs (Cohen 1999 - Figure 3.1).

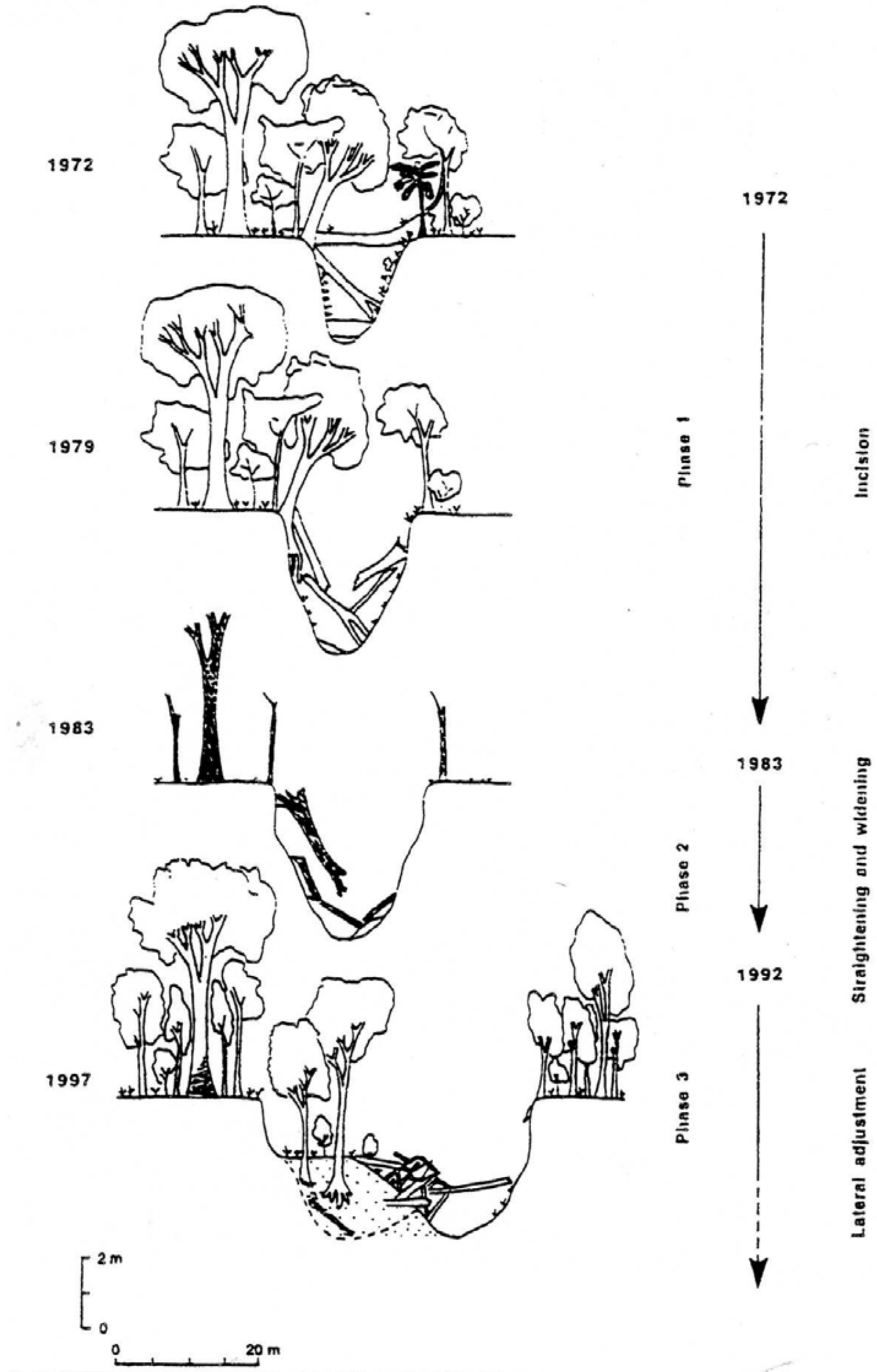

Figure 3.1 Schematic of channel changes in Jones Creek, Victoria highlighting the three phases of channel metamorphosis (Source: Cohen 1999).

Similarly there has been an increase in the colonisation of riparian vegetation, primarily river oaks, since 1941 in the Nambucca Catchment. In the Nambucca as in the Mary and elsewhere, many people have assumed a causal relationship between the increase in *Casuarinas* occurring simultaneously with dramatic increases in channel instability. However, river oaks are not the cause of degradation, rather indicators of natural recovery. Casuarinas and other early colonising riparian species, whose preferred habitat is newly exposed gravel bars, react to an increase in habitat suitable for colonisation as a result of channel instability. Whilst it appears that casuarinas which colonise gravel bars and snag fallen trees exacerbate bank erosion by flow diversion, they are not responsible for bed degradation (Doyle et al. 1999).

The effect of vegetation and coarse woody debris is to increase the ability and rate of recovery of the channel by increasing channel roughness and inducing sediment retention. In order to achieve effective river rehabilitation, rehabilitation plans need to recognise the role of within-channel vegetation and woody debris and aim to retain it.

3.4 Instream Biological Recovery

Organisms in flowing waterways have adapted to natural perturbations and a wide range of environmental disturbances. Townsend (1989) argues that streams conform reasonably closely to the patch dynamics explanation of community organisation which suggests that temporal variation is of overriding significance resulting in species with weedy characteristics being a particularly prominent feature of streams. He notes that disturbances that generate space do not always empty cells completely but may selectively remove particular species. The dynamics of such communities he describes as relict-controlled. Biological recovery from human perturbation can therefore be assisted by the occurrence of species within 'patches' or refuges which have evolved weedy, fugitive, ruderal or r-selected characteristics. High resilience seems to be a feature of stream fauna (Lake 1995).

The linkage between communities upstream and downstream is also important when considering biological recovery from degradation. The community of a particular degraded stretch may contain representatives of species that persist only because of continuous or periodic immigration from adjacent sections of the stream. This will arise particularly through downstream movements or displacements of invertebrates and plant propagules, but also by upstream movements of flying adults (Townsend 1989).

Similarly off-stream wetlands which can provide a refuge for species to recolonise a disturbed site can be an important feature to assist recovery.

The ability of stream ecosystems to recover from stochastic events is exemplified by observed recovery from high flow spates. Rapid recovery from flooding was recorded by Pidgeon (1978) with invertebrate densities in Commissioners Waters on the New England Tableland in NSW returning to pre-flood densities within two months after a severe summer spate. Boulton (1988) found that two intermittent Victorian streams recovered within two weeks of spring floods.

Armitage (1996) suggests that river biota will respond both to natural and anthropogenic influences and recommends biomonitoring to assess the extent and direction of these responses. Choy (pers. comm. DNR Seminar Brisbane, 1999), for example, has found increases in leaf case caddis fly lava (*Trichoptera Calamoceratidae* spp.) on sites where riparian revegetation/regeneration is occurring. Whether in-stream biological communities recover to somewhere along the pre-disturbance continuum of ecological patches will be dependent both the frequency and magnitude of human influences. Breen et al. (1999) research in Melbourne waterways found that after rehabilitation of in-stream physical habitat invertebrate communities in urban streams did not return to assemblages resembling more natural reference sites. They hypothesised rehabilitated sites continued to be impacted due to the continuing influence of significantly disturbed catchments.

4.0 CHANNEL RESTORATION STRATEGIES

> *"It has been argued that the failure of many traditional river channel management schemes results from the treatment of symptoms instead of causes, and this can be summarised as an inability to incorporate the catchment context into their plans. Consequently, the mostly obvious departure in new river channel management practices compared with traditional techniques has been an increase in the degree to which catchment-scale multidisciplinary scientific appraisals form the basis of design."*
>
> (Kondolf 1996 quoted in Erskine and Webb 1999, p.239)

Many river rehabilitation projects have been based on site specific priorities and assessment on a project by project basis. There are now a number of catchment-wide models for the development of rehabilitation plans (Newbury and Gaboury 1993b; Kapitzke et al. 1998; Brierley 1999, Erskine and Webb 1999; Rutherford et al. 1999). A number of these current frameworks are similar in their approach and recommend the multi-disciplinary approach proposed by Kondolf (Table 4.1). Lucas et al. (1999) also suggest a multi-disciplinary expert panel approach to ensure assessment takes into account the biological and physical attributes. Larsen (1996) reports that the hydraulic engineer, who would traditionally be in charge of river rehabilitation projects, now finds him/herself to be only one member of a team that includes botanists, limnologists, geologists, geographers and landscape architects. Outhet et al. (1999) highlight the use of such approaches in the New South Wales Rivercare program.

Considering the various elements contained within the models (Table 4.1) there is a marked difference between the channel geometry and planform dominated approach proposed by Newbury and Gaboury (1993 (a)), the stabilisation and infrastructure protection driven approach of Kapitzke et al. (1998) and the other three models. While Erskine and Webb's model is similar to Brierley's and Rutherfurd, Jerie and Marsh's, it does not include the crucial concepts of prioritising for conservation and recovery potential. Brierley's Riverstyles program is more limited in extent than the others in that it is strongly geomorphological in nature and begins and ends at more strategic, science based stages.

TABLE 4.1

Summary of Elements of Various Rehabilitation Frameworks

Recommended Elements/Steps in Models	Brierley 1999	Rutherfurd, Jerie and Marsh 1999	Erskine & Webb 1999	Kapitzke et al. 1998	Newbury & Gaboury 1993b
Set goals and vision for rehabilitating of your stream		X	X		
Do other people share your vision of an ecologically rehabilitated stream?		X			
Baseline survey of catchment boundaries, topographic and geological maps, sketch long profiles, identify discontinuities	X				X
Baseline Survey of river character and behaviour: Classification of (geomorphologically homogeneous) reaches	X	X	X		
Assessment of river condition, framed in terms of river evolution and recovery potential following disturbance	X	X			
Catchment Audit -What are your stream's main assets and problems? - biophysical and cultural characteristics to evaluate linkages between catchment processes and river instability	X	X	X	X	
Historical Analysis - to establish and understand links between catchment controls, local factors and river channel changes and to determine whether the pre-disturbance channel form can be reinstated or a different morphology designed because of altered catchment conditions.		X	X		
Identify relevant utilities that are affected by the problems.				X	
Setting priority reaches- which reaches and problems should you work on first, considering conservation, ecological and recovery trends in selecting reaches (as opposed to focusing on erosion control and stabilisation).	X	X	X		
Identification of reference reaches (relatively natural channel that is to provide a rehabilitation template)	X	X	X		X
Prepare summary of habitat factors for biologically preferred reaches using regional references and surveys					X
Create detailed, specific and measurable objectives that will be the core of your stream rehabilitation plan.		X	X	X	

Table 4.1 continued.

Recommended Elements/Steps in Models	Brierley 1999	Rutherfurd, Jerie and Marsh 1999	Erskine & Webb 1999	Kapitzke et al. 1998	Newbury & Gaboury 1993b
Develop strategies to protect natural assets and improve your stream -identify and list the things that you can do to protect and improve the important natural assets in the reaches that you identified as a high priority in the last step.		X			
Prepare flow summary for rehabilitation reach.	X	X			X
Channel Geometry Surveys establish channel geometry relationships with drainage area and bankfull discharge.	X				X
Identification of a Design Discharge - reference reach and the section of the channel to be treated should be investigated to determine bankfull, effective and characteristic discharges, test designs for minimum and maximum flows, set target flows for critical periods.			X		X
Integrate Hydraulics, Hydrology, Geomorphology and Ecology - create a Multi-functional team; community consultation and ownership is essential.		X	X		
Test feasibility of objectives - many factors, such as cost, politics, and undesirable consequences for other users of the stream, may require alteration of priorities.		X		X	
Prepare detailed design of your project. Technical design and specify actions to achieve objectives.		X	X	X	X
Environmental Impact Assessment			X		
Develop assessment criteria to evaluate project - measurable become the basis for evaluating the project.		X		X	
Project Management Planning -the plan needs to be implemented by developing a time line, allocating responsibilities, finalising funding, doing the works, and organising the evaluation schedule.		X		X	
Supervise construction		X		X	X
Monitoring and Auditing		X	X	X	X
Post Project Evaluation - Comparison of benefits and successes of the scheme against those predicted before the plan was implemented. Use of adaptive ecosystem approach		X	X	X	X

4.1 Setting Vision and Goals

A currently fashionable vision is one that restores the condition of the stream to that which existed prior to significant disturbance by humans (Gippel 1999). But is this realistic?

Brooks' work (1999a) in the Cann has revealed that over the last 100 years, and particularly the last 30 years, Cann River has increased its channel capacity by 700%, bankfull flow has increased 45 fold, sediment transport capacity has increased 1000 fold, bank stability parameters have fundamentally changed, as have form and Large Woody Debris (LWD) resistance characteristics. Flood plain sedimentology suggests that these changes are unprecedented over at least the last 26 900 years Brooks (1999a). He argues it would take at least 1500 years of accretion at prior sediment supply rates to return the channel to its former dimensions, and this is based on the implausible assumption that all the sediment is trapped within the degraded reach. If we consider realistic management time frames, rehabilitation targets for the Cann and many equally altered rivers must be set within the framework of fundamental post-European channel changes.

Before we can set realistic visions and achievable rehabilitation targets, it is important to identify lessons learnt from past mistakes, the theory which underpins our current knowledge base, and the current management strategies and techniques being promoted to address the restoration/rehabilitation of our rivers and waterways.

The initial step in establishing a vision for rehabilitation is to establish an ideal goal for ecological rehabilitation. This requires reconstruction of the ecological, hydrological and geomorphic conditions that existed before the river was disturbed on a large scale by human intervention. It is important to know what a river used to be like, because it helps identification of threshold changes, it places current patterns of behaviour into context, and helps frame realistic rehabilitation targets (Brooks 1999a). This forms a template from which a politically, economically, biologically, hydrologically and geomorphically realistic plan for rehabilitation can be derived through negotiation between stakeholders (Gippel 1999).

The structure and function of many alluvial rivers today is significantly different to those which prevailed prior to European settlement in Australia. Restoring rivers to pre-European condition is not possible in most cases, because they have fundamentally changed and are now operating under different conditions to those of the preceeding millennia (Brooks 1999a). In most cases rivers have been readjusting for more than a century, in response to riparian zone clearance and desnagging. Management goals must be viewed over similar (or longer) time frames. Kern (1992) considers that only in very few cases would a vision of returning a stream to that condition which existed prior to disturbance by humans be feasible.

The earlier 10 step rehabilitation models outline good procedures once you have identified the goal, for example bank stability (Kapitzke et al. 1998), and salmonid fish habitat (Newbury and Garboury 1993(b)). The approach proposed by LWRRDC (Rutherfurd, Jerie and Marsh 1999) however, begins somewhat earlier in the planning sequence, by defining the goal that drives the plan as rehabilitating the ecological values of the stream, and thus takes a generally ecological perspective. Planning in this model follows a hierarchy of scales approach with vision, setting priorities, and problem definition concentrating on the regional or whole-of-catchment scale.

4.2 Baseline Surveys of River Behaviour, Processes and Condition

Many rivers are still adjusting to the new post-European disturbance condition, so it is important to know how far down the readjustment path your river is (Brooks 1999a), and what is its potential to naturally recover from these perturbations. The River styles procedure developed by Brierley (1999) provides a geomorphic summary of river forms and processes on a reach by reach basis. The baseline geomorphic survey of river character and behaviour provides a dynamic perspective on river evolution. Ecological considerations are evaluated in terms of habitat availability as determined by the range of geomorphic units that compromise each river style.

Newbury and Gaboury (1993b) suggest that the combination of elements from geomorphology, open-channel hydraulics, and hydraulic habitat requirements of stream fish forms the basis for an ecologically sound ‘soft-engineering’ of river channels. They recommend interpreting and mapping the hydraulic geometry of streams and locally varied flow conditions. Like Newbury and Gaboury’s ten step procedure, the definition of river styles is based on channel geometry (size and shape) and channel planform. However, rather than focusing solely on planform-based attributes, the river styles approach to river classification is based primarily on the geomorphic units which make up both the channel and the floodplain (Brierley 1999).

Breen et al. (1999) suggest biological condition and consequently ecological targets may be derived from historical and comparative data eg. AusRivAS reference conditions and could be expressed in terms of:

- Composition: species present and relative abundance
- Structure: vertical and horizontal arrangement of habitat and biota, hyporheos, benthos, nekton , riffles , runs and pools
- Heterogeneity: a function of structure and composition
- Function: production and decomposition - nutrient dynamics
- Resistance and resilience: withstand and recover from disturbance.

The "Pressure, Biota, Habitat (PBH)" protocol being developed by Chessman (1999) is similar, in terms of the type of data collected, to the AUSRIVAS method used in the Queensland Monitoring River Health Initiative's program (Choy, 1997, Choy and Thompson 1996). Both methods involve biomonitoring supported by physico-chemical and habitat assessments, however PBH incorporates procedures more specifically developed for rehabilitation planning. PBH is a multi-faceted, rapid procedure for the assessment of ecosystem stress in small and medium-sized streams. Chessman (1999, p.1) describes it as '*an integrated physical, chemical and biological scheme that sits within a geomorphological framework'*. He argues that while PBH has some similarities to assessment methods currently in use in Australia, particularly Queensland's State of the Rivers Method (Anderson 1993), and Victoria's Index of Stream Condition (Ladson *et al.* 1997), it differs from both of these techniques in several aspects. The technique aims to provide an understanding of the relationships between causes (pressures), primary effects (habitat change) and secondary effects (biotic change) to assist in the development of effective strategies for river management. The method identifies indicators of these elements, to facilitate the identification of critical issues and relationships (Chessman 1999).

The Anderson method is used extensively in Queensland to compile 'State of the Rivers Reports', which are potentially useful for developing baseline surveys of river condition. These reports provide data at a reach scale on a variety of parameters including:

- Condition of reach Environs;
- Bank Stability;
- Bed and Bar Stability;
- Channel Habitat Diversity;
- Riparian Vegetation Condition;
- Aquatic habitat;
- Macrophytes;
- Scenic, Recreational and Conservation Values; and
- Overall Condition.

The mapped output is at a scale that is consistent with the needs of the rehabilitation plan.

4.3 Historical Analysis

It is important to know what your river used to be like. In order to restore or rehabilitate a stream it is essential that something is known about the stream's pre-disturbance form, and there is some understanding of the causal factors driving stream degradation (Davis and Finlayson 1999). Understanding geomorphic processes from a quantified history of the stream channel is a solid foundation for models and decisions that lead to better land and water resource management. Compiling stream channel histories is valuable as it can:

- provide a source of baseline data that can guide development, mitigation, or restoration plans;
- assist in the identification of threshold changes;
- provide context to evaluate erosion and sedimentation problems related to land use and stream flow regulation;
- reveal how natural events and human activities affect channel change;
- places current patterns of behaviour into context;

- help to define recovery rates and patterns; and
- help frame realistic rehabilitation targets (Smelser and Schmidt, 1998; Brooks 1999a).

Rehabilitation implies a return to some previous condition, yet often unsubstantiated anecdotal evidence, rather than sound historical research, is the only information used to determine what the previous condition was (Davis and Finlayson 1999). Historical information can generally be obtained from sources such as:

- explorers' diaries;
- surveyors' notes;
- archival records (eg Shire records, State Government records);
- railway and road bridge cross-sections;
- stream gauging station records;
- historic aerial photography; and
- local interviews.

Walker and Rutherfurd (1999) have used aerial photography, old maps, ground features and repeat cross-sections over a period of decades to historically reconstruct meander positions. Smelser and Schmidt (1998) examined historical information recorded with stream gauging to compile a geomorphic history of mountain streams to quantify the adjustability of the streams in order to successfully manage them. Davis and Finlayson (1999) investigated the history of Granite Creek since European settlement using historical maps and plans, land selection files and other archival records, as well as anecdotal evidence. This evidence was used to identify the original stream forms, the sequence of changes that have taken place over time and the factors driving those changes.

4.4 Assets and Problems

According to Rutherford et al. (1999), rehabilitation is about protecting natural stream assets and improving or creating other assets. In this context, an asset is any aspect of the stream already in good enough condition to meet a rehabilitation goal. They suggest that it is important to identify the main assets, degraded assets, and place problems into a hierarchy. They propose that a hierarchy of problems can be developed based on the following classifications:

1. **fatal** - so bad that they exclude a plant or animal from that reach;
2. **limiting** - problems that stress the species in question; and
3. **nuisance** - have minor effects on the population.

They also emphasise the need to keep track of interactions between problems so you know when fixing one problem will be linked to the condition of another (Rutherfurd et al. 1999).

Jennings and Harman (1999) use a process in which a multidisciplinary team works cooperatively with landowners and watershed stakeholders to identify problems and unstable stream reaches with the potential for restoration. They then access watershed land uses to determine sources of pollution and hydrologic changes and monitor streams to determine channel stability, aquatic habitat and pollutant impacts.

4.5 Utilising Reference Reaches

Hughes et al. (1986) proposed the idea of using reference sites as a basis for providing geomorphic, hydraulic and biological data and outlined four approaches for estimating the recovery end-point of a stream; forested streams, historical data, up and downstream sites, and before and after studies. Bartley and Rutherfurd (1999) suggest these methods combined with aerial photo analysis and historical research, will provide a picture of the appropriate target condition of a disturbed reach.

Newbury and Gaboury (1993a) in their rehabilitation process use relatively intact reference reaches to establish the natural channel geometry relationships. This is an important step in understanding the stream's behaviour and characteristics. Their technique is based on linking the drainage area, the channel and geometry measurements to the channel pattern and profile. These relationships are then used to dimension stream rehabilitation works that mimic natural. The amplitude of meanders and their radius of curvature may also be determined using sample reach surveys that have been prepared to scale.

The paired catchment approach is an extension of the reference reach concept whereby a relatively undisturbed river is used as a comparison for a degraded river of similar type within the region. Brooks (1999a) gained insights from the direct observation of channel structure and functioning in the pre-disturbance Thurra River which were then used to reconstruct the former condition of the adjacent, highly disturbed, Cann River. The Cann River was in many ways similar to the Thurra River prior to riparian vegetation clearance and desnagging. Catchment geology, vegetation, rainfall and hydrology are as good as an analogue as can be expected between any two catchments (Brooks 1999a).

Brierley (1999) uses intact sites (from a location within the same style) to determine the target condition of each river reach. Sites of the same river style are placed along a continuum of river condition (or recovery potential with intact sites being the highest level, followed by sites with high recovery potential, moderate recovery potential and those sites that are degraded).

4.6 Prioritising Reaches

During the sinking of the cruise liner Titanic they put the women and children on the lifeboats first. They prioritised where they could best expend their effort and protected the young, healthy and those that care for them. Rutherfurd et al. (1999) believe that similar principles can be applied to planning for river restoration. They suggest a model that plans to protect the good before repairing the degraded is both financially and ecologically responsible. Their argument suggests that most of our current river rehabilitation effort is akin to loading the lifeboats of the 'Titanic' with old and sick men from the infirmary.

Rehabilitation effort is frequently directed to the most degraded sites within the landscape. In river rehabilitation terms this has resulted in rehabilitation activity largely being constrained within an erosion control and stabilisation paradigm. This approach builds on the "River Styles" process developed by Brierley (1999). Both Brierley (1999) and Rutherfurd et al. (1999) advocate a biophysical approach to prioritisation of rehabilitation effort, based on river reaches/styles, geomorphic assessment of recovery potential of river and conservation status.

Rutherfurd et al. (1999) suggest setting priorities taking into account the following features:

- rarity (rare before common);
- condition (good before bad);
- trajectory (deteriorating before improving);and
- ease to fix (easy before hard)

Each of the methodologies then generate a ranked set of reaches based on priorities. Rutherfurd et al. (1999) recommend rearrangement of reach priorities if a reach is influential - highly visible, contain a charismatic animal, or if a reach has potential to have regional conservation value, even if it does not have the value now.

4.7 Develop Strategies and Specific and Measurable Objectives

There is a growing argument that abiotic conditions such as physical habitat, are a more achievable target for describing stream recovery than are biological factors such as density, diversity or production of certain species. It is also increasingly acknowledged that geomorphological surfaces form the template for the development of riparian ecosystems. For these reasons Bartley and Rutherfurd (1999) suggest that geomorphic complexity is considered an appropriate measure of stream recovery. The basic requirement of restoration works can therefore be to increase local morphological hydraulic and sedimentological variability given the natural constraints of the channel (Hey 1996).

Brierley (1999) considers that the geomorphic template is considered to be the key determinant of habitat availability along river courses. He therefore suggests that setting strategies to implement principles of ecological sustainable development need to be directly underpinned by geomorphic considerations in order for management efforts to maintain biodiversity of river courses.

When setting strategies, recognition of the fact that many post-disturbance rivers will have crossed critical internal thresholds is important. In these circumstances, successful management strategies will have to identify such thresholds and work within the constraints they now impose (Brooks 1999a). Rutherfurd, Jerie and Marsh (1999) stress the need for objectives to be both specific and measurable. An example of such an objective is provided by Doyle et al. (1999, p.202) in their recommendations for the Nambucca where they state: '*The channel width needs to be decreased by only 5-10 m at* *a time. …Once an initial reclaimed area has undergone sedimentation and, vegetation is taking hold, further reductions can then take place.'*

4.8 Evaluation, Monitoring and Auditing

Jennings and Harman (1999) stress that monitoring is essential to develop designs, measure success, and determine if follow up work is needed following initial constructions. There must be a continual re-assessment of design criteria and objectives in the context of geomorphic observations and environmental monitoring (Outhet et al. 1999). This process can be facilitated through proactive community participation strategies throughout the rehabilitation process. "*If a landowner with basic training in river behaviour is involved in the rehabilitation design and helps to build erosion control works, they feel part of the solution and act under these circumstances as if the works are 'theirs'. These people monitor and evaluate works, carry out repairs, make improvements and inform others along the stream about their success*" (Outhet et al. 1999, p490).

Babakeiff (1999) outlines how rigorous assessment and evaluation criteria can save a lot of wasted effort. The in depth planning and evaluation process in British Columbia results in 90% of proposals ending up with the "do nothing" option. He suggests that a lot of proposals were too far down the catchment with processes occurring further up in the catchment which would have mitigated against the success of the project.

Project evaluation indicates whether the project objectives have been achieved, and encourages the development of practical and sound environmental objectives. Stewardson et al. (1999b) base their project evaluation on changes in physical habitat diversity and channel capacity and point out that visual assessment of physical condition of rivers can be deceptive. They suggest, for example, that assessment of increased flood risk needs to be considered where there is a concern that instream rehabilitation works will reduce channel capacity by enhancing flow resistance within the channel. Such assessment should include measurement of the percentage increase in channel capacity following the rehabilitation works. Outhet et al. (1999) argue that channel and riparian vegetation condition is one of the best indicators of the stream's biophysical health and integrity. They therefore suggest assessment of the effectiveness of rehabilitation projects can be done simply by assessing the condition factors of extent, density and performance of native vegetation. This method however can be criticised for being oversimplistic.