Stream Rehabilitation Essentials: A Conceptual Framework and an Integrated Planning and Design Procedure

Ross Kapitzke [1]

SUMMARY: In recent decades, stream managers in Australia have moved from traditional objectives for flood and erosion control to more sustainable stream management practices, encompassing ecological issues. Land use planning, water management and revegetation programs are now being implemented in many river basins through regional strategies, integrated catchment management and stream health initiatives. As the industry shifts emphasis towards physical and biological rehabilitation of the stream corridor, stream managers require increased understanding of stream processes and the nature and causes of stream management problems. Other essential elements in sustainable stream management are the present and future human uses of the stream, the human pressures affecting the stream, and management objectives that reflect the different needs and expectations of stream users. This paper presents a conceptual framework and an integrated planning and design procedure for stream rehabilitation that recognise human use and natural function of the streams, and lead from problem definition, through choice of objectives, to the development and evaluation of options, and to the implementation of a stream rehabilitation program. These are essential areas for successful stream rehabilitation in Australia.

THE MAIN POINTS OF THIS PAPER

Successful stream rehabilitation activities are based on:

- guiding principles for good practice
- a management framework that applies from the regional scale through to the local scale
- a conceptual framework relating objectives and solutions to pressures, problems and stream processes
- an integrated procedure for planning, design and implementation of remediation programs

1. INTRODUCTION

'Do we know all we need to rehabilitate streams in Australia; is it just a matter of getting on with it?' This is the question posed in the call for papers for this conference. 'What do we really know about restoring and reconstructing physical and ecological systems?' These questions are obviously important to the stream management industry as it moves from traditional approaches emphasising flood and erosion control to stream rehabilitation initiatives that encompass broader social and ecological objectives.

On the surface, many would say yes to the first question. We can just get on with it. Society is aware of environmental degradation, government and industry bodies are advocating sustainability, resource managers recognise the impact of post-European settlement, and the community is not only interested in addressing stream degradation but also shows growing enthusiasm for reinstating natural values.

It is clear that progress is being made. National rehabilitation programs have been established (eg. *Natural Heritage Trust*; *One Billion Trees*), regional and local rehabilitation activities are fostered through Landcare and integrated catchment management, and management structures established, including landholder and community groups. Regional natural resource management strategies are developed (eg. regional environment strategies), strategic planning studies completed, catchment inventories prepared, and stream condition surveys undertaken (eg. *State of the Rivers*, *National River Health Program*, *Waterwatch*). Priority areas and issues are identified through rehabilitation plans, catchment management and riparian management programs are implemented, and hundreds of millions of dollars are spent annually around Australia on rehabilitation.

But stream rehabilitation (improved physical and biological condition of a degraded stream) falters still. In spite of regional planning and catchment studies, many programs continue to emphasise flood and erosion control, often in a reactive manner with band-aid solutions. Considerable effort is put into revegetation and selected issues such as water quality, often without reinstating natural channel form or instream and riparian habitats. Goals for ecological sustainability and biodiversity, although discussed extensively in strategy plans, mission statements and policy speeches, are not on the main agenda of most stream management agencies (Rutherfurd et al. 1998).

Traditional factors inhibiting progress in stream rehabilitation remain. Lack of political commitment, economic constraints, cultural barriers to change, and lack of understanding about application of techniques have all impeded rehabilitation activities. But projects also fail due to poor definition of project objectives, wrong diagnosis of the real problem, and failure to consider the catchment context of works (Rutherfurd et al. 1998).

[1] School of Engineering, James Cook University, Townsville QLD 4811

So if stream rehabilitation is faltering, what are the essentials for it to move ahead? This paper recognises four significant areas for good stream rehabilitation practice: (i) guiding principles; (ii) a management framework; (iii) a conceptual framework; and (iv) an integrated planning and design procedure. It claims that, although the management aspects and principles are being established, a lack of understanding of conceptual relationships and planning procedures is limiting progress. Before examining each of these in turn, I will first review approaches to stream management and examine stream rehabilitation trends.

2. STREAM MANGEMENT APPROACHES

Many stream management approaches have stemmed from traditional stream stabilisation practices, incorporating limited objectives for remediation, and relating principally to protection of human utility and property. These approaches typically involve narrow assessment of the problem or condition of the stream, usually focussed on the physical environment (eg, erosion) and socio-economic factors such as loss of land and flooding. Local problems are commonly the focus of these approaches, while broader catchment issues, and those relating to stream ecology and aesthetics are ignored. Human pressures on the stream system and causes of the problems are often not recognised, and natural stream values and impacts of remediation works on the environment are commonly not considered.

The principal approaches used in Australia during the 1990s (eg. Standing Committee on Rivers and Catchments 1991; Raine and Gardiner 1995) have clearly described the various types of physical stream degradation (erosion etc.) and have emphasised the importance of understanding stream behaviour for remedial actions. Stream stabilisation and revegetation techniques are suggested and the general characteristics and applications of the remediation options presented. But these approaches are limited in that ecological degradation and remediation objectives are only briefly considered, and the links between problems, objectives, solutions and causes are not fully established.

Even the international, ecologically-driven approaches that re-establish channel form (eg. Newbury and Gaboury 1993; Rosgen 1996) often deal principally with survey and classification of the natural stream system, and fail to recognise the causes of the problems, or to consider remediation objectives other than full restoration to the predisturbed state.

Local government agencies in Australia, and internationally, have recently attempted urban stream rehabilitation to enhance damaged habitats and to improve aquatic diversity (eg. Brisbane City Council 1994). These initiatives are intended to supplement mitigation measures to improve water quality through erosion, sediment and pollution control in new developments. Although the rehabilitation approaches commonly aim for natural channel design using an integrated approach with multiple objectives, they typically lack a structured framework that recognises the key stream degradation and rehabilitation elements, and their interrelationships.

A new interagency publication from the USA, *Stream Corridor Restoration Principles, Practices and Processes* (1998) presents a progressive new philosophy and technique, broader in scope than traditional approaches. The planning framework for restoration actions and alternatives promotes an integrated approach to meet the multi functional objectives of restoration. *River Channel Restoration: Guiding Principles for Sustainable Projects* (Brookes & Shields 1996) also reflects the state of the art in sustainable stream management.

These and other emerging broad approaches to stream management provide a good understanding of stream processes and causes of problems, and consider a range of remediation objectives. They embody several significant factors, notably a set of guiding principles for good practice, and a stream condition and analysis methodology (some say a physical framework) that provides a good model for behaviour of the natural stream and an understanding of the requirements for the rehabilitated stream. These factors are usually set within a tiered management framework that allows for local rehabilitation actions within the context of a regional natural resource management strategy.

These approaches, however, commonly lack a clear conceptual framework that relates the essential elements of the degraded and rehabilitated stream. A planning and design procedure is commonly presented, but is sometimes limited by poor sequencing or failure to recognise key steps. Before outlining a suggested conceptual framework and a planning and design procedure for stream rehabilitation, I will first review the guiding principles and management frameworks that are now reasonably well established. The stream condition assessment and analysis methodologies are well covered by Rosgen (1996), Newbury and Gaboury (1993) and others.

3. GUIDING PRINCIPLES FOR STREAM REHABILITATION

Stream rehabilitation is a complex endeavour subject to a variety of conditions and characterised by high levels of uncertainty and site specificity. Detailed prescriptive guidance is neither achievable nor appropriate, but guiding principles such as those outlined below can be applied (Kapitzke et al. 1998).

Sustainability: Provide for long-term ecological functions and utilitarian requirements of streams.
Multiple objectives: Adopt multiple objectives that recognise natural stream functions and human uses.

Catchment context: Plan rehabilitation within site and catchment contexts, recognising the different influences and processes that occur at these different scales.
Stakeholder consultation: Involve stakeholders in identifying problems, setting objectives, and determining appropriate rehabilitation activities.
Interdisciplinary approach: Integrate hydrological, geomorphological, ecological and socio-economic considerations in planning and design.

Most of these principles are well established in the literature (eg. Brookes & Shields 1996). They are integral to successful stream rehabilitation and provide a solid foundation for progress, although not yet universally adopted in Australian practice. They should not, however, provide a major obstruction to moving ahead with stream rehabilitation.

4. MANAGEMENT FRAMEWORK

State of Environment Australia (State of the Environment Advisory Council 1996) promotes an integrated, system-based approach to natural resource management. This requires a management planning framework operating at a range of spatial scales that considers all aspects of resource use and provides for local action to address specific issues such as stream rehabilitation within the broader catchment and regional contexts.

Integrated catchment management (ICM) provides the framework for community, industry and all levels of government to coordinate management and use of water, land and natural resources within the river catchment. Adopting the river catchment as a basic unit for natural resource management, ICM recognises spatial characteristics and stream processes; considers social, economic, environmental and other issues; develops links between problems and causes; and can be used to establish landuse control and rehabilitation programs within the catchment.

Another tier in natural resource management and planning is now being introduced at the regional level to protect the environment and achieve ecological sustainability. Integrated regional planning adopts a long-term strategic planning approach to the management of regional development and natural resources (eg. regional environment strategies and interbasin waterway management plans in Queensland). The *National Water Quality Management Strategy-NWQMS* (ARMCANZ & ANZECC 1996), through a suite of national water quality standards and guidelines, conforms with this regional planning approach to protect and improve water quality and prevent environmental harm (eg. urban stormwater planning and design).

These regional planning initiatives incorporate a tiered management framework that integrates environmental protection measures with planning and resource management functions. The regional waterway strategies and urban stormwater management strategies represent the highest planning level. At the next level, the catchment management plans are linked to the outcomes for the whole region and contain local strategies and actions to manage a wide range of local catchment issues. The third tier is sub catchment or stream reach planning, which relates to stream condition, flooding, water quality or ecological health priorities. This may include riparian vegetation management plans, stream rehabilitation programs, or stormwater management plans for particular areas within the catchment. The local management plan or site implementation plan is the fourth tier in the management framework. These plans usually detail specific local waterway actions such as revegetation, stream stabilisation, or management of localised stormwater issues such as flooding and pollution.

This tiered natural resource management approach provides a suitable management framework for stream rehabilitation. Once again, although not universally adopted in Australia, the building blocks are in place. This, therefore, should not provide a major impediment to ‘getting on with the job of rehabilitation’.

5. CONCEPTUAL FRAMEWORK

Something more is required to move stream rehabilitation beyond the policies and philosophies, the catchment inventories and stream condition surveys, the stream classification and assessment frameworks, and the regional strategies and management programs. Stream managers and practitioners require something else to make best use of the guiding principles and management frameworks and to successfully proceed with the planning, design and implementation of solutions to stream rehabilitation issues and problems.

Rutherfurd et al. (1998) call for a planning framework that provides a temporal and spatial hierarchy for rehabilitation activities, and a physical framework to describe stream condition and stream processes. Such a temporal planning framework is described by the sequence of stream rehabilitation activities presented in what I call the planning and design procedure (Sect 6). The physical (or assessment) framework is provided through the stream condition and analysis methodologies mentioned in Section 2, and the spatial planning hierarchy is inherent in this assessment framework and in the management framework (Sect 3).

But stream managers and practitioners require something more than this to meet the broad stream rehabilitation objectives of human use and natural function. They need to overcome the identified shortcomings that relate, among other things, to poor definition of project objectives, wrong diagnosis of problems and causes, lack of catchment context for analysis, and remediation options that ignore natural stream function. I propose a conceptual framework to describe the relationship between the essential elements

of a degraded and rehabilitated stream. Such a framework acknowledges human utility and natural stream values; recognises human pressures on the stream system; enables an understanding of stream processes; identifies relationships between problems and causes; and develops rehabilitation options to meet the desired objectives.

The suggested conceptual framework for stream stabilisation and rehabilitation (Figure 1) forms the basis for the planning, design and implementation procedure presented in *Stream Stabilisation for Rehabilitation in North-east Queensland* (Kapitzke et al. 1998). This identifies human use or **utility**(ies) of a stream (eg. water supply, recreational use, conservation value) and **pressures** on the stream that may be associated with these uses (eg. flow regulation, presence of exotic species - direct pressures; landuse and pollution - indirect pressures). Stream management **problems** or **issues** (eg. bank erosion, instream habitat degradation, degraded water quality) result from conflict between human use, pressures on the stream and natural stream processes. The **stream processes** provide the link between the human activities, pressures, problems and remedial actions.

The problems, therefore, may result from the effects of stream processes (eg. flooding, erosion) on human utililities (eg. water supply, agriculture); the effects of human pressures (eg. flow regulation, encroachment) on stream processes (eg. physical form, stream habitats); or the accelerated effect of human pressures (eg. landuse) on stream processes (eg. sedimentation), which in turn affect human utilities (eg. recreation). Stream management **objectives** to deal with these problems (eg. physical stability, enhance instream habitat, protect land and infrastructure) must relate to the problem itself, to the relevant pressures, and to the utilities. **Strategies** and **treatments** (eg. streambank stabilisation, catchment management) to meet the desired objectives are directly related to the objectives, and must be established within the framework of the stream processes.

Using this conceptual framework for stream rehabilitation, responses to stream management problems should therefore be based on: (i) an understanding of the nature and cause of the stream management problem(s); (ii) an understanding of stream processes; (iii) an awareness of the present and anticipated human use of the stream; (iv) a knowledge of the human pressures affecting the stream; and (v) a range of management objectives that reflect the different needs and expectations of the various users of streams and their environs. See example in Section 7.

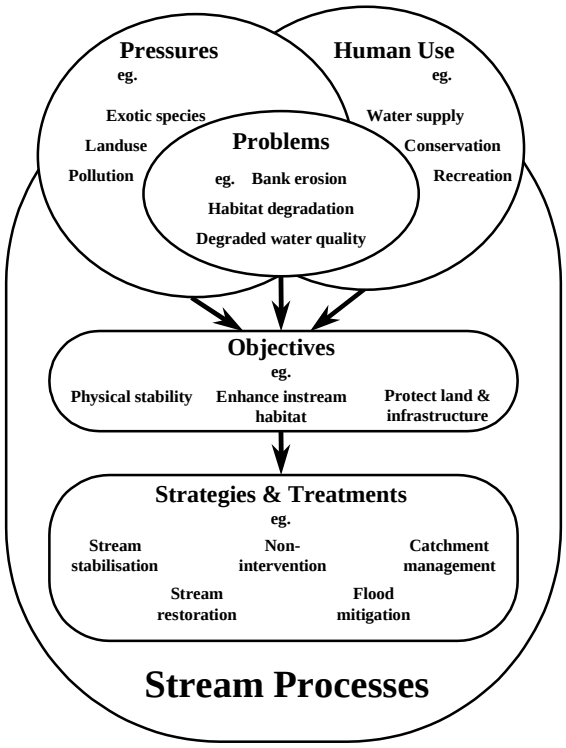

Figure 1 Conceptual framework

6. PLANNING AND DESIGN PROCEDURE

A structured planning and design procedure is also important for stream rehabilitation projects. Without this, stream managers and practitioners may propose solutions to problems before causes are established, or they may miss major factors and consider a narrow range of objectives, leading to band-aid solutions with inefficient outcomes. The stream rehabilitation approach presented in Kapitzke et al. (1998) follows a straightforward, yet rigorous process that addresses a broad range of issues and leads from problem definition, through choice of objectives, to determination of the strategy or treatment outcome.

The recommended planning and design procedure for stream rehabilitation (Figure 2) can be grouped into five sequential phases, leading from concept, through feasibility and implementation, to monitoring and review. A ten-step process guides stream managers through the project phases. See example in Section 7.

The concept phase can be applied at a range of spatial scales and is relevant to all tiers of the management framework described in Section 4 (from regional planning to site implementation). The feasibility phase applies at finer scales to stream rehabilitation projects within management tiers 3 and 4 (reach planning and site implementation), whereas the implementation, monitoring and review phases apply to activities at a specific site (Tier 4).

For example, human use and pressures (Step 2), stream degradation issues (Step 1) and their causes (Step 3), management objectives (Step 4), and options for remediation (Step 5) should all be considered in a broad sense in regional planning (Tier 1) and catchment strategies (Tier 2). The concept phase (Steps 1 to 5) and feasibility phase (Steps 6 to 7) are undertaken in more detail in reach planning (Tier 3). Implementation at a particular site (Tier 4) may iterate through the concept and feasibility phases in still more detail before proceeding with implementation, monitoring and review phases (Steps 8 to 10).

The ten-step process is not intended as a cookbook solution for stream rehabilitation. It does provide a consistent approach to address stream management issues at a regional scale, down to the design of suitable remediation at a specific site. The phased approach to assessment provides information at the most relevant time in a project, allowing, for example, big issues to be considered in a broad sense at a regional management level, and minimising effort for those projects that do not proceed to implementation. Distinction between phases will be less well defined for smaller projects and minor issues. For example, the feasibility phase may not be required where the solution is obvious, and the detailed design component may not be relevant where only non-structural solutions are adopted. The sequential phases and steps should nevertheless be followed in order to meet the broad objectives of sustainable stream management. Feedback between steps is important.

Phases	Steps	Description
Concept	***Step 1***	**Identify and describe the problems or issues**
	Step 2	**Identify relevant utilities and pressures**
	Step 3	**Examine stream processes and determine causes**
	Step 4	**Define remediation objectives and constraints**
	Step 5	**Identify remediation options and develop concept designs**
Feasibility	***Step 6***	**Feasibility design and evaluation**
	Step 7	**Decide on remediation program**
Implementation	***Step 8***	**Detailed design and implementation**
Monitoring & maintenance	***Step 9***	**Monitor and maintain**
Review	***Step 10***	**Review project**

Figure 2 Planning and design procedure

7. EXAMPLE

The following simplified example illustrates the conceptual framework and the planning and design procedure for a common stream rehabilitation project. The essential elements and their relationships (from Figure 1) are described, and the sequence of planning and design steps (from Figure 2) are presented.

Consider a stream on the fringe of an urban area that is progressively developing back into the catchment with consequential stream management problems. The most recent problems have occurred at a culvert on a new arterial road constructed across the stream at the lower end of the catchment to service new residential developments upstream. The streambanks around the culvert site have previously been degraded by infestation of exotic plants, recreational activities such as trail bike riding, and recent residential encroachment involving clearing of riparian vegetation and streambank reprofiling. An adjoining catchment was diverted into the stream upstream of the present culvert when a commercial area was established in the mid reaches of the catchment more than 30 years ago.

The stream reach adjoining the culvert has been affected in a number of ways. Aggregate was extracted from the stream immediately downstream of the culvert for construction of the road embankment. This effectively channelised the stream, cutting off a meander bend, and the stream has followed this new path since several large floods occurred shortly after construction of the road and culvert. Severe erosion has occurred at the culvert outlet, undermining and threatening the integrity of the structure. The stream reach downstream of the culvert has suffered severe physical and ecological degradation through altered channel form and destruction of instream and riparian habitat. Fine sediments from the erosion have smothered the streambed well downstream of the site.

The stream management officer in the local council is charged with the responsibility of solving the problem of degradation in the stream reach. The council, who constructed the arterial road and culvert crossing, are concerned about the culvert being undermined and road access being lost. Residents living close to the stream immediately downstream of the site consider that their properties are threatened by streambank erosion and change of channel course, while recreational fishers are aggrieved by the loss of instream habitat and disruption to fish passage in the stream. The general community, and the local conservation group in particular, have campaigned for improved ecological and aesthetic values in the lower end of the catchment and are distressed by disruption to the stream ecosystem and the visual scar associated with this latest problem.

A catchment management strategy (management tier 2) has been developed to guide the new residential developments in the upstream catchment and urban stormwater management plans (tier 3) restrict sediment and nutrient runoff to the stream from these new developments. These plans, however, are not able to deal with the present problems in the culvert reach, which result from the recent infrastructure development and past landuse practices. The council decides that, in addition to a remediation plan to address the immediate problems at the culvert (tier 4), they require a rehabilitation plan for the degraded reach (tier 3). The stream officer has been instructed to undertake a conceptual level investigation into a range of options for presentation to the local community and government agencies. The council will consider proceeding with the feasibility, implementation, monitoring and review phases of the remediation on completion of the concept design phase.

A simplified account of steps 1 to 5 (concept design) of the planning and design procedure is presented below.

Step 1 - Identify and describe the problems or issues: The problems at the site include stream channel erosion, change of channel course, habitat degradation, infrastructure damage and reduced conservation and aesthetic values. Downstream areas are affected by sedimentation and degraded water quality.

Step 2 - Identify relevant utilities and pressures: The stream reach is used for recreation and water conveyance and has natural resource and conservation values. Direct pressures on the site include flow diversion, culvert construction, aggregate extraction, encroachment of urban development and introduction of exotic species. Catchment landuse and pollution are indirect pressures on the site.

Step 3 - Examine stream processes and determine causes: Stream channel erosion and undermining of the culvert structure have been caused by the upstream flow diversion, downstream channelisation and poor culvert outlet design. The channelisation, trail bike riding and upstream landuse practices have contributed to the instream and riparian habitat degradation. These problems have combined to reduce aesthetic and conservation values.

Step 4 - Define remediation objectives and constraints: The range of remediation objectives for the various stakeholders includes stabilising the stream channel, securing the culvert against failure, controlling downstream sedimentation, restoring recreational fishing and improving ecological and aesthetic values. These activities are constrained by available funds, an urgent need to repair the culvert and the need to comply with legislative requirements.

Step 5 - Identify remediation options: Options for stabilisation include alignment training or rock revetment at the culvert, culvert repair and reconstruction of the outlet works. Instream and riparian habitat can be improved by reinstating channel form and riparian vegetation. The reach will benefit from local landuse controls to provide buffer zones and catchment landuse controls to restrict sediment and nutrient runoff.

8. CONCLUSIONS

Management and planning frameworks are important tools for stream rehabilitation, whatever the stream degradation issues and their causes. Irrespective of objectives and options for remediation, stream rehabilitation practices should follow the guiding principles of sustainability etc. But beyond the regional planning and catchment strategies, the stream condition surveys, and the revegetation programs, stream rehabilitation initiatives require a conceptual framework and an integrated planning and design procedure.

Stream rehabilitation in Australia is in its infancy. Indeed, we don't know all we need to know. A tiered management framework for integrated natural resource planning is acknowledged and guiding principles for stream rehabilitation are generally accepted. But for stream managers and practitioners to get on with it, it is essential that they go beyond these areas and adopt a conceptual framework and an integrated planning and design procedure similar to that presented here.

9. REFERENCES

ARMCANZ & ANZECC (1996). National Water Quality Management Strategy Draft Guidelines for Urban Stormwater Management.

Brisbane City Council (1994). Urban Stream Rehabilitation Principles and Guidelines.

Brookes, A. and Shields, F.D. (1996). River Channel Restoration Guiding Principles for Sustainable Projects. John Wiley & Sons, Chichester, 433p.

Kapitzke, I. R., Pearson, R.G., Smithers, S.G., Crees, M.R., Sands, L.B., Skull, S.D. and Johnston, A.J. (1998). Stream Stabilisation for Rehabilitation in North-east Queensland. Land & Water Resources Research & Development Corporation, Canberra.

Newbury, R.W. and Gaboury, M.N. (1993). Stream Analysis and Fish Habitat Design, A Field Manual. Newbury Hydraulics Ltd, Gibsons, British Columbia.

Raine, A.W. and Gardiner, J.N. (1995). "Rivercare Guidelines for Ecologically Sustainable Management of Rivers and Riparian Vegetation." Occasional Paper No 03/95 prepared for Land and Water Resources Research and Development Corporation.

Rosgen, D. (1996). Applied River Morphology. Wildland Hydrology, Pagosa Springs, Colorado, 390p.

Rutherfurd, I. D., Ladson, A., Tilleard, J., Stewardson, M., Ewing, S., Brierley, G. and Fryirs, K. (1998). "Research and development needs for river restoration in Australia." Report to the National River Health Program Management Committee of the Land & Water Resources Research & Development Corporation, Canberra.

Standing Committee on Rivers and Catchments (1991). Guidelines for Stabilising Waterways, prepared by the Working Group on Waterway Management, Melbourne.

State of the Environment Advisory Council (1996). State of Environment Australia 1996.

Stream Corridor Restoration Principles, Practices and Processes (1998).