Nambucca Valley River and Catchment Management Study

Technical Report F

River Management and Rehabilitation

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GLOSSARY OF TERMS

100 year recurrence interval flood	Flood occurring, on average, once every 100 years. While statistically 10,000 floods of this size or greater could be expected in a million years, there is still a 1 in 100 chance of such a flood occurring in any one year.
Aggradation	Accumulation of sediment, usually upwards but also sideways as in a migrating river bend.
Alluvium	Sediment deposited by running water.
Avulsion	A sudden change in channel location to a new part of the floodplain.
Climax species	Those plant species that occur in a final, stable community. Pioneer species which initially colonise an area gradually give way to other species as the plant community matures.
Entrenchment	The incision of a channel into its bed or the buildup of the floodplain on both sides of the channel thereby increasing channel depth.
Floodplain	The generally flat alluvial surface beside a stream formed by the stream, and the product of present climate and flow-regime.
Fluvial	Associated with rivers.
Gabion	A wire basket filled with stones. They are used collectively to provide river bank protection.
Geomorphology	The landforms and associated processes operating on the Earth's surface.
Geotextile membrane	A strong porous woven fabric made from synthetic fibre which is designed to separate different construction materials (eg boulders and mud).
Groyne	Reinforced concrete, quarried rock, excavated bed material, logs and brush dykes that extend from the bank to the river either at an angle or perpendicular, to the flow. Groynes are used to train a river along a desired course, create a region of low velocity to induce silt deposition and protect the bank by reducing local velocities.
Gullying	The erosion of a narrow deep channel by head cutting.
Head cut	The near vertical eroded wall of unconsolidated material at the head of a gully.
Hydraulic jump	Where water flow changes from super-critical to sub-critical flows, such as occurs at the base of a dam spillway or below a rapid where water enters a pool.
Hydraulic roughness	Surfaces and objects (such as rocks and vegetation) that offer resistance to water flow and thereby retard flow velocity.
Jack	A structure formed of a single log and a cross member at each end, placed collectively on the side of a stream channel in order to retard the flow and increase sedimentation.
Log sill	One to three logs placed across a stream in the form of a small weir, and designed to raise the bed level upstream.
Morphology	The form or shape of an object or landform.

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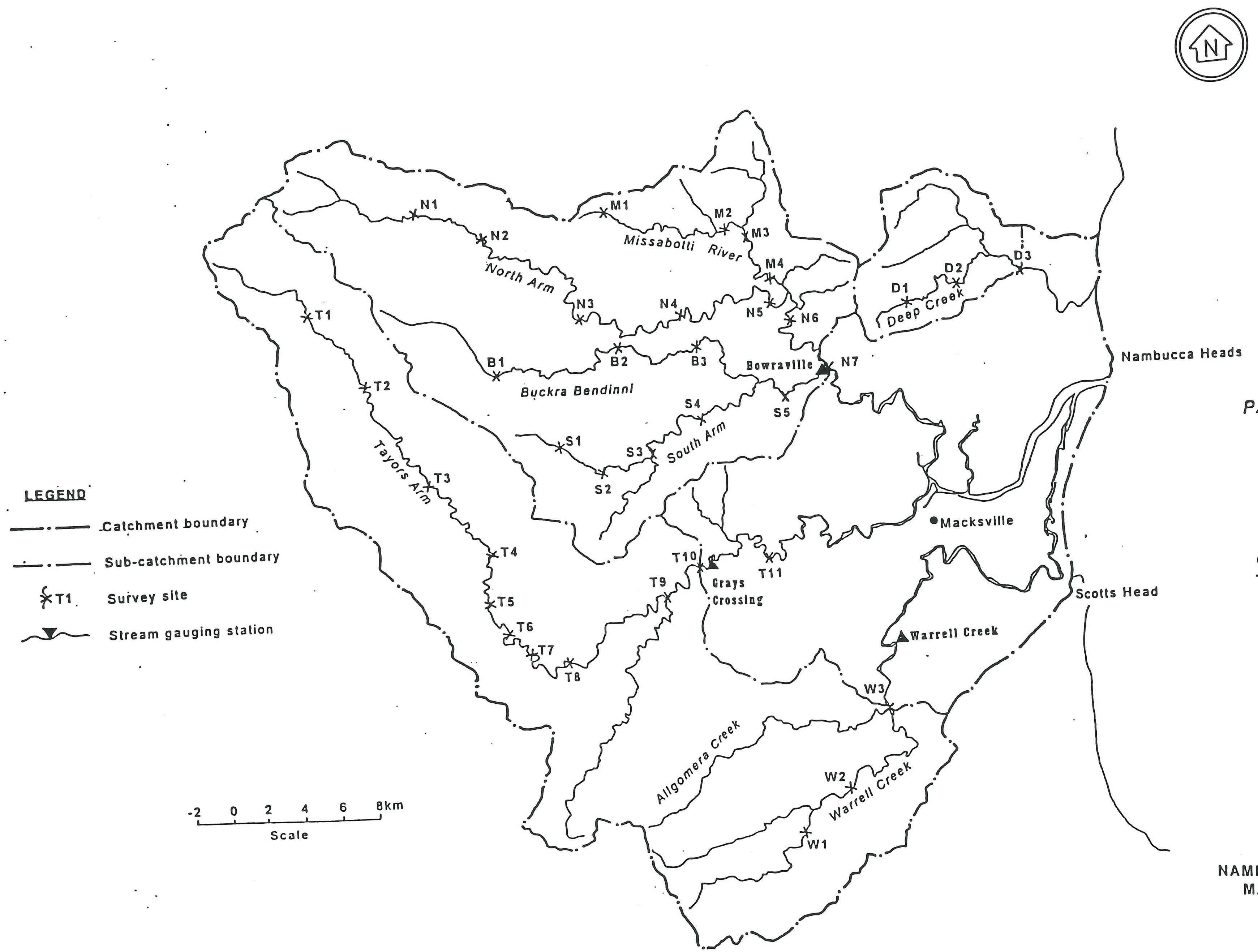
Nickpoint	A section of river bed with a sharp vertical or sloping drop in bed level. A nickpoint can migrate upstream with successive floods.
Phyllite	A low-medium grade metamorphic rock (between slate and schist).
Riffle	A small rapid formed of coarse sediment. They are often regularly spaced along alluvial channels with intervening pools.
Riparian vegetation	Vegetation growing on or very close to the stream bank or bed, or on associated islands.
Riparian zone	The zone very close to a stream.
Rock ramp	A sloping rock weir, constructed of large erosion resistant boulders, designed to raise the bed level upstream and/or to create a pool upstream.
Schist	A high grade metamorphic rock, between phyllite and gneiss.
Shear Stress	The stress exerted on the bed of a river by flowing water. The faster the velocity of flow, the greater the shear stress.
Sinuosity	The meandering path taken by a stream. Is usually expressed quantitatively as the ratio of the path length of the stream over the length of the same reach of valley.
Stratigraphy (alluvial)	The layers of sediment in a floodplain or river terrace.
Stream power	The rate of work being undertaken by a stream at some particular discharge (eg bankfull flow). It is a measure of the stream's potential to do work (eg. erode).
Surficial	To do with just the surface.
Thermoluminescence dating	A method of dating sediments that are between about 1000 and 200,000 years old.
Tidal prism	The total volume of water that flows in or out of a coastal inlet with the rise and fall of the tide.
Toe protection	The artificial protection provided to the base of a stream bank to help make the bank stable and resistant to collapse.
Terrace	An abandoned floodplain, usually formed under conditions associated with different climate and flow regime. They often occur as benches against the valley sides and are usually higher than the present floodplain.
Thalweg	The lowest point in the valley at any cross section (usually the lowest point of the stream channel at any cross section).



Map of Field Sites

NAMBUCCA CATCHMENT MANAGEMENT STUDY

1 Principles of River Management

The rationale behind river management practice forms a basis for the selection of engineering or conservation/rehabilitation techniques. Stream size, land use practices and the extent of channel and catchment degradation are all factors which determine the scale and type of river management practices to be adopted. Broadly, the rationale adopted for river management and rehabilitation can be from two objectives:

- altering the river environment to best suit our land use practices
- altering our land use practices to best suit the river environment

Some forms of river management and rehabilitation, it can be argued, fit into both categories and are not mutually exclusive. For example, revegetation of the toe of a bank has benefits for the channel as well as helping to arrest the loss of alluvial land. Altering the river environment can also be broadly separated into two approaches:

River Engineering:-

- flood mitigation works (eg. levee construction, desnagging)
- urban channel reconstruction (eg. enlarging, concreting)
- river training for erosion control (eg. groynes)
- dam and weir construction
- bed alteration and sediment control (eg. dredging)
- channelisation (re-alignment)
- sand and gravel extraction

River Conservation or Rehabilitation:-

- water quality control
- habitat diversity maintenance (eg. pools and riffles)
- vegetation management (eg. tree planting, weed control)
- 'soft' engineering control of moderate bed and bank erosion
- land use controls (eg. cattle access)

The rehabilitation of degraded rivers has recently become of increasing interest to practitioners of river management world wide (Brookes and Shields, 1996). Many studies are from an ecological perspective (eg. Harper and Ferguson, 1995), while some provide engineering solutions (eg. Jansen et.al 1979; Simon, 1995), however, few studies have examined the role geomorphology solutions can play in river management and rehabilitation (eg. Sear et. al. 1995).

Harper et.al. (1995) propose that in terms of human impact there are three states of river environment. The first is a pristine river environment which has endured minimal human activity. The aim for management is to protect (or minimise) these areas from human interference. Here, the environment is perceived to be too good to lose and is therefore adopted as the ideal end point in a model for river rehabilitation. It is always much cheaper to prevent river damage than to attempt to rehabilitate such reaches if they become degraded. The second type is the semi-natural river where there has been some human impact but not a major destabilisation or alteration. The goal in these rivers is to maintain and enhance the existing qualities of the system as small efforts can yield high returns. Finally, there is the degraded river system where alteration has been followed by little natural recovery. The aim here is to restore the system artificially as natural recovery is perceived to be too slow due to the magnitude of the disturbance. The costs of such rehabilitation can be very high and, as environmental damage can be very severe, the desired outcome is most often borne out of considerable cost.

There are some further questions which need to be considered at a degraded site before rehabilitation should go ahead. These include;

Ecological improvement or aesthetic enhancement? Rehabilitating channels may be undertaken more for aesthetic than structural or ecological reasons. In other words, the objective is simply to improve visual attractiveness. Aesthetic treatments include the reinstatement of pools and riffles, and development of more natural stream banks (Brooks and Sear, 1996).

Intervention or natural recovery? An important distinction in geomorphology is the assessment of channel stability and the identification of which channels are recovering and which are deteriorating. Enhancing the rate of natural recovery is often much more cost effective than full scale intervention. However, some systems do need intervention. For example, over a short time scale low energy environments may not have enough energy to adjust to a previous human-induced change. Also, straightened channels that have experienced a metre or more of incision require the entire valley floor to be eroded by a metre for natural recovery to occur such that the channel and floodplain are back in equilibrium. Such a recovery is not possible over a short period of time (Brooks and Sear, 1996).

River rehabilitation can be undertaken to varying degrees (modified from Brooks and Shields, 1996):

-**Full rehabilitation** is the complete structural and functional return to a pre-disturbance state. The management approach is direct intervention, natural recovery or enhanced recovery.

-**Partial Rehabilitation** is the partial return to a pre-disturbance structure or function using direct intervention or enhanced recovery.

-**Enhancement** is any improvement in environmental quality, mainly using direct intervention.

-**Naturalisation** is the development of a stream system that looks natural but that previously did not exist.

The aim of naturalisation is to determine the morphological and ecological configurations that are compatible with the contemporary magnitudes and rates of fluvial processes. Compatible means configurations that will produce stable, functionally diverse, self regulating geomorphological and ecological systems given the set of processes (including human utilisation of natural resources) associated with the contemporary environmental setting. Naturalisation objectives are broadly consistent with the objectives of rehabilitation (National Research Council, 1992) but they do not necessitate the disturbance required to re-establish pre-disturbance conditions ('full restoration'), or to move the system towards these conditions ('rehabilitation') (Rhoads and Herrick, 1996).

In essence, naturalisation is an attempt to produce an ecologically and geomorphologically stable river system given the prevailing environment and current state of the channel. The idea is not necessarily to move towards the previous channel conditions but towards a condition more compatible with the current channels requirements. Hence, the perception is that a new stable channel can develop more readily based on the existing unstable channel itself rather than by attempting to recreate the original pristine environment. Rhoads and Herricks (1996), the proponents of this rationale, state (p.334):

> "Naturalisation emphasises that human utilisation of natural resources is a component of the current 'natural' environment of the region and that this factor must be considered explicitly in efforts to protect or improve the quality of existing environmental resources.

> It establishes stability, self regulation, and diversity of form and function as geomorphological and ecological goals of stream management, rather than a return to some unknown pristine state or the creation of an entirely new state, while at the same time providing an appropriate framework within which to establish the viability of re-establishing documented pristine characteristics in contemporary stream systems. Although naturalisation embraces the notion that emulation of the present condition of an undisturbed system may be an appropriate way to achieve ecological and geomorphological goals when human intervention is not an ongoing process, it also explicitly recognises that human modified elements may be an important component of 'natural' configurations in systems characterised by frequent human intervention."

This characterisation has lead to a shift in the focus of river management planning, particularly in the U.S.A.. Previously, many managers of degraded river systems would have focused their efforts on restoring the channel to a state similar to pre-disturbance conditions. Now there is a realisation that human influences are going to continue regardless, so the direction of management strategies has focussed less on restoration and more on stabilisation and aesthetic enhancement of degraded channel systems. Stabilisation is often achieved through engineering solutions and maintained by conservation strategies.

A suggested approach to river rehabilitation appraisal and design can be seen in Figure 1.1.

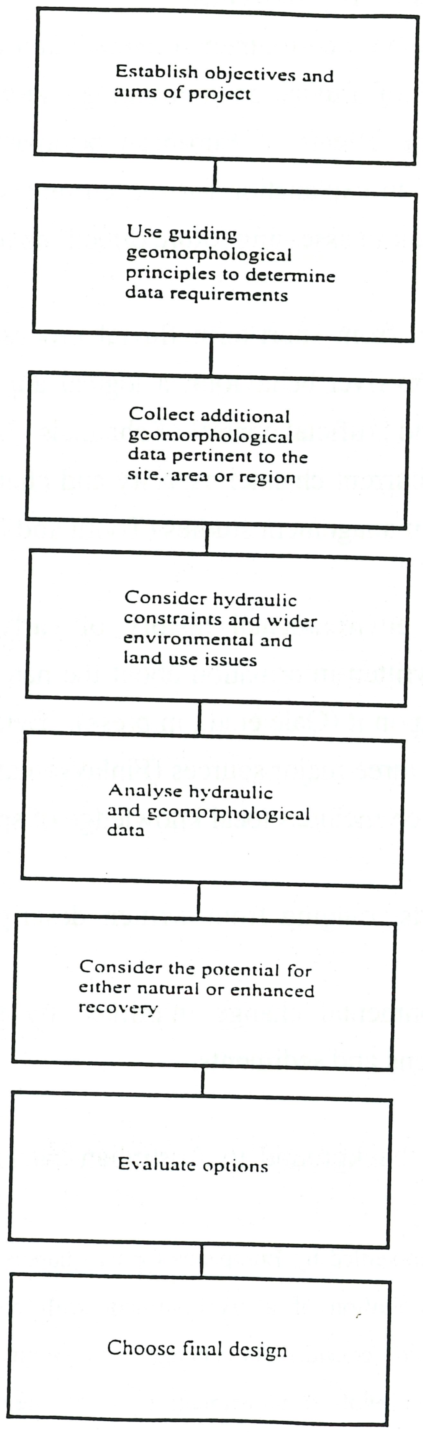


Figure 1.1: A method for planning river enhancement work (Brookes and Sear, 1996, p.76)

2 Issues and Problems in River Management : An Overview

2.1 Stream Degradation in Australia

An increasing concern about environmental degradation in Australia in recent decades has also spread to the field of fluvial geomorphology and geomorphologists have become interested in studying the effects of European occupation on Australian river systems. Such work is providing an explanation for the current state of the riverine environments and is extremely important in assessing future directions for catchment management.

From knowledge gained from short-term fluvial process-form studies together with that from studies of long-term river behaviour, a logical application is to the environmentally sensitive management and artificial control of channels. In ideal situations a combination of Quaternary, recent, and current channel capacity and change can be examined to maximise the potential benefits of management studies (Tooth and Nanson, 1995).

Efforts to interpret the environmental history of early colonial Australia are severely hampered by a lack of written information about the nature of the contemporary landscape and the human impact upon it (Gale et.al., in press). Evidence of post-European change is generally obtained from three major sources (Finlayson and Brizga, 1995):

(1) An oral tradition which includes local knowledge of specific examples of environmental change.

(2) Documentary records, ranging from written descriptions to maps, survey data and photographs.

(3) Evidence of environmental change imprinted by the landscape itself, such as in palaeochannels, pollens and sediments.

A brief summary of the background to Australian catchment degradation was written by Warner (1984, p.135):

> " Australia has been settled by Europeans for two hundred years. However, the tempo of settlement and exploitation of a dry continent with erratic and changing hydrological regimes has caused considerable changes to occur. Most examples of channel metamorphosis have involved adjustments in width, depth and consequently width-depth ratios. Greater increases in width together with increases in depth, have locally caused braiding with steeper in-channel slopes, and more bed material in transit. Additionally, meander chute cut-offs have tended to reduce channel lengths locally and increase gradients.

Very large floods have ruptured thresholds, as well as well as completely changing channel conditions and locations...In the moister east (of Australia) there has been large scale deforestation. Early forestry caused gullying and increased sediment loads in rivers."

Warner (1984) in examining the effects of European occupation on Australian rivers, identified indirect changes, or 'catchment changes', as well as the direct effects, or 'channel changes':

CATCHMENT CHANGES:
- Deforestation and ring-barking
- Grazing
- Cropping
- Urbanisation
- Conservation practices

Rural land use can result in disruption to the water balance of a catchment and hence the hydrologic regime of the river system. Vegetation clearing, surface compaction by hooved animals and cultivation may lower filtration and evapotranspiration thereby decreasing concentration times and increasing run-off coefficients. Two centuries of western agriculture must have altered runoff and sediment discharge balances to some extent, possibly causing changes in channel geometry, drainage network, flood frequency, flow duration and other aspects of the hydrologic regime of streams (Eyles, 1977a, 1977b; Prosser, 1991; Riley and Erskine, 1995). However, the extent to which this has occurred in the Nambucca has been difficult to judge and is the topic of Background Report E. The ensuing rationale behind many soil conservation and Landcare programs in upland catchments is the reversal of the hydrologic impacts of rural land use (NSW Landcare Working Party, 1991). Urban environments have had a even greater impact still on catchment hydrology, however urbanisation has not been a significant problem, as yet, in the Nambucca catchment.

CHANNEL CHANGES:
- Weirs and major dams
- Channel improvements and channelisation
- Sand and gravel dredging
- Navigation
- Water quality problems

Dams have had a major effect on river systems in Australia although, again, this has not been a factor in the Nambucca. The hydrologic regime of Australian rivers has been greatly affected by channelisation. Straightening of channels reduces channel length, increases slope and decreases form roughness. The combined result is a local increase in flow velocity, a reduction in concentration times, increasing peak discharges and, an initiation of bed degradation (Riley and Erskine, 1995). The impacts of channelisation have been exacerbated, in some instances, by the removal of large woody debris (LWD) which further reduces channel roughness. The removal of LWD has been carried out in NSW by the (then) Department of Water Resources and local councils (Erskine, 1990; 1992; Riley and Erskine, 1995), a policy also applied in the Nambucca catchment.

Riley and Erskine (1995, p.25-26) conclude their paper on the human impacts on NSW rivers by stating:

> "While it is possible to say that the recent land use practices have altered the hydrologic regime of NSW coastal rivers it is not possible to quantify the nature of those impacts for all streams. The hydrology of a river is complex and single index descriptions of impacts are unlikely to convey an accurate picture of the changes that have occurred. However, at the risk of being (taken to task) for obvious exceptions, we offer the following generalisations:
>
> - lower flow regimes have been significantly decreased by irrigation in rural areas and increased by channelisation in urban areas
> - the low frequency floods are largely unaffected by human activities in large catchments in rural areas
> - floods have increased significantly in magnitude and frequency in urban areas
> - secular climate changes contributes to observed hydrological changes in many large catchments but it is difficult to disentangle the significance of this cause of hydrologic change from human impacts on the hydrologic regime
> - management of hydrologic impacts must be a catchment-wide exercise if it is to succeed
>
> The complex combination of natural and human induced changes in the hydrologic regime have implications for river and Total Catchment Management. Not every change in a river or catchment can be blamed on humans nor is natural variability the sole cause of change. Resource commitment to ameliorating 'undesirable' change has to be tempered with an understanding of the underlying processes-response system. 'You cannot fight nature'."

Despite all of the site specific human-induced catchment changes outlined above, Brookes and Brierley (1997) argue that studies on channel change in Australia understate the effects of indirect and diffuse human impacts on channel morphology, such as forest clearance, or the more subtle effects of altered riparian vegetation communities. This despite the fact that catchment-wide vegetation cover is one of the primary intrinsic controls on sediment supply and hydrology to a river, and despite being the control most susceptible to human alteration.

The Holocene record shows that in humid south-eastern Australia, vegetation clearance of slopes, floodplains and channel banks in the period following European settlement has had a major impact on channel form and behaviour. Brookes and Brierley (1997) speculate that distinctive geomorphic traits of some coastal rivers in southeastern Australia, such as bench development (eg. Erskine, 1986), catastrophic channel widening (eg. Erskine, 1994), river avulsion (Brizga and Finlayson, 1990) and floodplain stripping (Nanson, 1986), may reflect the increased flood effectiveness associated with European clearance when river regimes were fundamentally altered from their pre-disturbance conditions.

2.2 First National Conference on Stream Management in Australia

In February 1996 the first national conference on stream management was held at Monash University, Victoria. The theme of the inaugural conference was the management of changes in stream morphology. The conference attracted speakers from universities, government funded research bodies, environmental consulting firms and state and local government authorities.

The editors of the conference proceedings note that there has recently been a convergence of four trends in river management in Australia. These are:

- the waning of many forms of human impacts on stream systems in Australia.
- an increasing understanding of stream processes.
- the rise of an holistic view of catchment management.
- the decline of public involvement in the water industry, coupled with a rise of local control of management priorities.

The fifty-two conference papers were loosely grouped into five themes that reflect these trends in stream management.

1. Our understanding of stream erosion and sedimentation is improving. This is reflected in a better understanding of the sources of sediment in a catchment, and the movement of sediment through various stores. Conceptual and numerical models are increasingly able to predict changes in these sources and sinks given a change of inputs (eg. a dam, gravel extraction, greenhouse effect etc.).

2. We have a growing appreciation in the relative role of human impact (eg. clearing vegetation and channelisation) against the natural variation in the rates of erosion and sedimentation (eg. catastrophic floods).

3. Revegetation, particularly riparian vegetation, is becoming the primary tool in stream management, and research in this area is growing.

4. Restructuring of the water industry in Australia, and a redirection of public resources, has seen an increasing role for catchment-based community groups in stream management, and new roles for State government authorities.

5. Catchment-based management has also lead to broader definitions of stream management. Several papers discuss the resolution in conflicts around the use of land in catchments, and the allocation of water in regulated systems.

The editors also note that there was only one paper dealing with the design of engineering structures for stream management, and that twenty years ago such papers would have dominated such a conference. The conference included at least 20 presentations that were relevant for assessing stream management in the Nambucca. Papers presented that were relevant references to the Nambucca catchment study dealt with bank stability (Kapitze et.al., 1996; Skull et.al., 1996), methods of repairing or controlling bank erosion (Frankenburg et.al., 1996; Brizga et.al., 1996) and gravel extraction (Erskine et.al., 1996). There were also papers examining fluvial geomorphic aspects of catchment management (Croke, 1996; Woodfull et.al, 1996; Millar and Quick, 1996) with studies on vegetation management also being well represented (Wilson et.al., 1996; Hairsine, 1996; Abernathy and Rutherford, 1996; Burston and Brown, 1996). Other papers examined the history of erosion in selected catchments (Geraghty and Volleburgh, 1996; Burston and Good, 1996; Erskine and White, 1996) and community based approaches to river management (Good and Burston, 1996; Gardiner, 1996; Outhet, 1996; Schur, 1996)

2.3 Applied studies on NSW coastal rivers

There are very few papers in mainstream journals that examine applied fluvial geomorphology in relation to NSW coastal rivers. In addition there are to our knowledge no reports that address the combined issues of Quaternary change, recent change, hydrology, sediment characteristics, riparian vegetation and, current management practices on a non-tidal NSW coastal river system such as this study on the Nambucca catchment.

Most of the recent papers dealing with applied fluvial geomorphology and NSW coastal rivers involve investigating channel change (eg. Erskine and Bell, 1982; Erskine, 1986; Warner and Paterson, 1987; Nanson and Erskine, 1988; Erskine and Warner, 1988; Warner, 1991; 1995; Brooks and Brierley, 1997). In addition there have been some studies examining the impacts of; specific floods (eg. Erskine and Melville, 1978), river training works (eg. Erskine, 1990; Nagel, 1995) and sand and gravel extraction (eg. Erskine et.al., 1985).

2.4 Gravel bed rivers

Gravel-bed rivers are a common feature characteristically associated with mountainous regions containing metamorphic rocks (Neill and Hey, 1982) and the size and shape of the bed material is crucial to the stability of the channel (Milne, 1982). The instability of bed material in gravel-bed streams is controlled by scour in a different way to sand- and silt-bed channels. Material of larger size or more oblong shape can armour the bed and control scour and can also control the location of pools and riffles (Hirsch and Abrahams, 1981; Clifford, 1992).

It can be argued that human induced changes to gravel-bed rivers can be just as problematic as those to sand or silt bed channels. The potential mobility of gravel-bed streams due to their steeper slopes and higher energy makes decreasing sinuosity and channel widening symptomatic of human disturbance (Patrick et.al., 1982). Retreating nickpoints due to artificial or disturbance -induced straightening leaves behind composite bank profiles in the form of cohesive silt in the upper and middle portion of the bank while the lower bank is comprised of cohesionless gravel exposed by bed lowering. The fluvial entrainment of the gravels renders the cohesive material above prone to mass failure (Thorne and Tovey, 1981). The failure of these cantilevers exacerbates the process of channel overwidening and the results in steep bank faces that exceed the thresholds required for stability (Millar and Quick, 1993). Well vegetated banks can also fail in this manner if the bed level drops beneath the root mat of the bank vegetation or if gravel is entrained from within the root mat (Cohen, 1997). Undercutting leads to trees falling into the channel and the subsequent flow divergence can continue to exacerbate the problem of bank erosion (Rankin, 1980). However, it should be noted that this is not a problem unless the river does incise and undermine the vegetated banks.

2.5 Theory and practice of channel rehabilitation and management

The realisation that humans have greatly altered river channels is not a recent occurrence. There has been a limited understanding for quite some time that human occupation, particularly agricultural practices, can have a dramatic impact on natural landscapes:

> "In the course of my fieldwork in the rural districts I am constantly struck with the effect of human culture on the streams. Hardly in any particular has man in a settled country set his mark more conspicuously on the physical features of the land." - G.W. Lamlugh on the state of rivers in the British Commonwealth (1914, p.61)

The need for channel rehabilitation and catchment management is, to some extent, identified from general appearances. In most cases, we observe that the physical appearance of a river is in decline, that it is degrading. However, our understanding of the causes of, and solutions to, the physical changes identified are sometimes misguided due to a lack of understanding of how rivers actually work. In examining possible solutions, attention must be given to understanding fluvial processes.

> "Many times human perceptions of geomorphic habits are fallacious. Three types of misconceptions are (1) a perception of stability, which leads to the conclusion that any change is not natural, (2) a perception of instability, which leads to the conclusion that change will not cease, and (3) a perception of excessive response, which leads to the conclusion that changes will always be major... such perceptions can lead to litigation and unnecessary engineering works." - S.A. Schumm (1994, p.129)

The fact that humans still have misconceptions as to how fluvial systems operate means that the era of management is not a guaranteed success simply because we now want to look after our waterways. Environmentally sensitive stream rehabilitation and management is in its infancy and stream managers everywhere are still coming to terms with balancing site specific management with holistic, ecologically sustainable, catchment management.

Many environmental problems result from a failure to recognise the nature of the fluvial system and its interaction with the biological system. Channels modified for flood control often experience severe environmental degradation due to erosion and sedimentation, loss of vegetation cover, reduction in the amount and value of habitat, and a decline in aesthetic values. Many negative environmental impacts can be avoided by designing (or reconstructing) channels that are in harmony with changed fluvial conditions and that minimise disruption to the existing fluvial and biological conditions (Brookes, 1991).

Arguably, three major components for any major technical project on natural systems, whether or not connected with rivers, are:

- Economics
- Engineering
- Environment

Although environment is a major component, economics is usually a deciding factor influencing the final outcomes and the methods implemented.

To make decisions on the type of rehabilitation methods to be used, a plan must be derived to ascertain the problems and the options. Examples examining potential resoration approaches and their impacts are given in the following section.

2.5.1 Overseas Trends

An important factor in the move toward environmentally sensitive catchment management in recent years has been the influence of geomorphologists and biologists in what was essentially an engineering dominated domain (Newson, 1995; Brookes, 1996). In the U.K., a long term catchment experiment has been set-up called the River Restoration Project (RRP). It was established to pool the collective expertise of river ecologists, engineers, planners, fisheries biologists, and geomorphologists drawn from both the scientific and river management communities. The aim is to establish a series of demonstration projects (incorporating rural streams, urban streams, and streams of varying bed material) which show how state of the art restoration techniques can be used to re-create natural ecosystems in damaged river corridors. The RRP is designed to ensure streams undergo improvements in; the understanding of the effects of restoration work on nature conservation value; water quality; visual amenity; and recreation potential. It is hoped that this approach will encourage other groups and individuals to restore streams and rivers (Brookes, 1995). An additional advantage of such a project is that each scientific and management field learns the basis and objectives of other fields. For example, geomorphologists will learn about the goals ecologists have for stream rehabilitation, and will learn new methods of attaining such goals, and vice versa.

Similar team river restoration projects in the United States have been hampered by a continual lack of understanding and acceptance of ideas between the various scientific fields. This is reflected in the ongoing conflict over the definition of restoration goals and a criteria for success (Haltiner et.al., 1996). Nonetheless, projects have carried on. Examples of some of the integrated works that have been carried out in the US can be seen below.

Stream: Wildcat Creek, California, USA
Environment: Rural
Catchment Area: 18km^2
Length Affected: 400m
Purpose of project: channel stabilisation; fish passage
Type of rehabilitation: boulder check dams; bank stabilisation using rootwads/boulders
Learning points: creative use of rock, rootwads can provide a diverse attractive habitat. Use of large boulders provide aesthetic benefits; however failure to adequately tie in or protect structures at the edges (sides, up- and downstream edge) resulted in erosion and failure or damage to some structures during high flows.
Source: Haltiner et.al. (1996)

Stream: Miller Creek, California USA.
Environment: sand/gravel
Catchment Area: 20km^2
Length Affected: 2km
Purpose of project: restoration of a deeply incised stream
Type of rehabilitation: creation of a compound channel
Learning points: For deeply incised streams, extensive reshaping is appropriate. Maintaining a wide corridor (100m) through an urban corridor allows the stream to meander. Benefits of vegetated spur dykes to control bank erosion.
Source: Haltiner et.al. (1996)

Stream: Sur River, Bavaria Germany
Environment: mountain torrent, high sediment load
Catchment Area: 151km^2
Length Affected: 500m
Purpose of project: channel incised following straightening with recurrent maintenance problems due to unstable bed and adverse impacts on the flora and fauna.
Type of rehabilitation: 'ramp weirs' constructed from stone used to raise the bed, leading to stabilisation and rise in adjacent groundwater levels.
Learning points: consideration of upstream catchment may be important in high energy rivers to attenuate flood peaks and/or reduce high sediment loads
Source: Brookes (1996)

European and American case studies of channel rehabilitation are dominated by lowland rivers that have had either; (a) their lengths shortened due to channelisation, or (b) fish populations threatened from weirs or pool and riffle destruction. The overwhelming predominance of these samples means that there are few northern hemisphere examples that can be related to the problems of the Nambucca.

2.5.2 Community Involvement - The Australian Way

An examination of overseas rehabilitation programs highlights the large budgets given to projects overseas in relatively densely populated countries. Such costs may not be borne in rehabilitating rural streams in Australia, such as in the Nambucca catchment which supports a relatively small. Budget restrictions and a consequent preference for 'soft' engineering approaches has caused Australia to develop a unique system of stream management where the majority of management strategies are community driven. In the country areas of Australia, large farms and small populations have meant that management plans rarely achieve on-the-ground management without community involvement. This means that no matter how good the scientific research is - no positive action will occur unless the landholders take part and support proposed initiatives (Good and Burston, 1996). This requires that residents and agencies share information and reach a common consensus as to the nature of the problem and what should be done.

The value of land holders experiences can be undervalued, but such experience must be utilised in Australia due to the isolation of some rivers and the lack of data available on channel change (Martin and Lockie, 1993; Good and Burston, 1996; Gardiner, 1996; Outhet, 1996). Involvement of the community does more than merely provide anecdotal evidence for channel change. It can lead to issues of stream management being raised that are not initially appreciated by scientists or government agencies. For example, a landholder may be able to report a decline in fish species, or problems in growing a particular plant species. Without this input, such problems may not be dealt with at all in the management process. Community input can also provide important follow-up support enabling river works to be repaired or maintained.

However, there are also examples of projects going wrong when they are based solely on community derived information (Finlayson and Brizga, 1995). The Nagoa River, Queensland, and the Avon River, Victoria, have both undergone some change since European settlement. In both cases, records documenting channel character had been ignored in place of an oral history of change. Reconstructions of river channel behaviour from the documentary record and field evidence on the Avon and the Nagoa suggest somewhat different histories of change to those perpetuated in oral folklore (Finlayson and Brizga, 1995).

In the oral tradition, erroneous ideas can be given legitimacy by being quoted frequently. Beliefs about river channel change stemming from the oral tradition have had a considerable impact on both the rhetoric and practice of river management. The revelation that erosion is not necessarily unnatural and that land loss has been much less dramatic than earlier thought make the arguments for a comprehensive and costly bank stabilisation program less compelling. The oral tradition may become widely and uncritically accepted because it lends support to the arguments put forward by land holders who want public money spent on bank erosion affecting their land. Surprisingly, there may never have been an analysis of the economic, environmental or social benefits of river management works on certain rivers despite large amounts of public money being spent over a long periods (Finlayson and Brizga, 1995).

The most useful form of community involvement comes from on the ground implementation of rehabilitation works. Rivercare works established on the Manning River (Gardiner, 1996) facilitated close liaison between the Department of Land and Water Conservation (DLWC) and land holders. Morphological features and channel histories were written onto enlarged aerial photographs. Rehabilitation options were then generated and the selection of the preferred method was selected on environmental and economic grounds (see Section 3.2). The process was assisted by the Riverwise program which educated land holders about stream processes and encouraged them to become stream managers (Outhet, 1996).

There are now manuals available (eg. Raine and Gardiner, 1995) which provide guidelines for community groups and river managers to follow for the ecologically sustainable management of rivers and riparian vegetation. The manuals not only outline approaches and methods for river management, but also provide background educational material on the Australian landscape and the effect of European settlement.

The implementation of imported ideas was the major engineering approach to river management in coastal NSW after the 1949-1955 floods (Erskine, 1990; Nagel, 1995). It was assumed that erosion control techniques successful in Europe would have the same benefits in Australia. To some extent the river improvement works (eg. those in the Hunter catchment) were successful in stopping further erosion at individual sites. However, the river improvement works have had no effect in controlling off-site erosion. Many overseas designs fail to take into account that Australian rivers are often ephemeral with a wide range of flows (Wasson et.al., 1996). The range of flows makes suitable channel widths and alignments difficult to determine (Nagel, 1995).

3 Stream Management in the Nambucca Catchment

3.1 Flood Mitigation

Prior to the late 1960's there is little documented evidence of river management in the Nambucca Catchment. Major forms of stream management were not official practice although there were efforts at erosion control and flood mitigation by individual land holders. Anecdotal evidence obtained from a questionnaire circulated to residents indicates that Council gravel removal from within the channel of North Arm took place as early as 1928, and gravel extraction has been commonly seen as a flood mitigation measure within the catchement. Information from the questionnaire also indicated that after the 1950 floods there were very large amounts of gravel removed from newly formed point bars. Apart from gravel extraction (see Background Report B), desnagging and the excavation of meander cut-offs have been practiced by landholders as recently as the 1990s.

Documented evidence of government inspired stream management began with a Water Conservation and Irrigation Commission document in 1970. The document, entitled "River Improvement Works within Nambucca Shire", examined Taylors Arm, North Arm, South Arm, Buckra Bendinni Creek, Missabotti Creek and Kennaicle Creek. Along lengths of each stream, river improvement engineers outlined the work required and estimated the cost for these works. The river works included; channel clearing and desnagging, tree lopping, channel realignment, bank protection, wire meshing for bank protection, earthworks and willow planting. The overall objective was to clear the channel of the debris that was slowing floodwaters and, to provide bank protection in reaches where bank retreat was becoming a concern.

A summary by the senior improvement engineer sets the scene in terms of the economic and social cost of river erosion at the time (WC&IC, 1970 p.1):

> *"Over a period of many years most of the creeks and streams in the Nambucca River Valley upstream of the township of Bowraville have suffered damage from floods. Riverbank erosion and movement of the channels have been the biggest problems to landholders. Generally, river flats in the Nambucca River Valley Catchment are scarce. Where they do exist , they are fertile and quite valuable. The erosion which has gone on unchecked in the past has made large inroads into these flats and in a lot of cases, particularly in the upper reaches*

of the various tributaries of the Nambucca River, landholders have been forced to leave their properties and move to towns and cities to find other employment for their livelihood."

Looking at the condition of the stream and the cause and remedy of the flooding problem, he continues (WC&IC, 1970 p.1):

"Conditions in each stream vary from poor to very bad, the two worst streams being North Creek and Missabotti Creek where river bank erosion is very bad. In all streams obstructions to flow are a major problem. Most channels are blocked by dense vegetation growth and other debris. In some places gravel has built up against tree growth and as a result flows have been diverted, at sharp angles, causing poor alignments to develop. Much of the flooding of flat land could be attributed to these conditions."

These interpretations appear to have been reached in ignorance of the fundamental cause of stream degradation in the Nambucca catchment; that of vegetation clearance and consequent bed lowering (by nickpoint retreat) and bank destabilisation (Background Reports D & E).

Cost estimates in 1970 for flood mitigation and bank protection works on each stream were as follows (WC&IC, 1970):

Taylors Arm	$193,070
North Arm	$400,840
South Arm	$ 46,125
Buckra Bendinni Ck	$ 34,965
Missabotti Ck	$ 78,425

The total cost estimated for the catchment as a whole was $753,425 which is equal to $5,130,824 in 1997 terms (Reserve Bank of Australia, pers.comm., 1/12/97)

Flood mitigation studies of the tidal reaches were also carried out by The Department of Public Works (1974). In 1979 the Water Resources Commission repeated the work of the WC&IC (1970) by identifying eroded sites and estimating the repair costs for the non-tidal channels of the Nambucca. The methods of river improvement included stream clearance (classed as light, medium and heavy), mesh bank protection, rock-fill bank protection, willow planting.

Cost estimates in 1979 for each stream was as follows (Water Resources Commission, 1979):

Taylors Arm	$342,000
North Arm	$915,000
South Arm	$704,000
Buckra Bendinni Ck	$193,000
Missabotti Ck	$578,000

The estimated cost for the river improvement works in the catchment totalled $2,232,000 which is equal to $6,227,280 in 1997 terms (Reserve Bank of Australia, pers.comm., 1/12/97)

The enormous cost estimated to carry out stream management practices throughout the 1970's should not be lost on stream managers today, however, the management rationale today is different. The aim in the 1970's (and into the 1980's - see Gutteridge, Haskins and Davey, 1981) was to decrease the height of floodwaters by clearing the channel and allowing greater velocities. The approach at the time was best put forward by the principal engineer of the Water Resources Commission (Rankin, 1980 p. 132):

> *"When the flow is blocked by a badly obstructed channel the discharge is not reduced...one of the most obvious benefits of stream clearance is that the removal of obstructions will increase the actual waterway capacity of a congested channel. The discharge in the stream will not be altered. The overall rate of flood flows will not be significantly increased and there will be less turbulence."*

This statement is clearly incorrect. The water discharge in the stream channel will certainly increase following stream clearance, as less water will flow over the floodplain. Studies at that time, and subsequently, have proven the very considerable value of vegetation and large woody debris (LWD) in maintaining bed and bank stability (eg. Keller and Swanson, 1979; Smith et.al., 1993; Assani and Petit, 1995). Today it is recognised that vegetation above low flow is very important for bank protection and overall channel stability. LWD plays an important role in bed stability and works best in conjunction with an established riparian vegetation zone. By stabilising the bed and reducing flow velocities, LWD can prevent excessive bedload transport and help maintain pools and riffles (Keller and Swanson, 1979; Assani and Petit, 1995).

3.2 Rivercare and Landcare

In the late 1980's a nationwide change took place in the approach to land management. At a national level, funding became available for Landcare - a national strategy of community based conservation strategies aimed at maintaining or restoring soil, water, vegetation and coastal land degradation administered through the NSW Soil Conservation Service. The Dept. of Land and Water Conservation (DLWC) (formerly the Dept. of Water Resources - DWR) began to work in association with the National Landcare Program and began to establish and oversee Landcare groups.

In the 1990's the DLWC began a 'Riverwise' program aimed at educating residents about rivers. This program attempted to get locals interested in 'owning' the problem of managing their local stream and thereby becoming involved in carrying out river rehabilitation (Outhet, 1996). The specific objectives were to:

- understand the behaviour of rivers and identify the causes of problems
- successfully obtain Rivercare grants and other funding for river rehabilitation
- successfully obtain permits for river rehabilitation
- assess the effects of proposed developments and land-use changes on rivers
- be aware that mismanagement on one property can affect properties up- and downstream
- control accelerated river erosion and sedimentation
- revegetate the riverine corridor
- control stock access to rivers
- strike a balance between flood mitigation and erosion control
- control the input of nutrients to a river
- consider the 'big picture' when planning river rehabilitation projects
- counter popular misconceptions about rivers
- use legislation to stop river damage by exploitation

In conjunction to the 'Riverwise' program is the 'Rivercare' process. On the mid-north coast of New South Wales the DWR/DLWC followed up an extensive period of river improvement works on the Hunter River with a more community driven and community involved series of works on the Manning River. Rivercare works are now the result of DLWC consultation with Landcare groups. Enlarged aerial photographs are used as the basis for the planning with transparencies overlain to provide different levels of information. Additional stages involve the assessment of permit applications, discussions upon the best method of river management and formal submissions of proposals. The different levels of information and the step-by-step overall procedure can be seen below:

1. **Aerial photograph base layer:** aerial photos are enlarged to enable features to be easily identified.
2. **Boundary and property owner**: marking on the photo of the existing infrastructure and the property owners affected.
3. **Environmental layer:** marking of features such as bank erosion, vegetation details, existing river works etc.
4. **Geomorphic features layer (and the identification of areas where permits are to be requested):** arrived at by looking at the dynamics of the river (eg. aggrading, history of waterholes etc, nature of modifying works such as gravel extraction and tree removal, position of rock outcrops or bars).
5. **Landowner management options and preferences for the next five years:** planning and marking on the map of proposed works by landowners.
6. **Final management proposal/TCM detail:** DLWC advisory staff discuss options, attributes and environmental factors and put together a final management plan.
7. **Final acceptance and approval:** Final information laminated onto aerial photos after endorsement by Rivercare group and TCM. Permits for work are then arranged.

Since the advent of 'Rivercare' and 'Riverwise' the number of Landcare groups in the Nambucca catchment grew from two in 1991 to fourteen in 1996. Each Landcare group organises its own funding applications and working bees. Due to the number of Landcare groups in the catchment, a Landcare co-ordinator was appointed in 1995.

The Landcare groups in the Nambucca catchment (and the study sites within these group areas) include:

- Upper Taylors Arm (eg. T4)
- Medlow (eg. T7)

- Utungun (eg. T10)
- Upper North Arm (eg. N2)
- Argent's Hill (eg. N3)
- Goalloma (eg. N4)
- North Arm/Missabotti (eg. N6)
- Junction (eg. N7)
- Bowra River (downstream of N7)
- Upper Missabotti (eg. M1)
- Sullivans Missabotti (eg. M2)
- South Arm (eg. S3)
- Buckra Bendinni (eg. B3)
- Valla (eg. D3)

In most cases the bulk of the funding required was for contractors to construct bank protection, remove or relocate soil and gravel, and for fencing and revegetation. Further work involving weed control and tree planting, stock fencing and, groyne and jack construction was carried out by Jobskill teams.

Coincidential with the era of Landcare was a new focus involving studies in the Nambucca. Gone was the emphasis on flood mitigation which prevailed throughout the 1970's and early 1980's. The new emphasis was aimed at controlling bank erosion and managing gravel deposition. Apart from several DLWC papers there were reports published by consultants (eg. Resource Planning, 1989; Thoms, 1994) examining bank erosion and the role of gravel extraction. DLWC produced papers on the importance of riparian vegetation (Raine, 1994) and provided guides for the implementation of river works that were required throughout the catchment (DLWC, 1995). All of the reports cited above called for a major scientific study to examine the cause of degradation and identify the steps involved in remedying the problem.

3.3 Rivercare and Landcare methods in the Nambucca

The main methods of stream rehabilitation in the Nambucca Valley carried out under the auspices of Rivercare and Landcare (and in one case, a special DLWC Task Force) were:

- Log sills (largely a DLWC Task Force technique)
- Groynes (pin groynes & brush groynes)
- Jacks

- Rock ramps
- Bank and toe revegetation

Below is a summary of each method including selected examples and the perceived advantages and disadvantages of each method :

3.3.1 Log Sills

Log sills are used in an attempt to restore the natural pool and rifle sequence that refers to quasi-regular alterations of shallows and deeps which are characteristic of gravel-bed channels of moderate slope. Riffles (topographic highs) and pools (intervening lows) are marked by stage dependant contrasts in flow velocity, water surface slope, channel morphology and bed sedimentology. Over most flow ranges riffles are shallower, faster zones of steeper water-surface slopes, with coarser, better sorted or more interlocking bed material than intervening pools (Clifford, 1992). Thompson et.al (1996) have concluded their research on sediment transport in pools and riffles by stating that pools are more competent zones of bedload transport than are riffles during high flows.

Local scour of a single pool creates deposition downstream which then generates the next downstream flow irregularity (Clifford, 1992). In general terms pools are most commonly found on outside of bends with riffles found in the intervening straight reaches. In instances where a channel has undergone bed and bank erosion, a priority with river managers is often to reconstruct the pool and riffle sequence. It has been recognised that the protection of an outer bank in a meander bend, could be in ignorance of the cause of the whole problem which is bed alteration (Neill and Hey, 1992). In streams which are actively eroding, channel slope is increased by reducing the sinuosity. In these circumstances it would be sensible to decrease the gradient in the meander bend by introducing small scale drop structures on the riffles between bends, reducing average flow velocities in the upstream bend and lowering outer bend shear stresses (Neill and Hey, 1992). This is the theory behind the use of log sills.

Log sills are the most widely used form of bed level control within the catchment. At a cost of approximately $1000 each they were identified as a cost effective method to restore the pool and riffle sequence to degraded channels in the Nambucca catchment. The concept of a log sill is simple. A partly submerged log is used to dissipate energy and help control the transport of bed material downstream. Logs are usually large hardwood trunks that exhibit longevity in water. There have been two types of log sills trialed in the Nambucca with differing results; straight log sills and v-notch log sills.

The straight log sill consists of a single hardwood log (or two logs together end to end) perpendicular to flow (Plate 3.1). The log is sometimes covered with geotextile which is buried 2 metres under the gravel on the upstream side of the log and 1.0-1.5 metres below the log on the downstream side. The geotextile membrane helps to raise the water table at the site and helps prevent the gravel washing out from beneath the log.

A v-notch log sill consists of two logs joined together end to end in a v-shape with the apex pointing upstream (Plate 3.2 and 3.3). This configuration causes water flowing over the sill to scour down the centre of the channel. In the Nambucca catchments, scour holes on the downstream side of the v-notch sills can be up to 1.5 metres deep at the face of the log but they diminish in depth downstream (DLWC, 1996). The straight log sills do not form scour holes as deep as the v-notch sills. In some cases rubber tyres, an additional log or rubble has been used to dissipate energy on the downstream side so as to help prevent undercutting of the sill. In some places in the Nambucca catchment log sills were placed in a series of up to 10 with a headloss of 0.2-0.3 metres for each (J.Bucinskas pers.comm.)

A major problem with log sills is that they can be outflanked by the flow. Plate 3.1 shows a straight log sill working on Taylors Arm. The success of this sill is, in part, due to the protection given by a 'splash log' placed on the downstream side of the main log, and to the placement of brush groynes along the banks at the outer ends of the log. These brush groynes help to prevent the sill being outflanked by flow in times of flood. Continual maintenance of the sills and brush groynes by property owners greatly contributes to their success. Plate 3.2 shows a V-notch sill on Missabotti Creek where a pool has been scoured on the downstream side. This sill has not been outflanked due to the fact that the logs have been embedded into a cohesive and vegetated bank of soil in contrasts to those where the banks consist of gravel. The narrowness of the channel here and the decreased chance of outflanking has helped the sill to remain intact. However, as the geotextile continues to breakdown, the structure will surely be undercut.

Plate 3.3 and 3.4 show the fate of a V-notch log sill that has been outflanked at Argents Hill on North Arm. This reach was oversteepened due to a meander cut-off in the 1980s. Figure 3.3 shows the sill just after completion, while Plate 3.4 shows it just after the May 1996 flood. The sill was soundly placed against bedrock on the left side of the channel but

Plate 3.1: Straight log sill on Taylors Arm (downstream of T3). June 1997.

Plate 3.2: V-notch log sill on Missabotti Creek (downstream of M3). June 1997.

Plate 3.3: Log sill constructed at Argent's Hill (N3). April 1996.

Plate 3.4: Log sill at Argent's Hill (N3) after the May 1996 flood. Undercut and outflanked

was only buried under gravel on the right side. The May flood, a one in five year event, caused the structure to be undercut and outflanked on the right side of the channel.

3.3.1a Case Study:

Argent's Demonstration Site (N3)

In 1995 the DLWC Task Force decided to establish a demonstration site to trial their methods of river rehabilitation and a problem site at Argent's Hill on the North Arm was chosen. This reach was in the vicinity of a meander cut-off artificially constructed in the 1980s. Gravel deposition has since completely filled in waterholes and left the water-table approximately 1 metre below the gravel bed during dry periods (DLWC, 1995).

The DLWC had nine v-notch log sills installed in 1995/96, but in a storm event in early 1996 six of these failed. By April 1996 these had been replaced by eight sills of various design (including the sill featured in Plates 3.3 and 3.4). Hence, by May of 1996 the demonstration site had 11 operational log sills. After the May 1996 storm event there were only two sills in working order (Plate 3.5). A report of DLWC (1996 p.4) states:

> *"The May 1996 flood caused many of the works at this site to fail. The main reasons for failure were the excessively steep bed due to the meander cut-off at the site and insufficient time for the revegetation works to become established. The flows over-topped the banks and many of the bed control sills failed by outflanking... the lesson to be learnt from this is that the installation of bed control works will generally be unsuccessful until they can be tied into well vegetated banks that are proven to be stable."*

Plate 3.5 shows DLWC file photographs of the site prior to river works in September 1995, after the completion of the works in April 1996, and after the failure of the works during the May 1996 flood. The newly created channel with a design width of 15m was unable to cope with the storm event and the floodwaters outflanked the log sills, also removing the groynes which were designed to prevent this from happening.

3.3.1b The Interpretation:

Most of the log sills emplaced in the Nambucca catchment have been eroded. A DLWC report in 1996 found that of 55 sills constructed between August 1995 and May 1996, only 14 were a success with a further 9 being classified as a partial success. The 40 v-notch sills had a 17% success rate and the 15 straight log sills had a 47% success rate. Since then,

ARGENT'S HILL LANDCARE GROUP

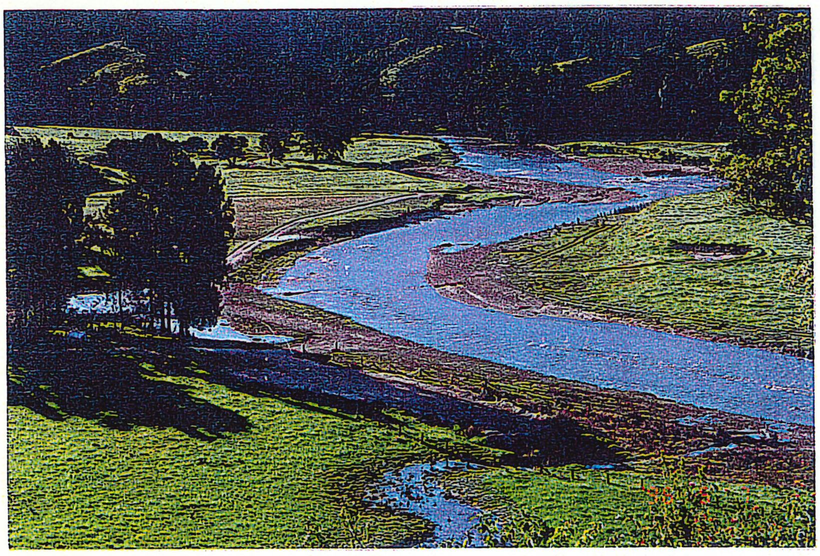
RIVER REHABILITATION PROJECT

September 1995

Excavation has already commenced
V-notch log bed controls being constructed
Alignment set to approximate low flow channel
Design Width determined as 15 metres.

April 1996

Site almost completed
Bed control sills rebuilt following 1/96 flows
New designs trailed including straight sills and rock ramp
Brush groynes installed on outside bends for short term protection until revegetation works established



May 1996

Photograph taken on falling stage of ~ bankfull flood
Note river meander process (erosion on outside bends)
River is trying to reduce it's slope by getting longer

Plate 3.5: Failed river works at Argent's Hill on North Arm (N3). (Source: DLWC)

many more have failed. From our observations it is apparent that the overwidened and bed-lowered channels found in the Nambucca are not conducive to retaining log sills for any significant period of time. Log sills fail predominantly due to outflanking or undercutting (caused by further upstream nickpoint movement or failure of the geotextile to handle the excessive scour). Our observations indicate that straight sills have been more successful than v-notch sills, but the straight sills however do little to scour out large pools which is an objective of sill installation. It has been noted that during high flows there is no 'drop' evident on the downstream side of most straight sills, because the transported gravel accumulates on the downstream and forms a 'ramp'. It is only when the high flow subsides that there is some scouring and the 'drop' returns (J. Desmond, pers.comm., 1997).

Log sills appear to be a tool suitable for preserving a gravel-bed river that is beginning to erode, rather than one for restoring a severely eroded gravel-bed stream. This is particularly true in much of the Nambucca catchment where eroding streambanks allow the sills to be quickly outflanked.

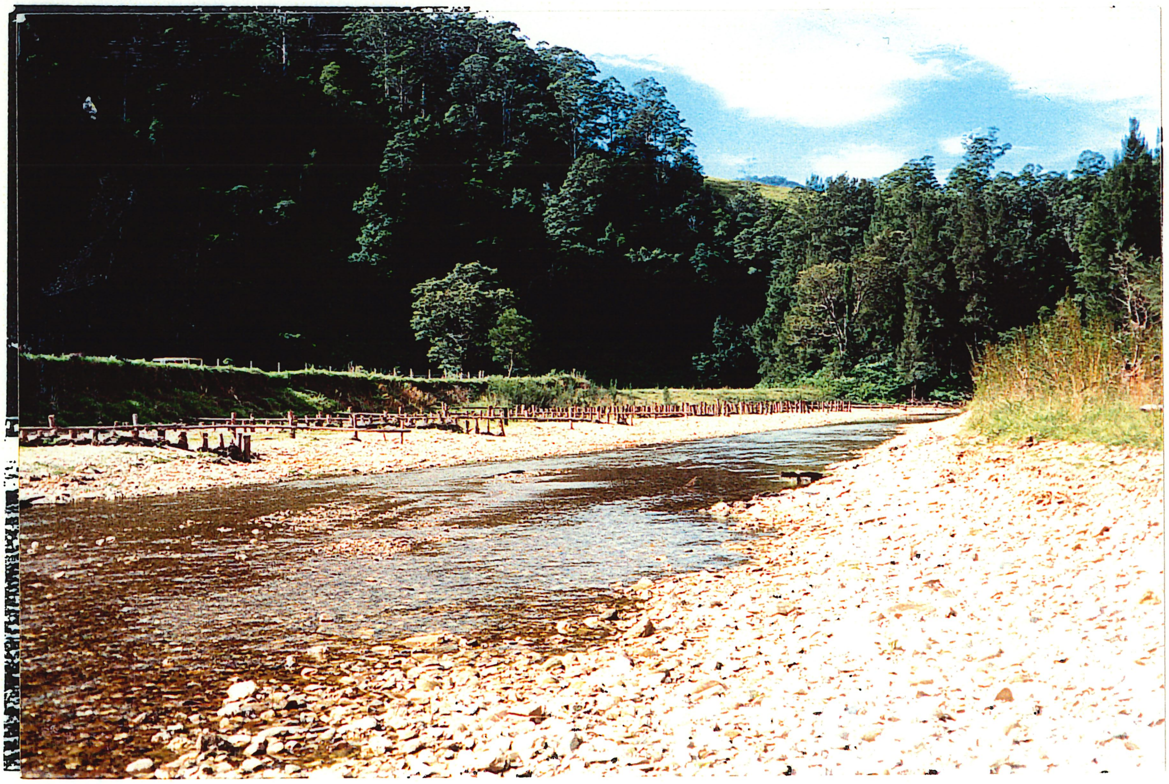
3.3.2 Groynes:

Groynes (or dykes) that extend from the bank to the river at an angle, or perpendicular, to the flow. They serve the following functions (Chang, 1988): (1) training a river along a desired course, (2) creating a region of low velocity to induce siltation, (3) protecting the bank by keeping the flow away, and, (4) contracting an overly wide river channel (Plates 3.6 and 3.7). Types of materials used to construct groynes include (in decreasing order of size and cost) re-enforced concrete, quarried rock, excavated bed material, logs and brush.

In the Nambucca catchment logs and brush have been used in an attempt to control bank erosion where there has been excessive channel widening or lateral migration. Groynes have been successfully used by excavating gravel from the inside of the bend and relocating the gravel to make a bench on the outside of the bend on which groynes are constructed. The effect is to continue deposition on the outside of the bend.

In the construction of pin groynes, logs 5 metres in length were cut from local forests, or from *Casuarina* that has colonised on the inside bend or point bar. These logs were driven into the new bench at least 4.0m in depth and approximately 0.5m apart, with approximately the top 0.5 to 1.0m of the logs remaining above the surface. The groynes look like a row of stakes aligned almost perpendicular to flow (see Plate 4.6). The rows

Plate 3.6: Downstream view of an eroded bank on Taylors Arm (between T2 and T3). (a) (above) In February 1996 before groynes were built, and (b) (below) June 1997 after the groynes were completed.



contain up to 30 logs, with each row space at approximately 15m. Debris is caught in these structures and velocity is decreased close to the bank.

Brush groynes involve fewer log pylons, or alternatively metal posts called 'star pickets' can be used where logs are difficult to obtain or install. The spacing is approximately 5m apart. The spacing is approximately 5m apart. Casuarina branches or stems are placed against the pylons such that they are almost perpendicular to the flow and are tied by wire to each pylon (see Plate 4.7). The spacing between each groyne is generally only 10m compared to 15m with the pin groynes, however as the rows becomes longer, so does their spacing. Brush groynes not only slow down velocities and induce bedload deposition, they also encourage sediment to be deposited from suspension. In both types of groyne system, the spaces between groynes are seeded to encourage tree and shrub growth.

In the Nambucca catchment the groynes have been installed not exactly perpendicular to flow, but are pointed slightly (10°-15°) downstream. This is intended to deflect flow away from the bank. However, there are also views that this method can concentrate flow towards the eroded bank. The theory is that high flows topple over the face of the brush groyne, or surge through the spacings of the pin groynes, toward the bank and cause scour on the downstream side of the groyne. If pointed upstream the 'overflow' would head toward the centre of the channel, much in the same manner as the v-notch log sill directs flow to the centre (I. Rutherford pers.comm.). To overcome bank scour brush groynes are also placed up against the toe of the bank, parallel to flow, to dissipate the erosive power of any flow at this point. Seedlings are also planted in this section to provide further toe protection.

3.2.2a Case Studies:

(1) Operation Sue, Upper North Arm (N2)

On this property a relatively straight reach of Upper North Arm had a low flow channel migrating into an alluvial left bank, undercutting the gravel layer at the base of the profile and causing bank collapse. Due to rapid migration of the thalweg, the right bank has experienced very little deposition, thus resulting in an overwidened channel. In this instance, a large colony of casuarinas on the right bank deflected much of the flow to the left bank and contributed to the erosion of this bank.

In October 1995 a gravel bench was constructed at the base of the left bank along the 130m reach, with 13 brush groynes made from locally felled casuarinas (Plate 3.8). After

Plate 3.7: Brush groynes constructed at Argent's Hill (N3) on North Arm. (a) (above) just after construction in April 1996. (b) (below) after the flood of May 1996.

Plate 3.8: Brush groynes on upper North Arm (upstram of N2) in June 1997. These groynes have survived a number of floods since construction in late 1995.

construction, 4000 seedlings were purchased and planted in November and December of 1995. Two floods in January 1996 caused the three brush groynes at the head of the works to scour, requiring minor repairs. The floods deposited silt between the groynes however and allowed a direct seeding trial to start with the site then being irrigated. The works survived the flood of May 1996 which destroyed the brush groynes at Argent's demonstration site further downstream (Plate 4.7). Casuarinas colonising a point bar on the right bank became a problem as the point bar developed towards the centre of the channel. The result was that the three downstream brush groynes became undercut. After a small works grant, the casuarinas were felled and a continuous brush groyne (30m long) was constructed parallel to the undercut bank (Plate 4.8). In November 1996, 230mm of rain over 24hrs on North Arm resulted in a flash flood. The groynes held up very well, the only damage being the loss of some seedlings. During 1997 ongoing maintenance and monitoring of the works have continued. Regular mowing, fertilising and mulching has resulted in excellent growth rates with many trees on the upper bank now about 1.5m in height. In general the site has proved an excellent example for the care and maintenance required of river works after the initial works are emplaced.

(2) Jacques' Property, Upper Taylors Arm.

The situation in this reach was almost identical to the one described above (see Plate 4.9). In this instance however, the eroded bank face extended 400m downstream and the channel width was over 50m. To remedy the problem, in February 1997 a bench was constructed at the base of the eroded bank using gravel from the point bar on the right bank. Using the method described above, fifteen pin groynes were emplaced on the newly constructed bench in addition to eight jacks and two brush groynes (Figure 3.1).

The works survived a flood in March 1997 (approximately a 1 in 1 year event), with only minor scour occurring around the brush groynes at the head of the reach. The channel maintained its new alignment and the groynes have resulted in a small build-up of gravel and some sand and silt in the embayments between the groynes. While as yet there has been little regrowth, the project is still in its early stage.

3.3.2bThe Interpretations:

As shown by these case studies, pin and brush groynes have been very successful in halting bank erosion along relatively straight reaches in the upper part of the catchment. Continual maintenance is crucial in the success of these structures and after each flood it is

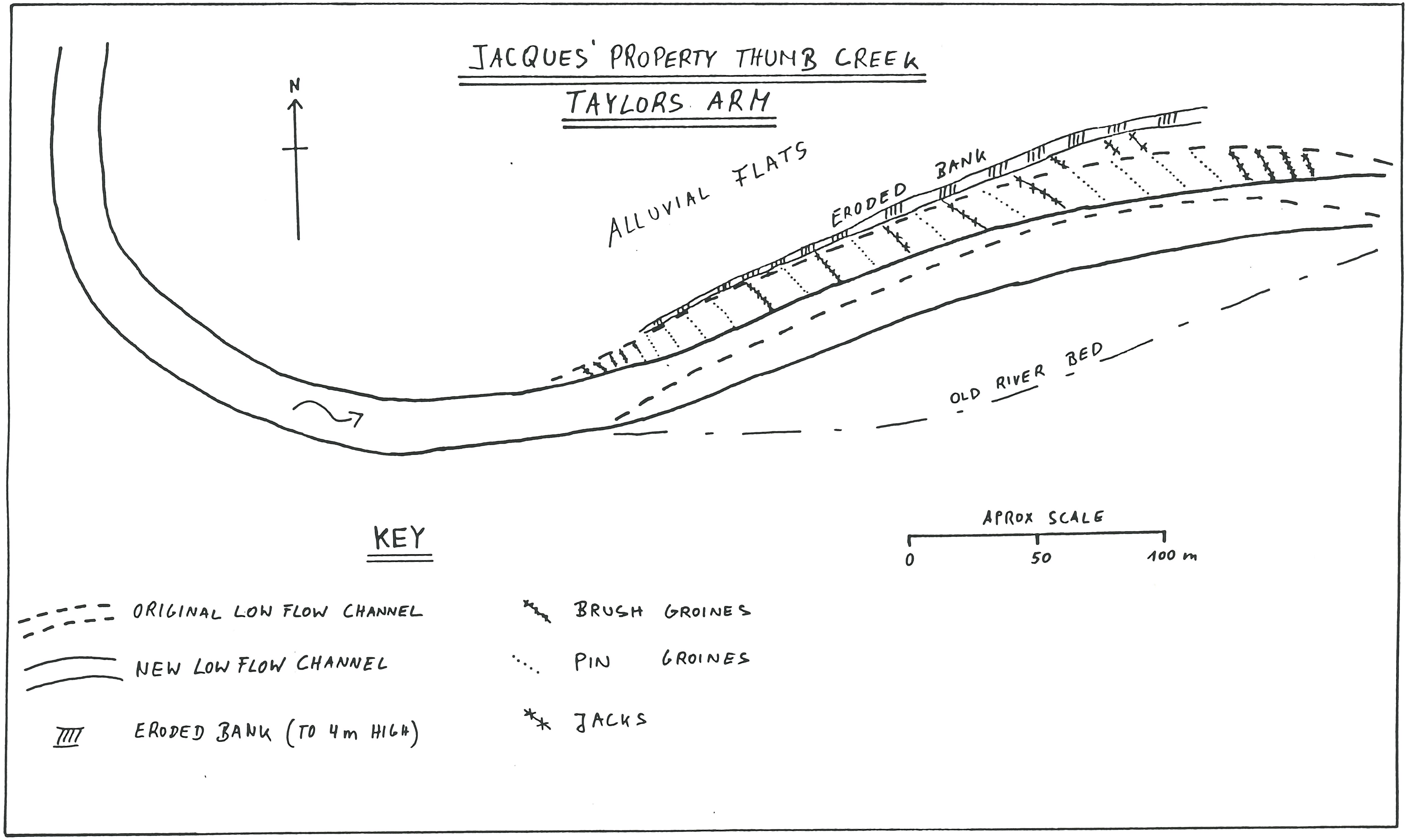


Figure 3.1: Diagrammatic representation of river works on the Jacques' property (reproduced with the permission of Mr & Mrs Jacques)

Plate 3.9: Pin groynes on Taylors Arm (between T2 and T3). (a) (above)Eroding bank in February 1996. (b) (below) after pin groyne constuction in February 1997.

imperative that any repairs required be carried out as soon as possible so that any small problem does not become a major one.

The performance of groynes on the outside of tight bends has not been as successful, particularly in the lower parts of the catchment. An example of this is Doolan's property (just upstream of N7). The alignment of the groynes is crucial and the use of large rocks along the toe of the bank may be necessary to help prevent flow getting in behind the groynes and causing scour. The groynes at the head of the works are, in many ways, the most important as they bear the brunt of the flow; if the flow does not get in behind these there is a much better chance of preventing bank erosion.

3.3.3 Jacks:

Jacks are another form of flow retard designed to catch debris and promote sedimentation at the base of an eroded bank. They are constructed from timber and are often placed on benches made in the same manner as the benches groynes are placed upon. Jacks are made by binding two pieces of wood (approximately 1.5m long) together with wire to form an X-shape. A matching pair is built with the two "X's" being joined by a length of timber in the centre which acts like an axle (see Plate 4.10). The jacks are placed perpendicular to flow and are anchored into position by wire. The wire is tied to a post at each end of jack and the posts are driven into the gravel bench. A series of these structures are placed only a few metres apart in what is known as a 'jacks field' (see Plate 4.11). This configuration allows flow to be slowed and for debris to be trapped. The advantage of these jacks is that they do not fail due to undercutting or outflanking and can move to compensate for a lowering of the bench level. In some instances, another form of jacks have been built by driving three logs into the bench at 5m spacings perpendicular to the flow. A fourth log is attached like a cross-bar (Plates 3.10 and 3.11).

3.3.3a Case Study

Hudson's Property, Upper Taylors Arm (Near T4)

At this site, a straight reach had become overwidened due to flow being deflected from an opposing right hand bedrock wall. A bench was constructed on the left bank by excavating gravel that had filled-in the adjacent pool. An initial field of jacks was placed on the bench in late 1995. Flooding during 1996 saw sedimentation occurring in the jacks field with no further erosion occurring on the left bank. At the end of 1996 deposition had laid down silt, sand and gravel up to the cross-bar on the jacks. An additional field of jacks were

Plate 3.10: Jacks constructed by the Jobskills team at Deep Creek near Valla (upstream of D3). February 1997.

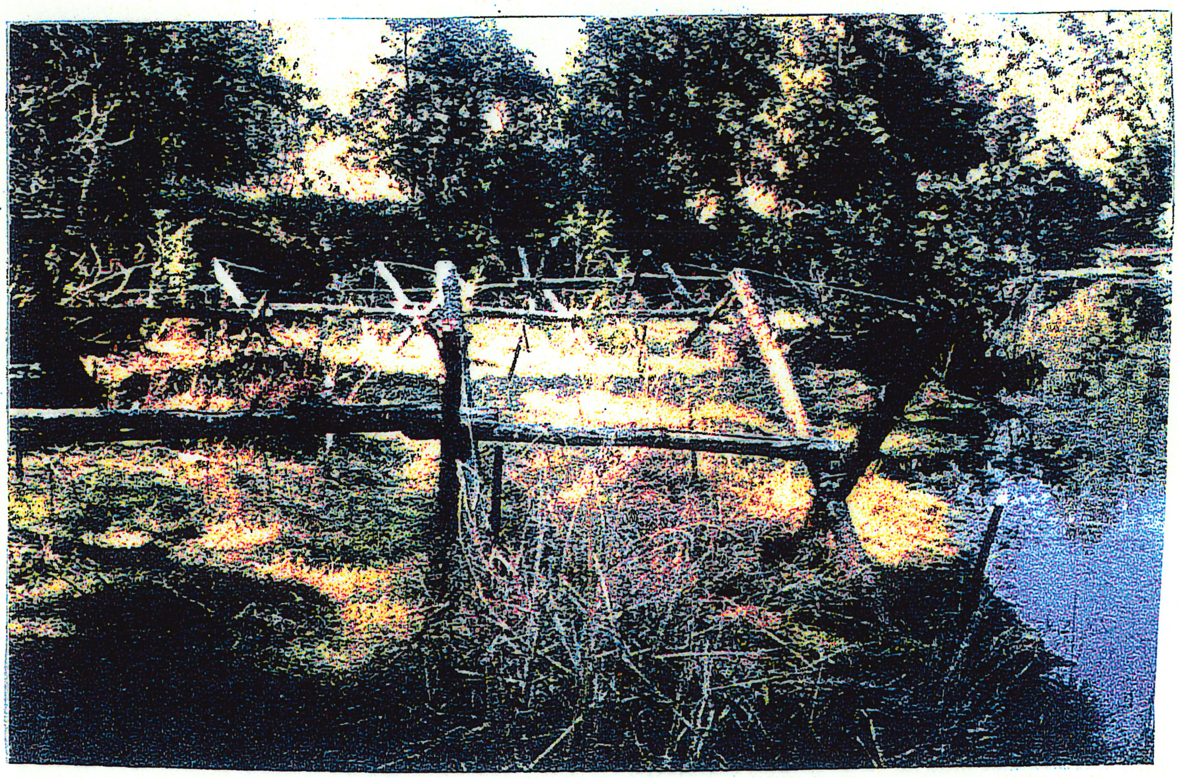


Plate 3.11: Successful jacks field on Taylors Arm downstream of T4. November 1996.

constructed on top of the previous field, allowing the bench to get built higher (see Plate 3.11).

3.3.3b The Interpretation:

Because jacks are designed to trap moving debris and not divert flow or alter flow, they do not pose a threat of causing further bank erosion such as a failed log sill or groyne could. Floodwaters that get behind the jacks fields do not have the same erosive power as, say, flow getting behind brush groynes because jacks do not constrict and alter the flow as much brush groynes do. Although labour intensive with volunteer labour, jacks are an inexpensive way of controlling bank erosion for short lengths of eroded bank (30m). A field of jacks built along an extended section of eroded bank may be too labour intensive, particularly considering the desirability of spacing them closely.

3.3.4 Rock Ramps:

Rock ramps follow the same principles as log sills. Their objective is to dissipate stream energy and to helping maintain or recreate the pool and riffle sequence. A major difference between rock ramps and log sills is that rock ramps impart a gradual fall in the stream bed height over a 30m distance downstream, whereas log sills provide just a single low fall. Designs similar to the one trialed in the Nambucca at Argents Hill on the North Arm have been used in Bavaria, Germany for incised channels with excellent results (see Plate 3.12).

To construct a rock ramp in the Nambucca catchment is relatively expensive, costing approximately $10,000, however, correctly positioned they have a low risk of failing. Rock ramps are best used to control bed levels in laterally stable reaches.

3.3.4 a Case Study:

Argent's Site, North Arm

A rock ramp was placed at Argent's demonstration site in March 1996. It extends over a 30m reach on the downstream side of a long pool with a bedrock wall. The headloss over the 30m is 0.6m which is equivalent to 2 or 3 log sills (DLWC, 1996).

Following the flood of May 1996, which largely destroyed the other works at the demonstration site, the rock ramp remained intact, and it has not been significantly damaged by any subsequent floods. Following its construction, a lengthy pool has formed on the upstream side of the ramp against the bedrock wall. It is envisaged that future

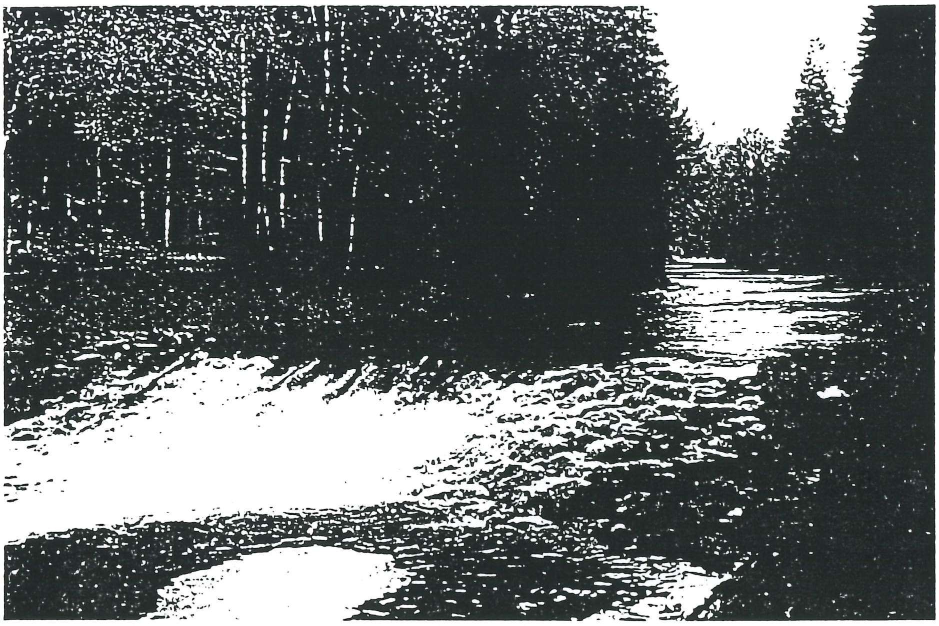


Plate 3.12: An example of the rock ramps used in Bavaria, Germany to control bed levels.

channel contraction along this reach will allow flow concentration within the pool to excavate the pool further. If this does occur then the rock ramp will be able to maintain the bed level at the head of the pool.

The Interpretation:

Rock ramps are an important option for channel rehabilitation, particularly in the middle and downstream reaches of the Nambucca. The potential for creating sufficient headloss to compensate for channel straightening, and the control of bed level that they provide, indicate that rock ramps are probably the best geomorphic option currently being trialed to control gradients and bed levels in the Nambucca. A batter of 20:1 on the downstream face of the ramps provides satisfactory fish ladder and adds to the natural appearance of the structure. As with all of the techniques examined so far, there is a danger that the stream can outflank the ramp. This means that these structures are better suited to controlling bed levels where the channel is laterally stable. The cost of rock ramps is the major limiting factor, and this cost is greater where the channel is very wide. But controlling bed levels in overwidened and laterally active reaches with a low floodplain is not a one-hit solution at all.

3.3.5 Bank revegetation:

The disturbance of riparian vegetation has been probably the most crucial aspect relating to destabilisation of the Nambucca catchment. A detailed examination of vegetation and its role in stream management in the Nambucca has been outlined in Background Report D. A wide and diverse riparian zone is essential not only for the stream ecology, but also to limit or prevent bank erosion and lateral movement of the channels, and to ensure the stability of any bed control works. If bed control structures can be outflanked by a mobile channel, then bed control structures are rendered useless and considerable money is wasted.

Much of the riparian revegetation work carried out in the Nambucca catchment has been carried out by Landcare groups and the Jobskills team. It is well understood by those Landcare groups involved with such projects, that in the first few years before the new vegetation at such sites becomes well established, the vegetation and the site are highly susceptible to flood damage. It should be stressed, however, that severe damage to a project incurred in the early years, does not necessarily mean that revegetation works will *always* fail at that site. It may be that the site was unlucky enough to experience a series of major flows immediately after the revegetation program was initiated.

Amongst the residents of the Nambucca catchment there are conflicting views as to what strategies should be adopted with regards to vegetation. These views range from removing trees and having a straight grassed channels, to a fully-fenced extensively planted riparian zone 60m wide on each side with the channel being left to find its own course within this zone.

It must be said that from a geomorphic perspective revegetation and the management of riparian vegetation are the most important aspects of river rehabilitation facing the Nambucca catchment. It is not just the initial planting that is important but the maintenance in the form of watering, weeding and thinning of vegetation that must be done on a regular basis if such schemes are to have any chance of success, and must continue until the vegetation is self-regenerating. A crucial factor is the management of existing or naturally seeded vegetation, particularly the management of casuarina regrowth. Perseverance and motivation after flood damage in order to work towards a species rich riparian zone must be very high on the list of priorities.

The development of vegetation at the toe of a stabilised bank is very important to build on the success of sills, jacks and groynes for preventing bank erosion. The management of casuarinas involves thinning dense stands of saplings, managing the height of such stands and, the promotion of other species that will eventually replace casuarinas. As a species they play a very important role in colonising and stabilising channel banks and bars, but they need to be managed and the older trees will often need to be removed. Large casuarinas when they fall can tear down otherwise stable banks, and once in the channel their trunks and root systems can deflect flow into otherwise stable sections of bank. The lon term goal is the establishment of riparian zone of mostly rainforest streambank species.

3.4 Other methods used in the Nambucca to control bank erosion

Apart from the approaches mentioned above, a number of other methods of stream management have been employed in the Nambucca catchment to lessen the threat of outside bank erosion. These include:

- Channel realignment
- The construction of tyre walls
- The construction of rock walls
- Gravel extraction from bars

3.4.1 Realignment:

Channel realignment involves the relocation of the channel, generally away from an eroding outside bend. In the Nambucca this process has been carried out by individual land holders often using Landcare grants. A danger with realignment is that the channel is usually shortened in the vicinity of a meander, reversing the process that bend erosion usually achieves. Shortening the channel results in steepening of the gradient, and often causes bed lowering, and increased deposition downstream. An additional problem is that realigning creates newly exposed alluvial sections that are extremely vulnerable to erosion before vegetation has had a chance to re-establish. Two different examples of realignment are used here to show the differences.

The first example (Plates 3.13 and 3.14) shows an area on North Arm (upstream of N4) where the landholder has attempted to realign the channel away from the outside bank, with the potential for severe erosion. The intended new channel was not only much shorter than the original channel, and therefore much steeper, but no new vegetation was established and no other attempt was made to encourage bank stabilisation. Furthermore, the project did not include the relocation of the extracted gravel to fill the old channel. Instead, the gravel was extracted for sale. The project was attempted without permission from DLWC and was halted at the time the photographs were taken.

The second example is from a reach on lower Missabotti Creek (site M4). An outside bend had been eroding into alluvial flats over a number of years prior to 1997 (Plate 3.15). A vegetation choked channel contributed to the problem. After funding was arranged the process of realignment began in April 1997. A new channel was cut through tea trees growing on the channel bed, well away from the cut bank. As a consequence, the new channel had existing vegetation lining both sides, and the extracted gravel was used to fill the old channel. Soil was stripped from a high part of the adjacent floodplain-terrace to cover the gravel fill and encourage vegetation growth. Pin groynes were also placed on the fill in the old channel and extended up onto the battered lower slope of the cutbank to slow down flow that will inevitably follow the path of the old channel. The works, as they appeared in June 1997, can be seen in Plate 3.16.

The precautions taken, with the realignment work in the second example by no means indicates that this will be successful. As there were no rock ramps or other such structures to compensate for the shortened length and steeper gradient of river, future floods could

Plate 3.13: Channel realignment on North Arm (downstream of N4) in 1995.

Plate 3.14: View of the gravel extracted from the channel realignment on North Arm in 1995.

Plate 3.15: Upstream view of an eroded bank on Missabotti Creek (M4). (a) (above) Prior to relignment works in November 1996. (b) (below) after realignment work in June 1997.

Plate 3.16: Upstream view of an eroded bank on Missabotti Creek (M4). (a) (above) Prior to relignment works in November 1996. (b) (below) after realignment work in April 1997.

disturb the bed level and undermine the gravel banks that the ti tree community flanking the new channel is perched on. However, this site does represent a better attempt to anticipate problems and it will be interesting to monitor its success.

Realignment, even when all the necessary precautions are taken, is a risky practice. Such projects elsewhere in Australia and overseas often require massive budgets, for sometimes they involve concrete or rock structures to compensate for the changes in slope and width. When 'softer' engineering approaches are used, such as in the Nambucca, there is no guarantee that the work will survive future floods over substantially steeper gradients. It is recommended that any future realignment works also involve bed-control structures, such as rock ramps, to compensate for any associated loss in stream length and increase in gradient.

3.4.2 The construction of tyres walls:

The use of tyre walls to provide increased bank protection is a method of erosion control that has been practised for some time in the tidal reaches of the catchment near Macksville. This practice has only been tried experimentally in the non-tidal reaches. Tyre walls were trialed on a section of Missabotti Creek between study sites M2 and M3 (Plate 3.17).

A tyre wall was constructed entirely by the landholder, without financial or government assistance, along two 30m lengths up- and downstream of a vehicle crossing. This reach is relatively straight but was undergoing channel expansion. The reason for this expansion appears to be due to two meander cut-offs that occurred between 1942 and 1991 between sites M2 and M3 (Background Report E). A 0.5-1.0m deep trench was dug along the bank face and wooden pylons were driven one metre beyond the base of the trench. Tyres were then dropped over each pylon, with the bottom two tyres placed below the low water mark in the trench. As each tyre was positioned, it was filled with gravel to weigh it down. It was then tied by wire to the tyre below. Each pylon contained 6-8 tyres with only the top 3 tyres above the ground surface. The pylon spacing allowed each column of tyres to be in contact with the next column to prevent breaching of the wall.

The tyre wall survived several minor floods over a period of twelve months with only minor repairs being needed. During this time there was no further bank retreat. However, the November 1996 flood resulted in flow getting in behind the wall on the upstream side of the vehicle crossing. Scour around the pylons led to the failure of the tyre wall (Plate 3.18) with the majority of tyres washing downstream. The downstream tyre wall has

Plate 3.17: Tyre wall on Missabotti Creek (M3). The wall survived the floods of May 1996.

Plate 3.18: View of the faied tyre wall at M3 one year later in June 1997.

remained intact but requires constant repairs as flow has scoured behind it. After each flood gravel is bulldozed behind the wall but invariably is eroded out during the next flood.

Further to the problems experienced in this case study, there have been concerns expressed by some residents that the tyres emit harmful toxins into the water as they break down, however, this study is not dealing with matters of water quality relating to chemical residues.

3.4.2 The construction of rock walls:

Rock walls are used to protect the material at the toe of a stream bank from erosion. Their design is simple yet expensive. Large boulders are placed in a line at the toe of an eroding bank (Plate 3.19). The line of boulders is not moved by high flows and consequently the toe is protected from further erosion. Problems arise however if flow scours behind the rock wall. Unlike jacks or groynes, rock walls are not designed to reduce direct erosion of the outer banks by trapping debris or inducing sedimentation. They are usually built to halt erosion rather than to rehabilitate the channel. Their use in the Nambucca could be in conjunction with other methods of rehabilitation, rather than a solitary form of erosion control.

3.3.4 Gravel extraction from bars:

The issue of gravel extraction is one of the most controversial issues in the catchment. Debate exists between residents themselves, and between residents and the DLWC over the effect of gravel extraction, the necessity of gravel extraction and the volume of gravel to be removed. Until the mid-1980's records of the amount of gravel extracted were so poor that estimates could not be made with any confidence. Department of Land and Water Conservation (1995) estimated that the amount of gravel extracted pre-1992 was in the order of 120 000m^3 annually, whilst the 1994 amount was in the order of 50 000m^3. Resource Planning (1989) estimated that 20 000-30 000m^3 per annum was extracted by private contractors annually. Official records from the Bureau of Mineral Resources from 1987-1993 indicate that an average of 95 444m^3 was extracted per annum in this period. These figures of course do not include any unofficial extraction of gravel. A survey of residents has shown that gravel extraction on North Arm and Missabotti Creek has been occurring since the end of World War 1 at least, with the periods 1970-1974 and 1989-1994 noted by many of those surveyed as periods when gravel was extracted from their properties.

Plate 3.19: Rock wall on Missabotti Creek (between M2 and M3). June 1997.

There remains strong support by many local residents for the continual removal of gravel from point bars within the catchment. Examples of point bars landholders would like to see removed to reduce the deflection of flow onto the outside of bends can be seen in Plates 3.20 and 3.21. The practice of completely extracting point-bars and selling the gravel has been stopped in recent years. Nowadays there is a trend to relocate the gravel from the point bar to form a bench at the toe of the eroding bank; jacks and groynes are commonly placed at the base of the eroding bank. Gravel is only extracted from point bars in a small number of cases, and then only at the discretion of DLWC.

The decision to place a halt on gravel extraction has upset some residents. They are concerned the system has an oversupply of gravel. However, bed incision, bank erosion, and a drop in the water table can give the appearance of channel with excess gravel accumulation. However, while gravel is more obvious along the channel, there undoubtedly has been a real increase in gravel loads. Because sinuosity has decreased (channels have straightened), this means a shorter length of river must support at least the same amount of gravel in transport. Furthermore, channel straightening involves bank erosion and the release of additional floodplain gravel into the system.

A 1994 Draft Plan of Management (DLWC 1994) endorsed gravel extraction in areas where there is no evidence of overall channel enlargement, and in these areas it was recommended that gravel be extracted only above low water flow level.

Almost all of the reports on gravel extraction for the Nambucca catchment are exclusively for North Arm and Missabotti Creek (eg. Department of Water Resources, 1994; Thoms, 1994; Resource Planning, 1989). These two streams have not only the most sought after gravel type (rounded quartz) in the catchment, but they are also the most severely eroded streams. Resource Planning (1989) stated that there were over 20 sites on North Arm and Missabotti Ck that either had permits or were potential sites for gravel extraction.

The Department of Water Resources (1990) emphasised the need to endorse extraction at sustainable levels. Reviews by residents groups pointed out the uncertainty of attempting to ascertain what sustainable levels are. Whilst sustainable yields are a logical concept for clearly renewable resources such as vegetation, there is confusion and uncertainty as to how a sustainable gravel yield can be determined given the very limited natural supply of bedload and the inappropriateness of using bedload equations to calculate bedload yields on many NSW coastal rivers (Hean and Nanson 1987). While bedload equations can

Plate 3.20: Extensive point bar looking upstream on North Arm (N4) in July 1996. Many residents want this type of gravel accumulation removed to ease pressure on the outside bank.

Plate 3.21: Extensive point bar looking upstream on Taylors Arm (T5). July 1996.

sometimes be used effectively in disturbed reaches of river where gravel is presently mobile (Background Report C), they will not provide evidence of sustained longterm trends.

With the exception of the Nambucca catchment, the prevention of gravel extraction along non-tidal coastal rivers in NSW underlines the growing realisation among stream managers of its harmful effects and the lack of certainty as to what actual bedload replenishment rates are. Evidence from Australia and overseas continues to cast serious doubt over the wisdom of gravel extraction.

In the Mendocino County of California, USA, a management plan recommending extraction of 50% of the natural replenishment rate on the Garcia River was reviewed by leading scientists in the field.

Prof. Jeffrey Mount of the University of California Los Angeles stated:

> "I know of no credible evidence which demonstrates that bar skimming produces positive water quality or wildlife impacts, even in areas where logging practices lead to high sediment yields and channel aggradation. First, bar skimming homogenises the cross-section and profile of a river, leading to reduced habitat diversity which, in turn, translates to declines in overall habitat quality. Second, bar skimming often leads to increases in accumulation of fines. Third, bar skimming removes the coarse surface layer, or "pavement" of a river. By controlling erosion of the bed, the pavement tends to regulate the rate at which sediment is transported through a river. When this pavement is removed or disturbed it can lead to local increases in erosion, and downstream increases in sedimentation of both coarse and fine material." - Mount (1996, p.1)

Dr. G. Mathias Kondolf of the Department of Geomorphology, Hydrology and Water Resources, UCLA, Berkeley comments:

> " The suggested harvest of 50% of the replenishment rate is in general a reasonable approach, provided the replenishment is derived from erosion in the catchment upstream. However, there is considerable evidence that much of the so-called replenishment in the river is derived from bank erosion in the downstream alluvial reaches. To mine gravel derived from bank erosion is robbing Peter to pay Paul, unless what appears to be accelerated bank erosion is addressed and, unless the environmental impacts of such a transfer of sediment from floodplain to channel bar are fully evaluated and mitigated." - Kondolf (1996, p.1)

These studies raise concern as to the long-term geomorphic effects of gravel extraction, particularly if the gravel entering the system is derived from floodplain or bank erosion. Without relating extraction rates to true rates of replenishment (Nanson and Hean, 1987) the widespread and unrestricted extraction of gravel from point bars could cause serious problems of channel stability.

3.5 Residents' Opinions

In July 1996, a survey was sent to residents living on stream frontage in the Nambucca catchment. The object of the survey was to canvass community opinion on the state of the channels, the history of change, the effects of different practices and, suggestions of possible solutions for the channel degradation problems. A total of 130 surveys were sent out and 51 were completed and returned. The breakdown by sub-catchment was:

Taylors Arm	17
North Arm	12
Missabotti Creek	8
South Arm	3
Buckra Bendinni Creek	6
Deep Creek	2
Warrel Creek	3
	51

The information was assessed by the study team to provide anecdotal evidence to supplement the scientific evidence obtained. From the study team's perspective it was perceived as important not only to gather collective views on stream change and causes of degradation, but to also establish what the landholders see as the main problems and possible solutions to the channel degradation problems.

The surveys revealed a myriad of conflicting views in relation to possible causes of channel degradation and suggested remedies. However, a recurring theme was dissatisfaction with the Department of Land and Water Conservation (DLWC). Most residents believed that the Department did too little in the catchment, and the small amount of work they did, or allowed to be done, lacked judgement and common sense. The lengthy bureaucratic process of referring all projects to head office has, in the eyes of the residents, allowed small problems to become large ones. Continual staff changes, delays in recruiting personnel and, an overwhelming backlog of work for the rivercare officers has continually frustrated the residents. In addition to this, frustration was expressed in relation to the changing views and attitudes of the Department in the last decade towards tree felling, gravel extraction and methods of rehabilitation. The overall picture is that there is an overwhelming lack of faith in the government system of river management.

Despite the conflicting views of pastoralists and environmentalists within the catchment, there were some questions in the survey which returned fairly uniform responses:

- Only 14% thought that all gravel extraction was completely unnecessary
- Only 6% thought that farming practices prior to 1950 had a positive effect on the streams
- Only 2% thought farming practices since 1950 have had a positive effect on the streams
- Only 12% thought that floodplain gravel extraction was positive for the channels
- Only 6% thought Landcare has had a negative effect on the catchment
- Only 21% and 13% were against the installation of log sills and groynes, respectively
- Only 6% thought that cattle trampling was good for the streams
- Only 24% of the residents were happy with the state of the stream where they lived

Some of the more contentious issues where the percentage of supporters for and against were very even included;

- The merits of point bar gravel extraction
- The issue of casuarinas
- Views on de-snagging

A summary of the results from the survey and a selection of the replies from the residents with regards to causes and remedies of channel instability are presented in Tables 3.1 to 3.3.

Below is a selection of some of the questions put to the residents and the overall results:

Table 3.1 : Results of the residents surveys

Are you happy with the state of the channel which runs through your property ?
24% YES
66% NO
10% NO COMMENT

Have any river works been carried out on your property ?
64% YES
36% NO

For those who have had works, were the works successful ?
59% YES
41% NO

Do you think gravel extraction is a necessary part of maintaining the channel ?
53% DEFINITELY
24% YES, WITH MAJOR RESTRICTIONS
14% NO
9% UNSURE

Do you think that a lack of riparian vegetation is a major problem in need of repair ?
45% YES
18% ONLY IN SOME AREAS
29% NO
8% UNSURE

Did farming practices prior to 1950 have a positive affect on the channels ?
6% YES
65% NO
29% NO EFFECT/ UNSURE

Have farming practices since 1950 had a positive effect on the channels ?
2% YES
60% NO
38% NO EFFECT/ UNSURE

Does cattle trampling have a positive effect on the channels ?
6% YES
65% NO
29% NO EFFECT/ UNSURE

Does gravel extraction on point bars have a positive effect on the channels?
38% YES
34% NO
28% NO EFFECT/ UNSURE

Does gravel extraction within the channel have a positive effect on the channels ?
25% YES
42% NO
33% NO EFFECT/ UNSURE

Does gravel extraction from the floodplains have a positive effect on the channels ?
12% YES
44% NO
44% NO EFFECT/ UNSURE

Do casuarina (or She-Oak) trees have a positive affect on the channels ?
35% YES
44% NO
21% NO EFFECT/ UNSURE

Do willow trees have a positive effect on the channels ?
60% YES
27% NO
13% NO EFFECT/ UNSURE

Does the Landcare scheme have a positive effect on the channels ?
65% YES
6% NO
29% NO EFFECT/ UNSURE

Do log sills have a positive effect on the channels ?
48% YES
21% NO
31% NO EFFECT/ UNSURE

Do groynes have a positive effect on the channels ?
52% YES
13% NO
35% NO EFFECT/ UNSURE

Does de-snagging (eg. Red Scheme in the 1970's) have a positive effect on the channels ?
33% YES
40% NO
27% NO EFFECT/ UNSURE

Do present forestry practices have a positive effect on the channels ?
17% YES
50% NO
33% NO EFFECT/ UNSURE

Table 3.2: Practices that the residents do not agree with
(•• denotes point made in many responses)

- •• Illegal extraction by landholders
- •• Cattle in water supply
- •• Vegetation clearing on banks
- •• Too much bureaucratic bungling and 'red tape'
- •• The frustration of landholders when their initiatives are held up by DLWC paper work
- •• 'Band-aid' approaches to large 'wounds'
- •• Logging and forestry in steep upper catchment is a major problem
- •• Self funding (from gravel extraction) Landcare results in no accountability, no records, no planning and no maintenance
- •• The opinion of DLWC who believe doing nothing is best. This has lead to small problems becoming large and too expensive to fix
- •• Far too much notice is taken to people who do not make a living off the land
- •• DLWC have no respect for the landholders or their accumulated knowledge
- •• Nambucca council removing gravel from sites and not being accountable
- • Projects at present not assessed and prioritised in regard to future impacts
- • Continual DLWC staff changes
- • Belief that mass tree planting is a solution
- • Tyres in the river are flushed downstream and their chemical breakdown is extremely harmful
- • Political agendas and factions within some Landcare groups
- • Landcare is a waste of resources in the Nambucca
- • Land holders sit and wait for someone else to fix a problem that are too naive to realise that they have caused
- • Uninformed or unpermitted works which; dig out swimming holes, create river crossings and remove vegetation
- • Farmers forming a Landcare group to extract gravel
- • Use of employment schemes to plant willows with no follow-up to remove them once natives begin to establish
- • River migration is our problem not degradation or bed lowering
- • Maybe nothing can be done but we shouldn't be stopped from trying
- • Battering of banks has lead to a wide shallow channel
- • Mining of the river flats should not occur whilst the channels are so unstable
- • Using tyres, concrete and excavators to instead of 'softer' options involving naturally occurring materials
- • Unskilled or uneducated operators using heavy machinery in the stream
- • Massive amounts of money wasted by Landcare planting trees unsuitable to the area such as frost intolerant rainforest species
- • The perception by some that the river is a drain
- • Irrigators who pump massive amounts of water especially in the dry season
- • Too many farmers are way behind in their thinking despite growing evidence on the effects of bank clearing and mass gravel extraction

Table 3.3: Residents proposed solutions

(•• denotes point made in many responses)

- •• Large scale below water-line extraction at all sites of previous deep pondage
- •• Attending to new sites of bank erosion immediately to stop gravel entering the system
- •• Fencing off the river from stock
- •• Use of sills, jacks and groynes as sediment traps
- •• A holistic approach to each stream rather than the piecemeal basis reliant on the co-operative landholders
- •• Clean the watercourse of unwanted vegetation and gravel
- •• Let the river turn on rock banks and not the river flats
- •• Mass planting of tree and shrubs
- •• Use gravel extraction to pay for works with the royalties going towards the maintenance of the works
- •• Cease all gravel extraction save for 'one-off' removal of gravel slugs
- •• Only practical solution is to extract gravel to pay for further restoration and vegetation control
- •• DLWC field officers should be able to give on the spot written approval for urgent preventative works such as felling undercut trees or snag removal. The current referral to head office has lead to landholders being anti the system
- •• Get rid of 95% of DLWC and bring back common sense not book educated fools
- •• All DLWC orders should be given in writing and they should pay compensation if the plan fails, just as they threaten landowners in their documents. If this were the case in the past they would owe millions
- •• Change priorities to minor problems so they do not become major. Treating the big problem areas rarely succeeds and in the meantime the smaller problems become large
- •• Use of log sills to limit stream bed lowering and brush groynes to stabilise the river
- • Battering down banks
- • Close liaison between DLWC and DEET workers to extend the work initiated by the Landcare groups
- • Get the environmentalists and pastoralists in Bowraville to learn to live together as they do in Taylors Arm
- • Clear timber out of the river
- • Strategic removal of gravel from former deep holes in conjunction with log sills and vegetation
- • Removal of gravel islands
- • Use large rocks to halt erosion once a minor episode begins
- • A supervisor must be appointed for each sub-catchment to allow jobs to be done without such long delays
- • Education in the schools so that kids don't inherit the misguided attitudes of their parents
- • Publicity and education to dispel urban myths on the benefits of gravel extraction
- • Don't change the course of the river
- • A raising of the stream level would assist
- • Need to fix problems in the upper reaches and then work downstream
- • Remove oak trees from the banks and stop water being diverted into the banks
- • All fencing-off and revegetation should be totally funded
- • Farmers should be convinced that losing a little land to revegetation is better than losing a lot to erosion
- • Remove camphor laurel and privet
- • Forget about worrying about fish access until the chain of water holes is restored
- • Management plans should be made by well informed people from outside the catchment with no vested interests
- • No weirs or dams
- • Start at the top of the catchment with stricter controls on logging

4 Geomorphic factors important for stream management

Background Reports D & E provided a lot of information important for future stream management. This type of information must be taken into consideration when management plans are devised and carried out. Background Report E categorised various reaches into groups based on the extent of channel degradation (Figure 4.1). The streams are in these varying states of degradation for a number of reasons. A summation of the findings of Background Report E that are important to stream management in the Nambucca catchment can be found below:

4.1 Stability Prior to European Settlement:

Radiocarbon dates from the Nambucca floodplains indicate that channel migration and lateral floodplain reworking took place 2500-1800yrs BP. From this time until the arrival of Europeans the channels and floodplains were very stable with any changes during this period primarily due to channel avulsion. By comparison to today's system the channels were sinuous with wet sclerophyll and rainforest vegetation on the floodplains and banks ensuring bank stability and a source of LWD to retard velocities, maintain bed levels and retain pools and riffles. The above well forested conditions acted to slow floodwaters and allow vertical accretion to take place on the floodplains.

4.2 Effects of initial European occupation:

Vegetation clearance began in the 1860s, but much of the selection and clearing of land upstream of the tidal limits took place between the 1870s and 1890s. The initial effects of settlement were the clearance of bank and floodplain vegetation followed by the more gradual decay and removal of LWD in the channels. These effects would have lead to increased run-off, a reduction of in-stream roughness, and the mobilisation of bed material. A clustering of flood events in the 1890s, following as it did closely on the heels of initial clearance, was probably the major trigger for channel change. As the population of the district increased, so too did the use of the river and its floodplains. However, a lack of large floods from 1900 until the 1940s meant that the partially altered channel system did not completely degenerate into its present form. However, the 1942 photos show that the floods in the first half of the twentieth century were still sufficient to cause and maintain a degree of channel expansion, probably exacerbated by the on going removal of LWD and bank vegetation, dredging of the navigable lower reaches, gravel extraction in the middle reaches and artificial channel straightening.

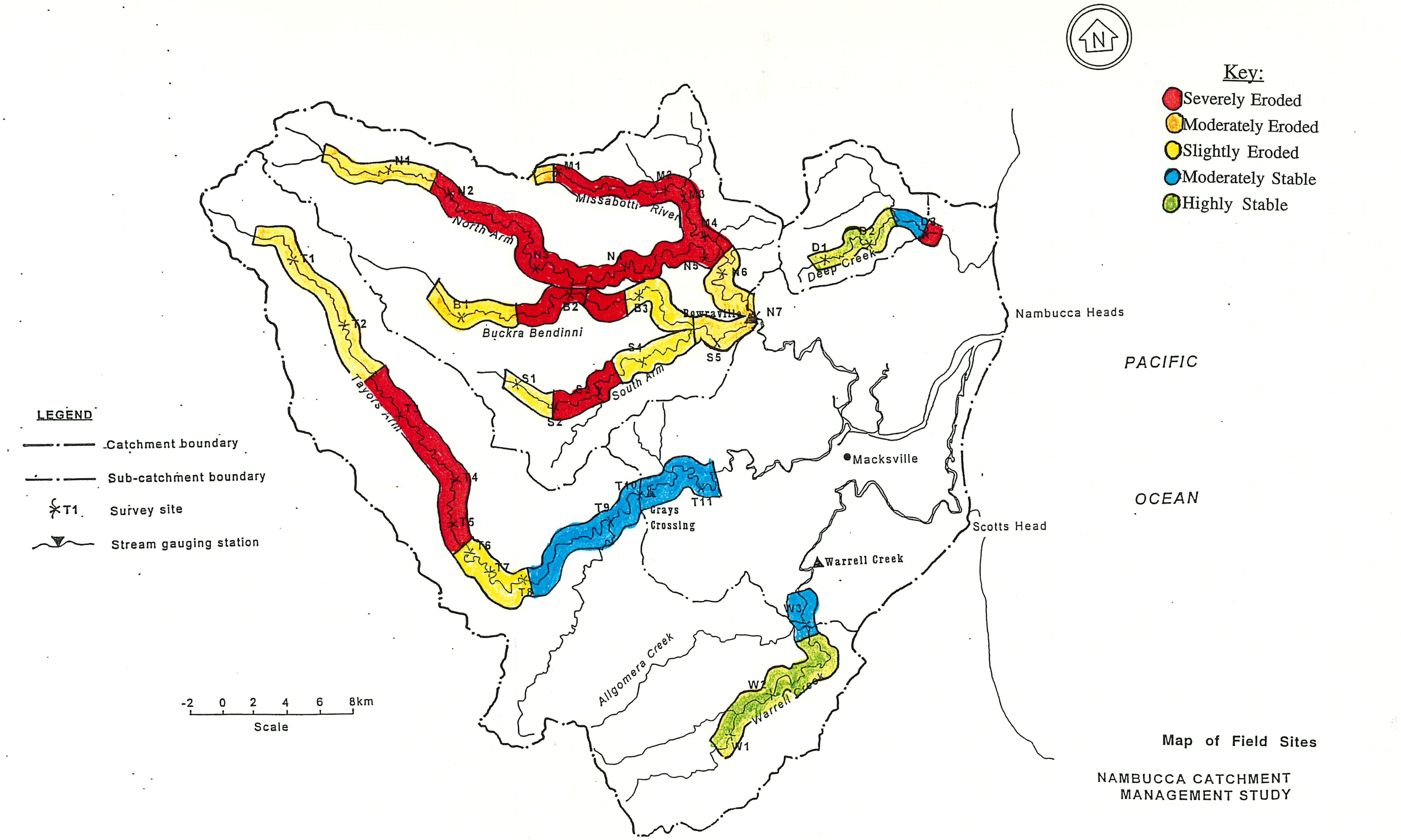


Figure 4.1: Comparitive states of degradation of the reaches of the Nambucca Catchment.

4.3 Catastrophic change in the 1950's:

Another series of large floods during the 1940s and 1950s triggered a second period of major erosion and channel expansion in the catchment. Contrary to some local opinions, the channels were already degraded prior to 1950, but not as severely as at present. The series of floods in the mid-century were noteworthy not only for the duration of the floods, which saturate the banks and floodplains to a level where further high velocity flow can cause mass failure, but also because anecdotal evidence suggests that 'flood waves' were responsible for much of the damage. This was particularly true for the June 1950 flood. Subsequent removal of the gravel bars by landholders and the lack of a replacement source of woody debris being eroded or otherwise removed from the system, contributed to the continuation of stream degradation. From resident surveys and discussions with landholders, the series of floods in the early 1960's (four of the largest floods on record in only two years) worsened stream conditions, as did floods in 1989-1990.

4.4 Erosion resistance of Deep Creek and Warrel Creek:

A lack of gravel available from stored floodplain banks has been instrumental in the preservation of upper and middle Deep Creek and all of Warrel Creek. Auger hole data indicates that there is no gravel down to the present water table at the channel margins. The riparian zone appears to have been densely vegetated throughout the post European history along most of the streams in these valleys, an important factor in their preservation. Lower Deep Creek has begun to erode though due to bed lowering which has exposed gravels at the base of the river terraces and is adding gravel to the channel. A similar fate could await Warrel Creek if the channel was allowed to incise below the current water table where stored gravel may also be present. However, before expensive remedial works are undertaken, the banks of Warrel Creek should be drilled to determine if erodible gravels are present.

4.5 Erosion in the middle non-tidal reaches:

The middle reaches of the non-tidal streams of the Nambucca catchment are the most degraded (eg. T3-T5, N2-N5, M1-M4, B2, S3). A combination of factors has lead to this situation. Gravel small enough to be readily entrained, and gradients steep enough to implement such transport, has probably always made the middle reaches more active and prone to geomorphic change. The floodplains are at their widest in these reaches and the stratigraphy displays fluvially derived gravels commonly encompassing the entire width of the floodplain. In recent times decreasing sinuosity has led the channels to straighten, flowing from one valley side to another in a direct line. Because of the decreased sinuosity and reduced in-stream roughness, gravels are entrained from the toe of the banks by velocities higher than previously experienced. Floodwaters become confined to the enlarged channels, thereby concentrating erosional energy.

4.6 Causes of bed lowering:

Extensive bed lowering in the Nambucca is the result of a number of contributing factors. The loss of LWD from initial channel clearance would have probably been the first major factor. Dredging of the lower reaches for navigation up to Bowraville could also have caused nickpoint retreat. This particularly explains the head cut that retreated up South Arm evident in and prior to the 1942 air photos. In more recent times bed lowering has continued due to meander cut-offs (human induced or otherwise) and gravel extraction from the channel bed. Once the channels start to enlarge, they retain higher, more erosive, discharges and erosion worsens. Numerous smaller tributaries are currently experiencing nickpoint retreat in response to base level lowering of the trunk channel. These tributaries are often located in the upper reaches which gives an indication of the extent to which bed lowering has occurred.

4.7 Sources of gravel influx:

Fieldwork has indicated that the sources of excess gravel in the channel are channel widening and bed lowering. Gravel is not being re-worked from the headwaters, for on inspection these are seen to be quite stable and are not providing significant amounts of coarse sediment to the lower reaches. This is particularly evident at the top of Missabotti Creek where there is a large store of gravel in the floodplain, considerably finer and more readily transported than the stored gravel found in the headwaters of the other tributaries. Despite this, the headwaters of Missabotti Creek are essentially stable, as revealed by the stability of the scour pits in the uppermost reaches. The danger of erosion in these reaches does not come from upstream, but from nickpoints that work their way headwards from downstream. These nickpoints cause bed lowering and expose the gravels in the base of the floodplains, causing the banks to collapse and the floodplains to erode. Evidence for the in-stream gravel coming from the eroded floodplain is the similarity in gravel size between the current bedload and adjacent floodplain deposits.

4.8 Loss of pools:

Initially, the loss of pools in the Nambucca arose due to riffle erosion at the downstream ends of pools. By a combination of nickpoint retreat and the loss of LWD the pools began to infill, resulting in a more uniform bed profile. The pools then ceased to be zones of energy dissipation. Increased velocities resulting from a loss of LWD, the loss of pools and riffles and reduced channel sinuosities, caused bank erosion and overwidening. Once a pool has become overwidened there is insufficient concentration of stream flow energy to maintain the depth of the pool, and it disappears

4.9 Role of vegetation:

Since 1941 there has been an increase in the extent of riparian vegetation, primarily river oaks, in the Nambucca catchment. Much of this increase has occurred at the same time as dramatic increases in channel instability, leading many to assume a causal relationship. However, river oaks and other riparian species, have not caused the instability within the streams of the Nambucca catchment. River oaks are a primary colonising species whose preferred habitat is newly exposed gravel bars. The expansion in the extent of river oaks is largely a response to the channel instability which has resulted in an enormous increase in habitat suitable for such a species. In channels subjected to major bed lowering associated with nickpoint retreat, bank erosion and channel widening, the formation of extensive bars is an inevitable consequence. Whilst in some places it appears that this species has exacerbated bank erosion by causing flow diversion, they are not themselves responsible for bed degradation - the major cause of accelerated stream erosion. Few riparian species are able to withstand the degree of channel erosion experienced along the Nambucca streams because their root systems are inevitably undermined. Some species will submit before others, but nearly all will go eventually. When substantial bed degradation occurs, the channel will adjust with much larger dimensions whether the boundary is grass or fully forested floodplain. The geomorphic difference between the two extremes of a fully grassed and an extensively forested riparian zone is in the recovery process after the bed degradation has occurred. Under the forested scenario the channel will gradually acquire LWD again and may form islands and benches. Locally this may cause bank scour, which in turn may lead to increased sinuosity, but this is a necessary part of channel recovery following such instability. The introduction over time of a large volume of LWD imposes a negative feedback on the system, aiding bed stabilisation and aggradation, reducing flow velocities, reducing bedload transport, reducing bank erosion and leading to re-stabilisation of the fluvial system.

5 Observations and Recommendations

5.1 Important facts and observations for the rehabilitation of the channels in the Nambucca Catchment.

The contemporary channels of the Nambucca catchment are far removed in form and process from those that existed prior to European disturbance. They are clearly not in balance with the alluvial floodplains they once formed. A situation now exists where channel erosive processes are grossly out of phase with the floodplain alluvium's ability to resist these processes. The long term objective must be to reduce channel sizes and thereby increase the proportion of large flood discharges that are routed across the floodplains. Without converting the channels at great expense into environmentally-alienated reinforced "drains" of present size or greater, it will not be possible to have both flood-free floodplains and stable channels. The process of an environmentally acceptable form of channel-size reduction will entail strengthening and stabilising the stream banks and immediately adjacent floodplains with riparian vegetation. Furthermore, bed stabilisation will be essential in the success of bank stabilisation.

Outlined below are specific facts, observations and consequent interpretions that must be appreciated in order to develop workable rehabilitation policies for the catchment.

5.1.1 Geomorphic Facts

• *Streams were degraded before 1950*

There must be a realisation that, despite anecdotal evidence to the contrary, the streams of the Nambucca were already severely degraded prior to 1950. Bed lowering and meander cut-offs are evident in the 1942 air photos despite long time residents claiming that not to be the case. The clustering of floods from 1949-1955 catastrophically changed the channels because they were already very unstable.

• *Influx of gravel derived from bank erosion*

The bulk of gravel entering the channel is derived from the stream banks, and hence from adjacent floodplains. A leading U.S. river scientist has stated: "...extracting gravel derived from bank erosion is like robbing Peter to pay Paul." (Kondolf, 1996). The channel will adjust by 'extracting' more gravel from the floodplains. Channel overwidening, bed lowering and the erosion of sand and silt has left the visual impression that the streams are 'choked' with gravel. In fact, the loss of such gravels is, in part, contributing to the existing problems.

• *Forestry not a 'major' cause of stream erosion*

Despite concern from many residents, forestry is not a major cause of bed and bank erosion in the alluvial reaches. Unquestionably, forestry can increase water discharge and siltation, and reduce water quality, particularly in the smaller headwater streams, but the removal of channel and floodplain vegetation is a much more serious problem for the alluvial reaches of channel below the forested areas of the Nambucca catchment. There is also no evidence that forestry practices over the past several decades have influenced a serious oversupply of gravel in the middle and lower reaches of the catchment.

• *The importance of bed material size*

Downstream reductions in sediment size help explain the locations of erosion within the catchment. In the upper catchment the large phyllite bed material is often too large for active transport despite steep gradients. In the middle reaches, the gradient has decreased but the size of the bed material has undergone a very large reduction (eg. T2-T3), so much so that even at a reduced slope, the quartz dominated bedload has the potential to be readily transported. In the lower reaches of the non-tidal streams, slope reduces even further, yet bed material size does not change very much from the middle reaches. This means that there is relatively little transport in the lower reaches. Bed material transport estimations indicate that on average, relatively little sediment is being moved from one reach to another. For example on Missabotti Creek, North Arm and Taylors Arm, bedload equations from Background Report C indicate that there is very little sediment transported annually. Indeed, out of the 36 bed material transport sites evaluated in the catchment, only 4 are transporting more than 750t/year. This supports the proposal that it is better to stabilise the bedload than to extract it and export such a limited resource.

5.1.2 Key Problems in need of repair

• *Need to re-build floodplains/benches*

The overwidened and deepened channels are, in a lot of instances, conveying floods up to 1-in-100year occurrence (eg. T5, N4, N5) within their banks. To lessen the total discharge and erosive power within the channels, benches need to form in order to displace floodwaters on to the floodplains. For within-channel benches to form, vegetation and artificial sediment traps are required. There also needs to be a dissipation of energy to reduce velocities and induce sedimentation.

• Decreasing channel widths

Overwidened channels in degraded streams need to be reduced slowly. Examples from Argents Hill have shown that narrowing the channel from 60m to 30m in one action is unlikely to be successful. The channel width needs to be decreased in stages, particularly as there is a risk that floods can occur before the stabilisation process is complete. Once the initial reclaimed area has undergone sedimentation and, vegetation is taking hold, further reductions can take place. In a system such as the Nambucca, where the bed is unstable and flash flooding can occur in 'waves', a 50% reduction in width at one time is often too much for the system to handle. Staged reductions of 10% to 20% are more likely to succeed.

• Restore sinuosity or create stable 'hydraulic jumps'

Due to the extent of straightening, overwidening, loss of LWD and riverine vegetation, channel lengths have become shorter, gradients steeper, and hydraulic roughness much less. To compensate for this, either sinuosity needs to be restored or stable 'hydraulic jumps' need to be installed. Unless one or both of these are carried out all the channels will retain too much energy and other methods of rehabilitation will be under threat.

• r/w ratio less than 2 in overwidened reaches eroding inner bends and overwidening pools

When the radius of curvature (r) (measured down the centre line of a channel) is less than twice the width of the channel (w), the risk of erosion of the inner or convex bank increases. This is evident on North Arm (eg. upstream of N2), Missabotti Creek (eg. M3) and Buckra Bendinni Creek (eg. B2). Erosion of the inner bank can have a two fold effect. It can take the pressure off an eroding outside bend but it can also result in pools becoming overwidened, especially in bedrock corners. Once pools become overwidened they commonly infill with gravel. Bends where the r/w is less than 2 need to be modified to enlarge their curvature or to decrease their width (or both) so as to increase their erosional stability. This is a complex issue that in each specific case requires the input of a competent fluvial geomorphologist or river engineer.

5.1.3 Stream Gravel

• No commercial gravel extraction

Gravel extraction has become a contentious issue for the coastal rivers of NSW. The rationale has shifted from one of simply exploiting an available resource, to one of both resource exploitation and channel rehabilitation in situations where the channel is believed to have "excess gravel", to one of solely channel rehabilitation in limited cases. Now the channels are so severely disturbed there is a great deal of gravel exposed on the bed, and this is derived from floodplains and terraces either adjacent or from not far upstream. Simple sediment budget considerations (Background Report C) show a very low overall bedload yield and that it is not possible to extract gravel from the Nambucca catchment channels at anything like the past rates of extraction without causing a serious sediment budget imbalance. A new regime of river management must ensure that nearly all gravel is retained within the catchment's active channels. This will enable natural and artificially induced rehabilitation processes to access this resource for the reconstruction of new channel and floodplain features.

Exceptions to this policy of not extracting or relocating gravel from the channels should be restricted to the following situations. Where possible, gravel should be relocated to a position in the channel near the removal site to ensure that the local system does not lose gravel, because the loss could result in sediment load compensation via bank and bed erosion. In cases 1-3, the opinion of an experienced fluvial geomorphologist independent of, but approved by, DLWC should be obtained beforew DLWC approves a gravel extraction application. In case 4, assessment can be soley by DLWC staff.

(1) In bedrock corners of former deep pondage where gravel is depositing and not actively eroding. At these sites gravel could be extracted under the following circumstances; (a) The alluvial bank is already well vegetated, (b) Jacks or groynes are constructed to narrow the pool width if required, and (c) Bed control structures are placed upstream to prevent changes in the bed level migrating upstream.

(2) Where gravel from an unstable reach of channel is being transported into a stable reach. Here, a sediment trap should be installed at the downstream end of the unstable reach, and this trap should be regularly emptied. An example of such a location is Site T7 on Taylors Arm where excessive gravel transport runs the risk of destabilising the channel downstream of here.

(3) On specific point bars or mid channel bars where excessive gravel accumulation risks serious channel instability. However, at these sites gravel extraction must be seen to be a "last resort" solution after bank stabilisation has already been attempted and failed, and where gravel has already been relocated within the reach as part of stabilisation attempts.

(4) Where gravel is extracted from one part of the channel (say a point bar) only to be placed in another part of the same reach (say a bench being built on an adjacent cutbank).

All of the above situations must be inspected and approval given by a qualified geomorphologist under the authority of the DLWC, before work proceeds.

• *Using gravel extraction to pay for rivercare projects*

The idea of letting gravel extraction royalties pay for river rehabilitation works is good in theory but not in practice. Given that; (a) the gravel being extracted is needed to construct benches for jacks and groynes, or (b) many river rehabilitation works do not require gravel to be moved, and (c) the amount of literature that suggests gravel extraction has little or no positive effect on the long term channel morphology or ecology - using gravel to pay for river works is only providing funding by creating the next problem.

5.1.4 Methods of rehabilitation

• *Groynes and jacks are less successful on outside bends than on straight reaches*

From observations made throughout the catchment, it appears that jacks and groynes are not as successful in controlling erosion on the outside of tightly curving meander bends as they are in stabilising and contracting overwidened straighter reaches. Due to the nature of flow vortices on the outside of a meander bend, a gravel bench constructed on an outside bend is prone to failure. Whilst a groyne may protect the bank from erosive low-stage flow, the pattern of flow at higher stages in a meander bend may impact turbulent flow into the bank. Further experimental work needs to be done to determine the alignment, and spacing, of groynes on meander bends, as well as the most useful method of toe protection to counteract flow vortices.

• *Jacks and/or groynes -when and where ?*

Uncertainty remains over the preferred locations of jacks and groynes. In many cases they should be used together (eg. Jacques' Property - Taylors Arm). Generally, groynes are most successful in long straight reaches where undercutting has caused bank retreat. Jacks, on the other hand, are the preferred method in shorter reaches of overwidened channel, particularly adjacent to pools. Due to the close spacing of jacks, a channel length of over 50m is to be treated as generally too labour intensive for this form of treatment.

• *Log sills recommended only for entrenched channels beginning to erode*

It is common knowledge that nearly all of the log sills installed within the Nambucca catchment have failed. In overwidened channels that are undergoing bed degradation, their application is very limited. Their most effective use is in controlling bed degradation in narrow, laterally stable channels (eg. S4, B3). If a log sill can be placed between two relatively stable banks, and the bed profile maintained, then prevention certainly is better than trying to cure the problems that result. Our recommendation is that most of the disturbed channels in the Nambucca catchment need to be made more laterally stable and substantially reduced in width before log sills are installed. When such sills are used, the adjacent banks must be secure against erosion.

• *Toe protection of banks in conjunction with jacks and groynes*

Toe protection is imperative due to undercutting and cantilever failure, however, the practice should be discouraged as a singular solution to a problem. Vegetating the toe and/or the use of heavy rock or sandbags (or 'gravel bags') is best used in conjunction with jacks or groynes. The jacks and groynes retard flow and allow sedimentation to occur. An important factor to be aware of is the vulnerability of the upstream end of the works. If toe protection is breached here, then the chance of further bank retreat downstream, no matter how solid the toe protection, is greatly enhanced.

• *Endorsement of rock ramps*

Although costly from our observations in the Nambucca catchment, rock ramps appear to be the best method of introducing stable hydraulic jumps. A particularly successful example is at Argents Hill (N3). However, there was also a failure on Missabotti Creek (between M1 and M2) where a nickpoint retreated around a small rock ramp. A precautionary note is that rock ramps need to be securely protected and tied into the channel banks. They should have a batter of approximately 1:20 to promote fish passages and to reduce oversteepening which induces scour. In wide and shallow channels the cost is going to be greater because of the protection needed on the banks to prevent outflanking. In these reaches a decision possibly needs to be made upon whether channel narrowing works are going be carried out before grade control structures are introduced.

• *Fence off cattle from the streams*

Fencing the stream from cattle is one of our major recommendations. The effect cattle have on preventing vegetation regrowth and causing bank destabilisation (Background Report D) is underestimated by many landholders. It is only when comparisons are made between fenced and unfenced riparian zones that the sharp contrasts can be seen. Cattle trample or eat seedlings, trample the bank face and, disturb the channel bed. Fencing the riparian zone is essential if riparian revegetation programs are to succeed. There is however, the issue of costs. The practice of watercourse fencing needs to be partly funded to entice residents to carry out such projects. In the Denmark catchment of Western Australia, land holders are given grants of $400/km to fence the riparian zone. This represents approximately 50% of the actual cost (Schur, 1996). Limited water access points can be included in such a fencing program, reducing the cost of water reticulation to stock kept away from most of the channel. Weed infestation within the zone of protected riparian vegetation may become a problem if landholders do not manage these zones properly.

- *Bed levels need to be constantly monitored*

Bed lowering is a critical problem in the Nambucca catchment. It is not always an obvious visual problem in the manner of bank erosion or vegetation clearance. While it can occur dramatically in the form of nickpoint retreat overnight or over weeks, it can also occur incrementally over years. The first step in controlling bed degradation is understanding the extent of the problem. This can be done in two ways. Firstly, rock ramps or partly submerged logs can be used to retain and to monitor bed levels, particularly up- and downstream of any channel works. Retreating nickpoints or localised bed lowering will become noticeable by the undercutting or displacement of these structures. Secondly, annual surveying of cross sections and long profiles is highly recommended to give an overall picture of changes in bed levels from year to year.

- *Concrete bridge floors to set the bed level*

Bridge piers are a threat to the bed level of the channel due to scouring. This is particularly so where the bridge is constructed over a riffle. Due to the narrowness of bridges crossing the Nambucca catchment, there is some merit in concreting the bed of the channel beneath these (eg. Burrapine Bridge at T4). If the reinforced concrete floor is only 0.5m thick then subsurface flow can still take place within the gravels. If the bed level lowers it will be readily visible and any nickpoints below the bridge can be stabilised with rock. If the bed aggrades sediment will accumulate. There is only a threat to fish passage if there is substantial bed lowering and this can be adjusted for with the type of nickpoint stabilisation employed.

- *Potential necessity of low weirs*

Hard engineering methods are not a preferred option for economic, ecological and aesthetic reasons. However, they must be realistically considered if conditions of some reaches of the Nambucca catchment fail to improve. The most likely hard engineering method required could be a series of low weirs with fish passages built to the guidelines of the Department of Fisheries. The current situation on all of the streams, except Deep and Warrel Creeks, where streams are flowing in a straight line from valley side to valley side, cannot be remedied unless sinuosity is restored or grade control structures are constructed. Due to extent of overwidening and bed degradation, neither of the 'softer' options are guaranteed. If erosion is not decreased in these reaches, 'harder' engineering options could be a necessity. Site and design details should be tailored individually for each proposed site.

5.1.5 Vegetation Management

• *Appropriate species for vegetation management*

The use of native species in revegetation programs is important. In other catchments in NSW 'hybrid' willows are, in fact, proliferating and have become a menace (Background Report D). The ability of many introduced species to dominate the riverine zone and inhibit vegetation is a problem. The most suitable trees for colonisation of the riparian zone are river oaks (*Casuarina cunninghamiana*), tea tree (*Leptospermum brachyandrum*), and bottle brush (*Callistemon viminalis*). All of these species play a pioneering role in the same manner as willows. Sedges and rushes such as lamandra are also effective silt trapping supplements to the native trees mentioned above. The objective should be the eventual establishment and maintenance of a rainforest river bank plant community.

• *Manage she-oak growth*

Despite the common perceptions, *Casuarina cunninghamiana* (or she-oaks) play a useful role in stream rehabilitation. As the pioneering species they have the potential as a monoculture to stabilise bars and benches. Selective pruning and thinning of them can result in a stabilised reach that supports the establishment of later successional species. Casuarinas are an opportunistic species and are an indicator of change, they are usually not the cause of change. Individual large trees grow precariously on the river banks and may need to be removed to prevent bank collapse.

• *Vegetation planting and maintenance*

It is essential that native vegetation is used to reduce and prevent stream bank erosion, and to facilitate the narrowing of overly wide channels. The longterm objective should be the re-establishment of subtropical rainforest species along most of the catchments channels. It is the most cost effective, environmentally friendly and aesthetically pleasing method. It can be used on its own or with soft engineering works in the middle or upper reaches, but may have to be used in conjunction with more costly engineering works in the downstream reaches. It is imperative that any rehabilitation strategies have contingency plans to deal with any setbacks arising from flood damage during, or just after, the works are carried out. Constant maintenance, monitoring and repairs are essential and should be a major consideration in the planning and budgeting of such works.

• *Fine sediment for revegetation and stabilisation of gravel bars*

Gravel benches are often constructed at the base of an eroding bank from materials removed from a point bar. For vegetation to grow and stabilise these bars, the bench must be stable and, sedimentation needs to occur. Sedimentation is best initiated by jacks and groynes. Colonising shrubs and rushes are also useful at trapping sediment. It is important that species with an extensive root mat establish to stabilise the bench.

5.1.6 Administrative Aspects

• *Encourage the keeping of detailed records*

A common thread throughout departmental and community projects in the Nambucca catchment is the inability to find or access written or photographic records of rehabilitation works, gravel extraction, or other important pieces of information. If catchment managers in the Nambucca are to learn when and where different management strategies are to be used, there needs to be a well maintained library of information built up on what previous works have been successful and, under what conditions. Save for a few diligent residents, there has been very little written and photographic evidence collected to provide follow-up information to Landcare schemes. A condition of Landcare grants should be an annual photographic and written report is submitted to the DLWC for a set number of years after the funding is provided.

• *Anecdotal evidence should not be used on its own*

Anecdotal evidence should not be used as a substitute to researching for evidence of change. Aerial photos, photographs, cross-sections, parish maps and geomorphic features are the most reliable forms of evidence. Anecdotal evidence is an important supplement.

• *Air photo examination*

Before any works commence, all available air photographs should be examined stereoscopically to gain information on how the river has changed.

- *Funding*

Funding will need to be obtained for ongoing maintenance of the rehabilitation work implemented.

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