COOPERATIVE RESEARCH CENTRE FOR **CATCHMENT HYDROLOGY**

EVALUATING THE EFFECTIVENESS OF HABITAT RECONSTRUCTION IN RIVERS

TECHNICAL REPORT
Report 04/11

July 2004

Michael Stewardson / Peter Cottingham / Ian Rutherfurd / Sabine Schreiber

COOPERATIVE RESEARCH CENTRE FOR
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Evaluating the Effectiveness of Habitat Reconstruction in Rivers

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Foreword

Over the last thirty years, the focus of river management has shifted from the protection of physical and economic assets, to include the protection and enhancement of environmental assets. River restoration is a new science and many projects are necessarily experimental. Our understanding of processes of degradation is improving but our ability to prescribe efficient restoration treatments which might include environmental flows, reintroduction of large wood debris and riparian restoration is still limited. Responsible investment in river restoration requires some monitoring and evaluation of these projects. Indeed planning for larger river restoration projects almost always includes recommendations for monitoring and adaptive management. However, successful monitoring programs are limited because we are yet to establish practical and widely applicable methods for evaluating river restoration projects.

The main contribution of this report is in Chapter 4, where various approaches to river restoration are reviewed. Those considering an evaluation will benefit from reading the limitations and advantages of the various approaches. River engineers, aquatic ecologists and fluvial geomorphologists now work in multi-disciplinary teams to plan river restoration work including monitoring and evaluation. In recognition of this, Chapters 2 and 3 discuss conceptual aspects of restoration planning and evaluation as common ground across the disciplines. I sincerely hope this report is of benefit to river restorers and leads to a better understanding of how we can influence our river landscapes for the better.

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The advisory committee had major input to this project through interviews, a workshop and review of the project documentation. Members of this committee are (in alphabetical order):

- Dr Barbara Downes
- Assoc Prof Brian Finlayson
- Dr David Fox
- Dr Chris Gippel
- Dr Terry Hillman
- Dr Tony Ladson
- Prof Sam Lake
- Prof Tom McMahon
- Dr Gerry Quinn

The survey of sites in the North East Region (Victoria) which have been subject to riparian restoration (discussed in Section 4.1) was undertaken by Michelle Ezzy as part of her Honours Project in the School of Anthropology, Geography and Environmental Studies at The University of Melbourne.

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[1] Two people from this organisation shared a position on the committee.

Executive Summary

Introduction

There are considerable resources being used to rehabilitate streams and in particular reconstruct stream habitats across the Murray-Darling Basin and there is a legitimate concern that available resources are used to achieve the best possible environmental outcomes. This report is the result of a project[2] in which the CRC for Catchment Hydrology and the CRC for Freshwater Ecology were asked by the Murray-Darling Basin Commission (MDBC) to investigate methods for evaluating river rehabilitation works. Just as the Murray-Darling Basin Commission wants to understand the effects of habitat reconstruction, so to do other agencies and community groups involved with river rehabilitation. It is hoped that this report will be of use throughout Australia.

Habitat Reconstruction

Stream *habitat reconstruction* refers to manipulations that result in physical, chemical and biological changes in habitat that are intended to reinstate aspects of the biological condition or function of the stream. Most river rehabilitation projects rely on assumptions, often unstated, regarding the impact of changes in stream environmental conditions on characteristics of the biological community and ecosystem processes. In order to ensure that such assumptions are stated and tested rehabilitation experiments should be framed within restoration ecology.

Successful rehabilitation involves linking the activities of environmental managers, scientists and engineers, each with distinct roles in the planning process, starting from general principles and gradually refining the outline to produce specific performance indicators, hypotheses and restoration techniques. There is a concern that past rehabilitation projects have progressed to a detailed stage in one area in isolation from the other groups and their activities.

Principles of Experimental Design

One of the challenges of an inter-disciplinary rehabilitation experiment is harnessing the different perspectives of the parties involved in the task. In order to resolve these differences, some general principles of experimental design and analysis are discussed. Chapter 3 of this report attempts to focus on the integration of different perspectives of the task rather than the precise details of experimental design. Most of this section deals with technical details that are not essential to understanding the main recommendations of this report. For this reason, and for simplicity, it has been largely omitted from the Executive Summary.

Approaches to Evaluation

Three approaches to evaluating the effectiveness of habitat reconstruction are considered for this project.

1. **Post-project evaluation:** examining conditions at sites that have been subject to habitat reconstruction sometime in the past.
2. **Combining management and monitoring:** design a monitoring and evaluation program as a part of a current habitat reconstruction project.
3. **Dedicated experimentation:** design an experiment with the sole objective of improving our knowledge of habitat reconstruction.

The first approach to evaluating the effectiveness of habitat reconstruction works is to use sites that have been restored at some time in the past either using a technique called space-for-time substitution or by comparing restored sites with control or reference sites. A review of riparian restoration sites in north-east Victoria was undertaken to assess the feasibility of this approach. It was concluded that this approach is not feasible, mainly because most historic restoration projects used techniques that are now out of favour or were undertaken at sites that are unsuitable for evaluation.

The second approach is to use current restoration projects for evaluating the effectiveness of habitat reconstruction work. The conventional approach to evaluating such projects is to undertake a monitoring program in parallel with the stream management work. Such an approach is unsuitable for evaluation because of the high potential that the project will be compromised by management needs. Alternatively,

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[2] Stage I of the Murray-Darling Basin Commission Project R10008.

with the support of management agencies involved, it may also be possible to transform a conventional habitat restoration project into an adaptive management project in which management interventions are deliberately selected to improve our knowledge of restoration ecology. With such an approach, some potential but major challenges exist including establishing and maintaining support from the management agencies of the experimental objectives of the project. In light of the significant challenges confronting these projects, it would be unwise to rely on adaptive management alone for providing an evaluation of habitat reconstruction in Stage II of this project.

The final approach to evaluating the effectiveness of habitat reconstruction is conducting a dedicated experiment designed to provide reliable and useful inferences regarding the performance of the habitat reconstruction. Experiments focus on a small number of treatments, possibly limited to a single type of habitat reconstruction. The advantage of a dedicated experiment is the ability to make inferences based on the experimental results and that some confidence can be placed in these inferences. A limitation is that, in order to achieve reasonable statistical power, the range of site types and methods of habitat reconstruction will necessarily be limited and monitoring costs may be quite high. However, a dedicated experiment is the most reliable approach to evaluating the effectiveness of habitat reconstruction and is recommended for Stage II.

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1. Introduction

1.1 Background

Habitat reconstruction refers to local management work along a river reach to recreate environmental conditions that occurred prior to European settlement. Such work is intended to reinstate the natural biological community and ecological processes. Whilst sound in principle, this approach to restoration is not yet proven. There is a risk that degradation resulting from human activities cannot be reversed using this approach. In particular, there is a possibility that restoration will not be achieved unless catchment-scale changes, such as land clearance, have been addressed or barriers to colonisation by native species are overcome.

There are considerable resources being used to reconstruct habitats in Australian streams by restoring the riparian zone, introducing large woody debris and installing structures designed to improve habitat conditions. Given that the current state of ecological knowledge is limited, particularly in terms of how ecosystems respond to human disturbance and rehabilitation measures, we must accept that these projects are planned in the face of considerable uncertainty regarding their performance. There is a legitimate concern that available resources are used to achieve the best possible environmental outcomes.

This report is the result of a project[3] in which the CRC for Catchment Hydrology and the CRC for Freshwater Ecology were asked by the Murray-Darling Basin Commission (MDBC) to investigate methods for evaluating river rehabilitation works. In this project the CRCs sought to establish through extensive review, consultation and negotiation, a project with a robust experimental design to assess the effectiveness of stream management works in restoring biological diversity and natural processes across several rehabilitation sites within the Murray-Darling Basin. The outcomes of the initial project are guiding a further stage in the MDBC project in which riparian restoration practices are being evaluated.

Just as the MDBC wants to understand the effects of habitat reconstruction, so to do other agencies and community groups involved with river rehabilitation. It is hoped that this report will be of use throughout Australia and we have tried to keep it generally applicable. However, in some cases we have referred specifically to the Murray-Darling Basin and Riparian Restoration to illustrate a point. We hope this adds some clarity to what would otherwise be a rather abstract discussion.

1.2 Overview of the Report

Sound planning, ecological, and engineering principles should be used in any habitat rehabilitation experiment. To achieve this, the experiment should be based on strong linkages between restoration ecology, geomorphology, hydrology and restoration planning. These linkages are explicitly discussed in the rehabilitation planning process outlined in Chapter 2.

Chapter 3 provides a discussion of the key principles of experimental design for habitat reconstruction project work. These principles provide the basis for comparing the various approaches to conducting evaluation. Any habitat reconstruction experiment will require contributions from different scientific disciplines. It is important that there is a common understanding of the basic principles that guide such a multi-disciplinary project. Chapter 3 provides the principles on which this shared perspective can be established.

Chapter 4 presents three approaches to evaluation:

Approach 1- Post-project Evaluation:

Evaluating the performance of habitat reconstruction work that was carried out some time in the past. This type of evaluation can take two forms:

a. Space for time substitution: We examine trends in the response to habitat reconstruction by comparing the condition of sites that were restored at different times in the past.

b. Comparison of restored and control sites: Alternatively, we can simply compare sites that have been restored with those that have not, without consideration of spatial or temporal trends in response.

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[3] Stage I of the Murray-Darling Basin Commission Project R10008.

Approach 2- Combining Management and Evaluation:

Habitat reconstruction work is being implemented throughout the basin. This approach to evaluation uses these projects as the basis of an experiment and may include monitoring of reference sites. There are two ways to convert these projects into an evaluation project:

a. Adaptive management: We can use an adaptive management approach at these sites which would include a detailed planning phase in which a model is developed of how the system will respond to habitat reconstruction. In an adaptive management project, learning from the project is a key management goal.

b. Conventional monitoring: Alternatively, we could monitor the response of the site to habitat reconstruction without major scientific involvement in the planning phase. With conventional monitoring, learning is a secondary priority to other management concerns.

Approach 3- A Dedicated Experiment:

An experiment could be conducted with the sole purpose of improving our knowledge of how streams respond to habitat reconstruction. In this approach, we would test specific ecological and physical hypotheses in a rigorous experimental design.

2. Habitat Reconstruction

2.1 Introduction

Stream *habitat reconstruction* refers to manipulations that result in physical, chemical and other changes in habitat that are intended to reinstate aspects of the biological condition or function of the stream. We define *habitat* here simply as the living space of individual organisms or populations of individuals (Chapman and Reiss, 1992; Kendeigh, 1974; Odum, 1971). Within the context of a rehabilitation study, *habitat reconstruction* refers to physical, chemical and other changes towards habitat characteristics that existed prior to any change perceived as degradation. Habitat reconstruction can result in improvements to the habitats of a range of target species, communities or ecosystem processes, and may be beneficial or detrimental to the species already present at a rehabilitation site. It should be noted that the terms habitat reconstruction and rehabilitation are used interchangeably. Habitat refers to both the abiotic and biotic components of an organism's environment.

Most river rehabilitation projects rely on assumptions, often unstated, regarding the impact of changes in stream environmental conditions on characteristics of the biological community. In order to ensure that such assumptions are stated and tested, rehabilitation experiments should be placed within an ecological framework by integrating rehabilitation procedures with restoration ecology. This is in contrast to the general trend of rehabilitation procedures to be management oriented (e.g. NRC 1992), a trend that has been strongly criticised (e.g. Hobbs and Norton, 1996).

2.2 Planning Habitat Reconstruction

Successful rehabilitation involves linking the activities of several parties with distinct roles in the planning process. For example, *environmental managers* are concerned with setting priorities based on environmental, social and economic values in the community and evaluating projects in relation to these priorities. *Scientists* are concerned with identifying the physical, chemical and biological mechanisms by which human activities, including rehabilitation, influence streams, and in building knowledge about human effects on ecosystems by testing hypotheses based on proposed mechanisms. *Engineers* are concerned with designing and maintaining practical solutions to rehabilitation problems.

All of these groups play a role in the development of rehabilitation plans, starting from general principles and gradually refining the outline to produce specific performance indicators, hypotheses and restoration techniques. The work of these groups is generally iterative, with ongoing re-assessment of general issues in the light of more specific information (Figure 1).

Ideally, approaches used by different groups should operate simultaneously and be fully integrated at both the general and detailed levels. There is a concern that past rehabilitation projects have progressed to a detailed stage in one area in isolation from the other groups and their activities. For example, detailed specific techniques may have been developed before the relevant ecological processes affected by

Aspect of Rehabilitation Planning	**Management Goals**	**Ecosystem Perspective**	**Practical Methodologies**
General ↓ **Detail**	**Protection of Values** ↓ **Specific Performance Indicators**	**Ecological Components and Processes** ↓ **Specific Hypotheses**	**General Methods** ↓ **Specific Techniques**

Figure 1. Different Approaches to Rehabilitation

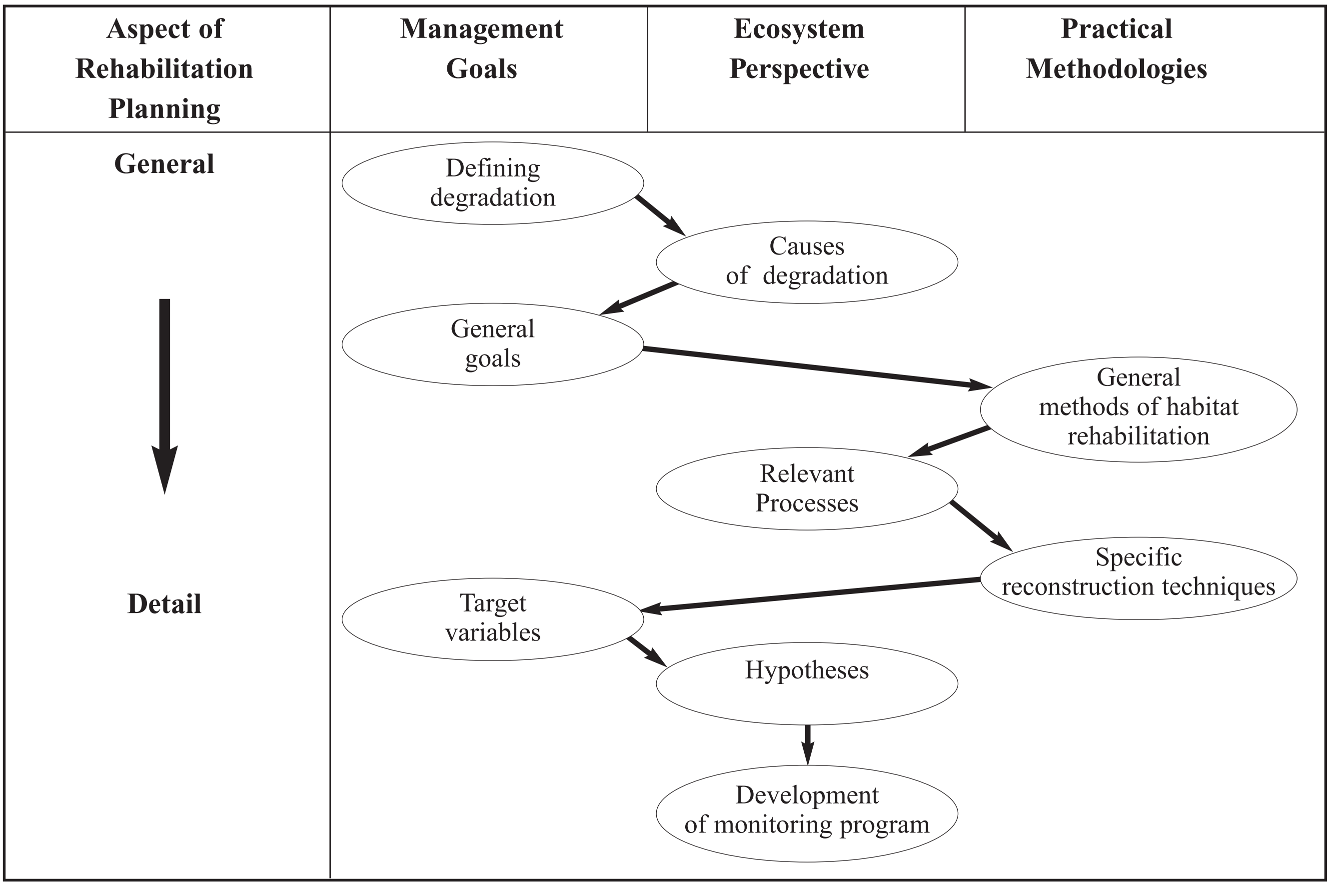

Figure 2. Steps Involved in Planning a Rehabilitation Experiment.
Planning normally involves some iteration through these steps.

rehabilitation have been identified. In this project we have started to consider ecosystem perspectives and practical methodologies, but have not yet considered management goals in detail.

The sequence of steps that links the three approaches identified in Table 1, leading from general issues to more specific rehabilitation details, is outlined in Figure 2 and forms the basis of discussion in this chapter. The important and general aspect of this structure is that the development of details regarding (1) management goals, (2) ecological models and (3) rehabilitation techniques, is integrated. This planning process is intended to be an integrated-consensus approach that includes all stakeholders.

2.3 Defining Degradation

There are no standard procedures for defining the environmental values that guide rehabilitation projects; this is an area that requires collaboration between the various stakeholders associated with particular river systems. Generally a lead agency would take primary responsibility for identifying environmental goals that reflect the values of their organisations and other stakeholder groups concerned with a rehabilitation project.

The Murray-Darling Basin Commission identifies "biodiversity and natural processes" as the goals of habitat reconstruction. This suggests that the Murray-Darling Basin Commission perceives any loss of biodiversity and modification of natural processes as degradation. In this context, natural processes could refer both to biological and physical processes. For this agency, degradation is defined as the process of reducing biodiversity or modifying natural processes in streams.

2.4 Causes of Habitat Degradation

Australian streams, including those in the Murray-Darling Basin (Mackay and Eastburn 1990), are considered to have been severely degraded since European settlement (Lake and Marchant, 1990). In particular, degradation is associated with a reduced stability of stream beds, increased salinity, reduced water quality through the introduction of toxic chemicals, an increase in nutrients and pathogenic organisms and reduced biodiversity and eutrophication. The following land-use changes, in particular, are thought to have contributed to this degradation (Boulton and Brock, 1999):

- Clearing of original native riparian vegetation and other areas within a catchment is thought to have contributed to salinisation, sedimentation and the presence of exotic species in streams and their catchments;
- Runoff and discharges from urban and industrial developments result in the introduction of toxic chemicals, eutrophication, thermal pollution and the introduction of exotic species in streams;
- Runoff from cropping land can contribute to eutrophication, sedimentation and salinisation;
- The introduction of toxic chemicals and exotic species; and
- Changes in flow and sediment regimes: due to the size, and economic and geographic importance of the Murray-Darling Basin changes in flow regime through river regulation by dams and weirs, by water extraction and by channelisation and associated activities, have also been particularly prevalent in this area. As flow, and the temporal and spatial variations in flow, are of major importance to stream ecosystems, changes in flow regime can have profound effects on the fauna and flora of streams (Boulton and Brock 1999).

In addition, degradation is considered to have resulted from the direct manipulation of the channel through:

- Removal of snags - this practice has been adopted in the Murray-Darling system in order to clear river channels for navigation, to remove perceived hazards for boating and swimming, and to increase channel conveyance. In soft-bottomed streams, snags represent the only solid surface available to the biota, as well as providing refuge and shelter for biota such as fish;
- Mining within the channel for sand, gravel and gold;
- Transformation of a natural channel to a uniform cross-section to alleviate upstream flooding;
- Engineered structures which are barriers to the passage of biota and nutrients;
- Channel stabilisation works; and
- The construction of artificial levees.

Projects aiming at the rehabilitation of habitats are more likely to be successful if the underlying causes of habitat degradation have been stopped or even reversed (Hobbs and Norton 1996). This requires that the processes leading to degradation have been identified.

2.5 Rehabilitation Goals

A common understanding of the project's goals is critical to the success of any rehabilitation project (Stewardson, 2000). The underlying assumptions of project objectives and what may realistically be achieved with rehabilitation must be clearly understood by all stakeholders in order to maintain consensus between the participants in the project. Assessing whether project goals are realistic is a basic but necessary step. If the causes of degradation cannot be manipulated, then the goals of rehabilitation may be unrealistic and the project is unlikely to succeed. Clarification of rehabilitation goals is of particular importance for rehabilitation experiments involving multi-disciplined teams and multiple stakeholders.

2.6 General Methods of Rehabilitation

The next step is identification of general methods designed to reverse or ameliorate the degradation. At this stage the aim is to identify whether general methods are available and practical for the project. Generally, these methods should reverse the causes of degradation identified in the previous step (e.g. riparian restoration). Hobbs and Norton (1996) discuss this process within the context of removing and reversing the effects of stressors on particular aspects of a given ecosystem. However, specific restoration techniques, designed to re-dress the problem caused by degradation (e.g. fencing of riparian areas, re-vegetating riparian areas, introducing woody debris) are not identified at this stage, as they ultimately will depend on specific goals within a given project.

2.7 Relevant Ecological Processes

Prior to developing measures to assess ecological changes in response to rehabilitation, potential ecological changes associated with the degradation must be identified. In order to do this, we need to identify the ecological importance of the particular aspect of a given ecosystem that has been altered. Natural systems are highly variable in their ecological characteristics and thus the validity of particular relationships between the ecological aspects of the system and its physical and chemical degradation should be examined in more detail, if possible. It is important to try and specify how physical, chemical or biological degradation can affect the biological aspects of a given system. Rehabilitation targets are often stated in terms of creating a change in habitat without identifying particular groups of biota that may benefit. If biological goals are set for a rehabilitation project then the outcome needs to be measured using biological parameters.

For example, information on the potential importance of riparian vegetation to stream ecosystems has been gathered from our present knowledge of the literature and from the input of advisors to this project. The riparian zones can affect aquatic life in several ways:

- by providing habitat for stream organisms in the form of large logs and space in areas undercutting the bank or amongst tree roots;
- by affecting the structure and stability of the stream bank, and influencing the geometry of the stream channel;
- by shading the stream channel and potentially affecting water temperature and primary production;
- by being a source of litter from terrestrial vegetation (in the form of bark and leaves), which can provide a substrate for fungal and bacterial growth or a food source for invertebrates;
- by influencing the input of sediment and nutrients to streams, from both surface runoff and groundwater;
- by providing inputs of terrestrial biota that may be important food resources for fish; and
- to provide resources for adult insects emerging from the stream.

2.8 Specific Riparian Rehabilitation Techniques

The next step is to identify more specific techniques for carrying out the habitat reconstruction. These techniques should draw on knowledge of the key processes involved with habitat degradation and goals for the project. The identification of specific techniques will then be used to refine goals into specific target variables and express assumptions regarding the effect of techniques as testable hypotheses.

For example, the recently released guidelines for the management of riparian land (Lovett and Price, 1999b) discusses management approaches, including:

- controlling nuisance aquatic plants,
- managing snags and large woody debris,
- controlling stream erosion,
- reducing sediment and nutrient delivery to streams using buffers,
- rehabilitating riparian vegetation, and
- managing stock in the riparian zone.

The techniques suggested to deal with these issues are:

- planting and encouraging natural regeneration of trees, shrubs, macrophytes and grasses,
- resnagging,
- removal of willows and other exotic trees,
- weed management,
- fire management,
- management of stock access, and
- soil inoculation.

2.9 Target Variables and Hypotheses

The next stage of the project is to develop hypotheses of how we expect habitat conditions to respond to habitat reconstruction measures. If we consider the example of riparian rehabilitation, rehabilitation is expected to result in narrower and deeper channels as a result of sediment trapped by vegetation along stream banks (working hypothesis 1). During periods of baseflow, riparian rehabilitation is expected to reduce stream temperatures as a result of shading in small streams only (working hypothesis 2). Riparian vegetation is also expected to increase the organic matter reaching the stream to support stream productivity and increase available habitat for biota, such as fish (working hypothesis 3). In the longer term, rehabilitation of the riparian zone is expected to result in increased abundance of instream large woody debris (working hypothesis 4) and an associated increased variability in the longitudinal bed profile (working hypothesis 5) and hydraulic habitat conditions (working hypothesis 6). Increasing spatial hydraulic variability is expected to increase the diversity of fish (working hypothesis 7).

Two general groups of variables have been identified that could potentially measure ecological effects of regenerating riparian vegetation:

1. Biological variables **(Tables 2 and 3)**.
2. Physical and chemical variables.

Biological variables were further divided into two groups, which reflected the general goals identified for this project by the Murray-Darling Basin Commission:

i. Variables measuring ecological processes **(Table 2)**;

ii. Variables measuring biodiversity **(Table 3)**.

These variables were also categorised according to whether they measured short-, medium- or long-term responses, and some indication of spatial scale was also provided **(Tables 1, 2 and 3)**.

Both temporal and spatial scales are important considerations when identifying the ecological processes that may respond to habitat rehabilitation. A major practical problem often encountered in rehabilitation projects is the relatively short time frames over which projects are conducted and are typically monitored. To overcome this problem, a monitoring and evaluation strategy has, therefore, been developed to include a range of measures, including measures of short-term ecological responses (e.g. around two years), others reflecting medium-term responses (for example two to ten years), and others reflecting long-term effects of the rehabilitation treatment (more than ten years). Measures of potential short-term responses will allow an evaluation of the rehabilitation success within the relatively short periods over which projects are normally funded (e.g. three years). Measures of medium and longer-term response, such as those proposed in Chapter 2, are particularly useful if they are cheap and easy to implement. Lake (2001) provides a discussion of time-scales of responses to restoration and selection of indicators.

Table 1. Ecological Processes that could Potentially be Affected by Riparian Vegetation.

Process	**Variable**	**Time-scale**	**Spatial Scale**
Nutrient Input and Spiralling	measures of nitrogen and phosphorus, above and below sites, accumulation at sites	short to medium	small-scale small-scale
Carbon Processing	measures of carbon and particulate organic matter, above and below sites, accumulation at sites	short to long	small-scale
Primary Production	chlorophylla	short to medium	small-scale
Decomposition	decomposition rates measured with e.g. litter traps	multi-scale	small-scale
Energy Processing	P/R ratios	long-term	small-scale
Coarse Woody Debris Input	Abundance	long-term	small-scale

Table 2. Measures of Biodiversity which may Respond to Riparian Regeneration.

Diversity	**Variable**	**Time-scale**	**Spatial Scale**
Shoreline Vegetation, Including Macrophytes	composition and density	short-term	small scale
Riparian Vegetation	composition and abundance	short to long-term	multi-scale
Target Taxa (e.g. Freshwater Shrimp)	presence and abundance	short-term	multi-scale
Fish as Target Taxa	aggregation	short-term	large scale (at least 500 m length reach)
	habitat use	short-term	large scale (at least 500 m length reach)
	biomass	short to long-term	large scale (at least 500 m length reach)
	recruitment	medium to long-term	large scale (at least 500 m length reach)
	exotics vs natives	medium to long-term	large scale (at least 500 m length reach)
Freshwater Mussels	presence	long-term	small to medium
Terrestrial Invertebrates	composition, abundance	short to medium	small to medium
Terrestrial Vertebrates	presence, composition, abundance	medium to long	medium to large

Table 3. Physical Processes and Characteristics that may Respond to Riparian Regeneration.

Physical Process or Characteristics	**Variable**	**Time-scale**	**Spatial Scale**
Bank Erosion	mechanism of erosion, erosion rate	short-term (stock access) long-term (bank vegetation)	small
Sediment Deposition	volume of stored sediment	medium to long	small, medium and large
Channel Geometry	cross-section shape, mean channel width, variation in channel width, variation in longitudinal bed profile	medium to long	medium to large
Bed Material	composition	long	medium
Hydraulic Habitat	composition of flow types defined by flow type and substrate, distribution of velocity and depth	long	medium
Baseflow Water Quality	temperature, disolved oxygen	long	small

3. Principles of Experimental Design

One of the challenges of an inter-disciplinary evaluation project is harnessing the different perspectives of the parties involved in the task. In order to resolve these differences, some general principles of experimental design and analysis are discussed in this section. For many, these principles are self-evident and indeed are more comprehensively treated in texts such as the discussion of monitoring ecological impacts in rivers by Downes *et al.*, (2002). However, these principles have been included here in order to provide a common basis with which all parties can decide on a design for this habitat reconstruction experiment. This discussion attempts to focus on integration of different perspectives of the task rather than the precise details of experimental design.

3.1 Experimental Design

The classical experimental design for detecting environmental impacts (Before-After-Control-Impact: BACI) consists of two sites one at which some disturbance takes place and the control, which is not subject to the disturbance. Monitoring is carried out before and after the disturbance at both sites. The structure of a BACI design includes two fundamental components. First is the measure of baseline conditions, the before intervention sampling, so we can assess change correlated with the onset of human activity. Second is the inclusion of spatial control sites, so we know what would have happened if the human activity had not occurred. Green (1979) first suggested a single observation at each site before and after the impact. Such an approach ignores the possible effect of temporal variations in the absence of the experimental manipulation and provides weak inference for attributing environmental change to the disturbance unless the variable being examined is stable. It has subsequently been suggested that monitoring should be repeated through time at the two sites both before and after the impact (Bernstein and Zalinski 1983, Stewart-Oaten *et al.*, 1986). If observations can be taken concurrently at the two sites then they may be paired and the test is for a difference in the means of the sites before and after the disturbance. Underwood (1991) describes an analysis for the case when observations at the control and impact sites are not paired. Linear models (e.g. analysis of variance) are used to test if there is a change at the impacted site that is not observed at the control site. This test requires that replicate observations are sufficiently infrequent to prevent autocorrelation (Underwood 1993), or else the autocorrelation must be accounted for in the modelling process. The BACI design tests for a change at the impact site at the time of impact but does not rule out the possibility that the change is the result of some factor other than the treatment that only affects the impact site at the same time as the disturbance. To address this problem, Underwood (1992) presented a design in which there are replicated control sites. Replication of the control sites ensures that the change observed at the impact site is unusual and likely to be a result of the disturbance under investigation. Such designs can be readily applied to test the effect of habitat reconstruction where the impact site is the one subject to rehabilitation.

Even with replication of control sites, there is still a possibility that some aspects of the treatment site contributed to the response and that the response would not be observed if one of the control sites was chosen as the treatment site. The strongest inference about an impact or rehabilitation comes from a design that replicates the intervention (i.e. habitat reconstruction) at a number of sites that are ideally selected randomly from the set of rivers in which we are interested. The MBACI approach is a design in which multiple control and impact sites are monitored before and after the intervention (Keough and Mapstone 1995).

We are often in the situation where availability of resources precludes a full MBACI design and we have to compromise between the spatial and the temporal components. Where we cannot randomise which sites are treatments and which sites are controls, then it is very difficult to causally link any difference between controls and treatments without before data, some idea of what the sites were like without human intervention. However, we may be more willing to restrict or even forego before data if we can randomly allocate replicate sites as being treatment and control sites, because it less likely that other factors might confound our control versus treatment comparison. Nonetheless, a design that includes both replicated spatial and temporal (before data) components will always provide stronger inference if resources allow.

It is important to be aware of inferential limitations when one of these two components is compromised.

The above designs treat the sites and periods (i.e. before and after) as homogeneous sample spaces. In reality, there is likely to be both temporal and spatial patterns within these sample spaces. For example, there may be variations in species density between pools and riffles, between the edge of the channel and the thalweg, during different seasons of the year or in response to flood events. More importantly, responses at the sites undergoing habitat reconstruction may develop over time rather than occurring as a step change at the time of reconstruction. There are two things to note about these patterns. Firstly, these variations can increase the variability within each before and after set of observations and obscure variations resulting from habitat reconstruction. Secondly, these patterns may be important for interpreting the results of a study and for the development or any management recommendations (Underwood 1994). When designing an experiment, it can be difficult to specify the appropriate scales for sampling so they are consistent with the patterns of response variables associated with the underlying mechanisms controlling these variables (Underwood 1993). In such cases it may be desirable to design the monitoring program so that comparisons can be made at various spatial and temporal scales. Such designs require more observations and some thought about the scales of interest and are more complex to analyse statistically.

The important mechanisms associated with the river's response to habitat reconstruction or other factors affecting the response variables are sometimes better described in the physical sciences than in ecology. Mathematical models representing these mechanisms may use continuous predictor variables such as discharge or sediment load. If such models are available, they may be incorporated into the analysis. For example, consider a simple parameter such as flow depth. It would be foolish to monitor flow depths in a traditional BACI style experiment without considering the effect of discharge on this variable. If these models are regression models, they can be incorporated into the analysis of variance tests. For more complex models, alternative techniques need to be identified to incorporate them into an integrated ecological experiment.

Most of the standard ecological impact assessment designs focus on the detection of step changes in the response variable over the entire site (Downes *et al.*, 2002). It is also possible to consider samples through space and time as an ordered series and look for patterns in these series. In the temporal domain, we may be interested in longer-term responses that develop gradually rather than step changes at the time of habitat reconstruction. In the spatial domain we may be interested in the extent of the effect of habitat reconstruction downstream of the project site. Trend analysis is a more effective tool for detecting these changes. Such trends can be useful in identifying important processes and suggesting future management actions and experiments. However, it should be noted that the detection of a trend is not sufficient in itself to implicate the experimental manipulation as the cause of the trend. The use of before monitoring and control sites in addition to replication of treatments can provide the same role in confirming a treatment effect for trend analysis as for hypothesis testing using ANOVA techniques.

The important differences between experiments in which we are evaluating the performance of habitat reconstruction efforts and assessment of environmental impacts from some other disturbance is that we should have a target in mind. This target is likely to be related to some prior condition of the river but could also be the state of some reference river or an entirely different target (e.g. increased abundance of an exotic sport fish) depending on management objectives. In such cases, we are not only interested in whether or not there is a change at the project site but also if the direction of the change is someway towards the target condition (Downes *et al.*, 2002). There is a good argument that in addition to control sites that are in a similar state to the treatment site(s) prior to habitat reconstruction, we need reference sites representing the future desired state. Our test then becomes whether or not the site subject to habitat reconstruction has moved someway toward the reference state. A test of bioequivalence has been proposed for analysing such experimental designs (McDonald and Erikson, 1994).

3.2 Decisions vs. Conclusions

Tukey (1960) pointed out that managers and scientists require quite different levels of confidence in information for it to be considered useful. Whereas scientists require high levels of certainty before a positive effect of some treatment can be reported, managers are often required to act in spite of high levels of uncertainty and are therefore justified in using the best available information. Essentially, scientists are concerned with making conclusions that are unlikely to be proven wrong and managers with decisions that are justified based on the best available knowledge but may be shown as flawed in the future. This is not meant to imply managers are not interested in knowledge that is highly certain. Quite the contrary, such knowledge provides for more certainty in the outcomes of decisions and therefore more effective management. However, managers will make use of the best knowledge available in the absence of certain information.

In the classical hypothesis-testing framework, scientists examine the available evidence to decide if the null hypothesis (i.e. the manipulation has no effect) is accepted or if it is rejected in favour of the alternate hypothesis. In an experiment designed to test the effectiveness of habitat reconstruction, the null hypothesis would be that reconstruction does not restore some component of the stream, e.g. biodiversity or natural processes. The alternate hypothesis is that the habitat reconstruction does have the desired effect in restoring the streams biodiversity or natural processes. The level of confidence required using the classical hypothesis testing approach demonstrates the demand for high confidence levels by scientists.

Alternate hypotheses are generally only accepted at a significance level of 5%. This can be loosely interpreted as indicating that the probability that the alternate hypothesis is wrongly accepted (a Type I error) is less than 5%[4]. Traditionally, scientists are less concerned about failing to reject the null hypothesis when indeed the null hypothesis is false (a Type II error), although environmental impact assessment has seen more focus on Type II errors. **In terms of the stream restoration evaluation, scientists would place the burden of proof on the hypothesis that reconstruction has a positive effect. The "default" position is that habitat reconstruction fails to achieve the desired effect.**

Consider the two possible errors in an experiment to test the effectiveness of habitat reconstruction for restoring a river to some desired state;

- concluding that the project resulted in the desired restoration effect when in fact this was not the case, and
- concluding that the project did not achieve the desired restoration effect when in fact it was successful.

As we have already said, in the classical hypothesis-testing framework, we refer to these two errors as Type I and Type II errors respectively. The maximum probability of a type I error is the significance level[5], α.

In a good experiment we wish to minimise the probability of both errors. Our difficulty is that all things being equal, a reduction in the probability of one error results in an increase in the probability of the other. If we denote the probability of a type II error as β, the probabilities are related by:

$$1 - \beta = E\,\frac{\alpha\sqrt{n}}{s}$$

where:

n, is the sample size,

s, is the standard deviation between sample units and the effect size,

E, is the change in the variable of interest as a result of habitat reconstruction, for example a measure of biodiversity.

The term $(1-\beta)$, is referred to as the power of the experiment and can be interpreted as the probability of correctly concluding that habitat reconstruction had an effect.

An important consequence of this relationship is that reducing the significance level required for rejecting the null hypothesis (i.e. reducing α) reduces the power of the experiment (i.e. increases β), i.e. there is a trade-off required between power and significance

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[4] More correctly the significance level, α, refers to the probability of getting a particular sample statistic or more extreme value, under repeated sampling if the null hypothesis is true.

[5] If the probability of a Type I error exceeds the significance level then we do not conclude that the project is successful. This is the decision criterion we use in making a conclusion from our experiment.

level. This has particularly important implications for impact studies where failing to detect an effect when one has actually occurred (a Type II error) is perhaps more serious than detecting an effect when in fact there hasn't been one (a Type I error). In recognition of this, Mapstone (1995) recommends that the ratio of the probability of the two types of error (β and α) should be specified at the start of an impact study and the experimental design and significance level chosen to maintain this ratio.

Type II errors are important in this project, so the experiment must be designed to ensure sufficient power. Furthermore the commonly used significance level of 0.05 may not be appropriate for this study. It may be necessary to relax the significance level to ensure the experiment has sufficient statistical power. Consideration of power in experimental design requires specification of an expected effect size and knowledge of the sample variation.

3.3 Bayesian Analysis

Bayesian analysis of experimental results is an alternative to the traditional hypothesis testing approach. There are two important aspects of Bayesian analysis that set it apart from the conventional approach:

1. The results can be presented without making a somewhat arbitrary decision of whether or not an impact has occurred, and
2. Bayesian analysis allows an experimenter to incorporate prior knowledge of the likely effect of the treatment into the analysis.

Bayesian analysis provides a probability distribution for the variable of interest rather than the probability that it takes a range of values. In our habitat reconstruction experiment, the variable might be a measure of biodiversity or some characteristics of a natural process. Bayesian analysis can indicate the distribution of possible values given the observed experimental data. This approach allows others to assess the environmental significance of the effects rather than the experimenter. This is useful for communicating results between scientists and managers who may use different criteria for assessing the significance of the result. Nevertheless, for the results to be used to assess the success of habitat reconstruction, some decision criterion will need to be applied to the probability distributions provided by the Bayesian analysis. It could be argued that this decision criterion should be selected before conducting the experiment rather than during the interpretation of the results to prevent some form of bias.

The other major difference with Bayesian analysis is that prior knowledge regarding the impact of the treatment can be included in interpreting the results of the experiment. However, in some experiments regarding the effects of restoration experiments, it could be argued that we have little prior-knowledge. In such circumstances, Bayesian analysis and traditional hypothesis testing will give similar results.

As Downes *et al.*, (2002) point out, the selection of which type of analysis is used is independent of the experimental design and both forms of analysis could, in theory, be applied to the same experimental results. Given the poor knowledge of the effects of habitat reconstruction, traditional hypothesis testing may be a more suitable approach in many rehabilitation experiments. However, the statistical power should be established at an acceptable level and significance level should reflect management interests. Downes *et al.*, (2002) provide a systematic procedure for optimising a monitoring program to provide adequate power.

3.4 Effect Size (E)

In the previous sections, it was pointed out that given a certain experimental design, in our analysis of the results, there is a trade-off between the probability of Type I and Type II errors. From Equation 1, it is apparent that we can enhance the statistical power or our experiment for a given significance level by increasing the effect size.

There are two ways of increasing effect size:

1. Use a treatment that is expected to have a larger response, or
2. Select response variables that are more sensitive to the form of habitat reconstruction being considered.

For the case of riparian restoration, greater effect sizes may result from restoring longer river reaches, incorporating management of stock access with revegetation, or restoring a wider zone along the channel. Response variables are discussed in the previous chapter. However, the important thing to note with respect to choosing more responsive variables is that such variables must have a large change in response to the treatment over the period of monitoring. Furthermore this change must be large relative to variation between samples.

It is likely that the overall response of a site to restoration will be detected on the basis of a number of observations through time and space at each site. Temporal and spatial variations in observations will result from the natural dynamics of the river and random observation errors. For a given monitoring program, greater temporal variations will result in greater noise in any comparisons used to evaluate the performance of habitat reconstruction obscuring any response to habitat reconstruction. Taking a greater number of more accurate observations can achieve reductions in this noise. The feasibility of increasing the intensity of measurements will depend on the costs of taking individual observations.

If the natural dynamics of the response variable are understood, this understanding can be incorporated in the evaluation to make better use of the observations. For example, if there is a strong seasonal pattern, it may be decided to take observations at a critical time of the year or to pair sample observation at the treatment site with observations at some other site. Alternatively, season may be treated as an additional factor in the analysis. Many physical variables will respond in a predictable way to discharge variations. This knowledge allows us to take observations at fewer discharges and predict conditions at other flow levels using established models. Alternatively comparisons between sites could be based on changes at a specified discharge.

Choosing response variables to give greater statistical power should be based on:

a. the expected effect size for the treatment on each variable,

b. a pilot study or other source of data which provides the spatial variation in the variables,

c. variations in observations at a site (which includes measurement errors and temporal and spatial variations),

d. understanding of factors influencing temporal and spatial variability, and

e. the number of observations that can be feasibly taken (which depends on their cost).

If these attributes of response variables are not precisely known, some estimate may be used to provide, at least, a guide for selection of more responsive variables. Such estimates will not compromise the results of the study but do provide a more reliable approach to experimental design. It should be added that the requirement for statistical power is not the only factor to be considered when selecting response variables. The response variable must also relate to the objectives of the habitat reconstruction project.

3.5 Sample Variation (s)

The power of an experiment is inversely related to variability in the response variable between sample units. Greater background variation makes it more difficult to detect a response to habitat reconstruction. Such variability can be reduced in a number of ways. The simplest approach is to restrict the range of sites considered by specifying a region or stream type that is to be considered. For example, constraining the study to rivers smaller than some objectively defined size is likely to reduce the variability in the response variables between sites and increase the power of the experiment.

An alternative approach is to include additional factors in our analysis in a multi-factor design. For example, we might want to consider stream size as an additional factor, treated as a continuous variable or we could define size categories for the rivers and compare response between these sizes. Generally, the more factors we consider, the more samples are required in order to provide an adequate data set to test their influence.

If the sources of high variability can be identified in advance, pairing of control and treatment sites may be a useful way of improving the power of the experiment. Pairing may be useful for sites, located over a large region with different geology or climate. Paired sites would be located relatively close to each other. Pairing could also be arranged according to stream size, catchment land use or biology.

3.6 Meta-Analysis and Multiple Lines of Evidence

If a sufficient number of relevant studies have been published in the literature, it may be possible to analyse this data to indicate the performance of habitat reconstruction. Such an argument can then be strengthened or altered in response to new research or the results of on-going restoration projects. One approach is meta-analysis, which usually refers to a formal statistical approach of combining effect sizes from different studies with some measure of variance in these effect sizes and testing for an overall effect. Downes *et al.*, (2002) summarise an approach used in epidemiology in which multiple lines of evidence are considered in a well-structured procedure to make some recommendation for the likely impact of a treatment. Such an approach may be a good interim measure while experiments are undertaken, assuming the information is available in the literature.

However, the results of meta-analysis or a multiple lines of evidence approach are unlikely to provide much certainty when dealing with the poorly understood ecological processes associated with stream restoration. Quinn and Keough (2002) also point out that there is bias towards publishing only statistically significant results so that non-significant results, possibly indicating no effect of restoration, will be under-represented in the literature.

4. Approaches to Evaluation

This section discusses three approaches to evaluating the effectiveness of habitat reconstruction.

1. Post-project evaluation: examining conditions at sites that have been subject to habitat reconstruction sometime in the past.
2. Combining management and monitoring: design a monitoring and evaluation program as a part of a current habitat reconstruction project.
3. Dedicated experimentation: design an experiment with the sole objective of improving our knowledge of habitat reconstruction.

The potential advantage of the post-project evaluations is the possibility of examining longer-term responses. This has particular benefits for riparian zone restoration, which may take decades to achieve a stable condition following restoration. The advantage of combining management and monitoring is the possibility of collecting data before habitat reconstruction and influencing the habitat reconstruction work (including site selection) to learn from the experience. The advantage of a dedicated experiment is that aspects of experimental design such as site selection and the selection of experimental treatments (i.e. form of habitat reconstruction) are not constrained by the normal management priorities associated with habitat reconstruction projects, and can be specified to suit the sole objective of improving the knowledge base for future rehabilitation projects.

4.1 Post-Project Evaluation

The first approach to evaluating the effectiveness of habitat reconstruction works is to use sites that have been restored at some time in the past. An advantage of this approach is avoiding the need to carry out habitat reconstruction works and waiting for responses to develop saves funds and time. Two approaches to this type of evaluation are possible. One type is referred to as space-for-time substitution (Section 4.1.1). With this method, temporal trends are inferred from the study of sites that were restored at different times. The alternative approach is to ignore temporal trends in response and compare restored sites with control or reference sites (Section 4.1.2).

4.1.1 Space-for-Time Substitution

Ergodic theory or space-for-time substitution (SFT) involves inferring a temporal trend from a study of different aged sites (Schumm *et al.*, 1984; Pickett, 1989). The ergodic hypothesis states that, “an infinitely long record at one point has the same statistical properties as a record taken over an infinite number of spatial assemblages at a particular point in time” (Harvey, 1967). The assumptions and limitations of this technique are (1) the assumption that processes operating in the stream are the same as they were in the past, (2) that we correctly understand the cause of variability in our models, and (3) that suitable sites can be identified. With these assumptions in mind, ergodic theory could be a powerful tool for assessing recovery processes associated with habitat reconstruction.

Space-for-time substitution has been used extensively in geomorphic studies to document long-term changes to river systems (Fryirs and Brierly, 2000; Hupp, 1997; Keller, 1972; Schumm, 1984; Simon, 1989; Simon, 1995). Space-for-time substitution has also been applied to successional studies, including small mammal succession following sand mining (Twigg *et al.*, 1989) and vegetation succession following disturbance (van Aarde *et al.*, 1996; Larsen and MacDonald, 1998). The tool is more commonly used in geomorphology where it is often not practical, or even possible, to observe the full evolution of geomorphic processes, some of which can take hundreds of years to occur. As yet, ergodic theory has not been used in the area of stream restoration or evaluation.

The feasibility of using SFT to assess riparian zone rehabilitation is dependent on:

1. Identifying sites that are similar in all respects except the time since restoration; and
2. The response trajectory in stream condition to the increasing age of the vegetation be monotonic between the times represented by different aged sites (Michener, 1997). Pickett (1989) notes that for SFT to be an effective method, all sites must share the same trajectory and end point. If this is not the case, reversals in trend and alternate pathways to end points may not be observed, and the true effect of the riparian restoration not known. For example,

wattles colonise quickly and provide a dense shade to the stream in a short time, however they are a short-lived species and will eventually die and be replaced by secondary successional species. The shading effect produced by the successional change in species would not be linear, and may not be picked up by SFT unless sites are sufficiently close in age.

A major limitation of applying this approach to studying the response to habitat reconstruction is the availability of sites. To examine this issue, Ezzy (2001) located sites in north-east Victoria subject to riparian restoration and considered their suitability for SFT analysis. Based on consideration of the key processes associated with recovery following riparian restoration, the following constraints were applied to site selection:

- Vegetation must be continuous along reach with a minimum length of 250 m, the minimum length required in order to detect an effect on stream temperature (Rutherford *et al.*, 1997).
- Vegetation must be a minimum of 10m wide, the minimum width for a buffering effect (Lovett and Price, 1999a).
- Channel width must be no more than 10-15m, the maximum width for an effect of shading the stream (Lovett and Price, 1999b).

Consultation with the North-East Catchment Management Authority (CMA), the Goulburn-Broken CMA, and the Department of Sustainability and Environment stating these requirements and exploring the most efficient way of identifying suitable sites highlighted the lack of documentation on revegetation work. Until recently, records of revegetation were almost non-existent and could only be gleaned from records of physical works, such as the construction of rock chutes, with which revegetation was often associated. Knowledge of where revegetation work is located exists almost solely in the memories of the people who undertook the work.

Potential study sites were identified by field visit in consultation with CMA representatives. Sixty-five potential sites were identified over four days.

The site inspections indicated the following difficulties with applying SFT to assess recovery following riparian restoration using these sites:

- *Incised streams (25% of sites):* Several of the sites occur on incised streams. These sites were considered unsuitable for the study because the effect of the vegetation on the stream will be compromised by the incision. For example, any shading due to vegetation will be negligible when compared to the shading caused by steep, incised banks (Rutherford et al., 1997). Similarly, the root ball of trees rarely extends more than 2 m and hence will have little binding effect on very steep banks (Lovett and Price, 1999a).
- *Remnant vegetation (4% of sites):* Several sites had extensive remnant vegetation as well as new revegetation. This would make it impossible to relate the effect of the vegetation on the stream to the age of the vegetation.
- *Stock access (25% of sites):* Where stock have access to young vegetation the trees are eaten and, if they live, are stunted and have much less dense canopy than would be expected. These sites are unsuitable for the study.
- *Sand slug (1 site):* One site has a sand slug making the substrate too different from the other sites to allow comparison.
- *Banks unrestored (1 site):* One site had vegetation planted only on one bank.
- *Restoration technique:* A major component of the variability between the sites appears to come from the vegetation. Visual inspection of sites has shown that planting regimes have changed over time and this has been supported by discussions with CMA representatives (Table 4). Three different practices are identified for these sites: past practice (5 sites), interim practice (53 sites) and current practice (7 sites). It is only since 1999 that riparian restoration has been undertaken independently of instream works and consisted entirely of native species.

Of the 65 sites inspected, a total of 54% are considered unsuitable for SFT analysis of recovery potential following riparian restoration for one or more reasons (Table 5). This leaves 46% (or 31 sites) that are suitable for the study. However these sites should be considered as representing three different treatments corresponding to past, interim and present riparian restoration practice. Including these different treatments in a single SFT analysis violates the

Table 4. Changing Practices in Riparian Restoration in North-East Victoria.

Past Practice (1981 to 1989)	• Revegetation performed only in conjunction with engineering works such as rock chutes. • Mainly exotics such as willows and poplars planted. • No management of the riparian vegetation.
Interim Practice (1990 to 1998)	• Combination of exotics (in channel) and natives (higher on banks) used. • Little management of riparian vegetation. • Mainly carried out in conjunction with engineering works.
Current Practice (1999 to 2001)	• Revegetation recognised as a stand-alone restoration objective. • Species sourced locally and attempt made to imitate pre-disturbance density and composition (including consideration for understorey and aquatic species). • Management of riparian zone, such as stock exclusion and weed control, made a condition of CMA revegetation support to landholders.

assumptions of the method. It is the performance of current practice that is of most interest to managers and we can find only five sites subject to current management practice that are suitable for SFT analysis in north-east Victoria. Of these, four sites were restored in 1999 and one site in 2001. This is an insufficient number of sites to justify the application of SFT analysis for this region. There may be sufficient sites to apply SFT analysis to the sites subject to interim practice. However, these results will be confounded by variations in the instream works conducted at many of these sites at the time of riparian restoration. Furthermore, management is more interested in the performance of current practice.

4.1.2 Comparison of Restored and Control Sites

An alternative approach to SFT analysis is to compare sites that have been restored with (i) degraded sites in an unrestored state and, (ii) sites that have not been disturbed (reference sites). Successful restoration would be indicated if the restored sites were more similar to the undisturbed sites than the disturbed sites. This approach has been referred to as bio-equivalence, since we are testing for similarity between the restored and undisturbed sites. In the north-east Victoria region, there are four sites subject to riparian restoration in 1999 that could be evaluated in this way. However, closer examination of these sites has highlighted further problems in making such comparisons. For example, an extreme flood catastrophically altered the morphology of one of the sites (Black Ranges Creek) in 1993. Riparian restoration work was an element of a more comprehensive restoration program at this site to address the changes induced by this flood, including reconstruction of the channel and channel stabilisation works. It is unlikely that we can distinguish any response to riparian restoration at this site from responses to the flood-induced changes and subsequent instream works.

Table 5: Summary Statistics for Sites in North-East Victoria Subject to Riparian Restoration.

Practice	Number of Sites	Stock Access	Incised	Remnant Veg.	Sand Slug	Planted on One Bank	Suitable Sites
Past	5	0%	20%	0%	20%	0%	60%
Interim	53	28%	28%	6%	0%	2%	43%
Current	7	29%	14%	0%	0%	0%	71%
All	65	25%	25%	4%	1%	1%	46%

One of the major benefits of an experiment based on past restoration works is that it is more feasible to examine longer-term responses. Unfortunately, many of the older sites are likely to be unsuitable for this study because they were generally "restored" using exotic plant species such as willows rather than with the native vegetation that is now preferred. Furthermore, information regarding the state of the older sites prior to restoration and the nature of the restoration work is unlikely to be available. For example, Ladson (2001) evaluated the performance of river management works in the Mitchell River catchment. He found that the lack of historic data, including photographs and design drawings, made it difficult to determine the location of previous works accurately because sites were identified by landholder name rather than map coordinates. Relevant documentation and people familiar with the project are more likely to be available for more recent projects.

These two factors: (a) dissimilarity of the work carried out at previous project sites with current practice and (b) lack of available project documentation, means that the most useful information relates to recently rehabilitated sites. In the case of north-east Victoria, only sites restored since 1999 would be included. This would undermine the major benefit of using past restoration sites as there has been insufficient time for longer-term ecological responses at these sites. This problem is likely to be encountered elsewhere and with other forms of habitat reconstruction.

Another limitation of using past restoration projects is the possibility of pseudoreplication (Hurlbert, 1984). In a well-constructed experiment, the experimental sites (restoration sites, control sites and reference sites) would be interspersed throughout the region being considered. The use of previously restored sites restricts us to using sites deemed worthy of restoration by the relevant management authority. It is unlikely that such sites will be representative of sites within the region. For example, sites may be close to town centres or public space, or they may be sites subject to severe erosion. It is quite possible that restored sites are a biased sample of streams within a region, making it difficult to infer the general benefits of restoration.

4.2 Combining Management and Monitoring

This section examines the use of current restoration projects for evaluating the effectiveness of habitat reconstruction work. The conventional approach to evaluating such project is to undertake a monitoring program in parallel with the stream management work. This approach is described as conventional monitoring and is discussed in Section 4.2.2. With the support of management agencies involved, it may also be possible to transform a conventional habitat restoration project into an adaptive management project (discussed in Section 4.2.1), in which management interventions are deliberately selected to improve our knowledge of restoration ecology. Adaptive management requires integration of scientific and management goals in the planning stages of the project.

4.2.1 Adaptive Management

Adaptive management refers to a structured process of "learning by doing" in which management actions are designed as experiments, which are intended to improve the knowledge base for future management decisions (Walters, 1997). Adaptive management begins with a focussed effort to integrate existing inter-disciplinary knowledge into models that make predictions about the impacts of alternate management policies. The modelling step serves three functions:

1. Problem clarification and enhanced communication among scientists, managers and other interested parties,
2. Policy screening to eliminate options that are unlikely to achieve the management goals, and
3. Identification of key knowledge gaps that make model prediction uncertain.

A key element of successful adaptive management is a strong commitment by all parties to learning. On the basis of this commitment, parties accept that management decisions will be made not solely for purposes of achieving local management goals but also to improve the knowledge base. This commitment can be difficult to achieve, particularly when the primary focus of managers is with meeting the interests of the community affected by the project. Compromises that may be required of adaptive management projects in achieving their knowledge goals include (i) carrying out just one management intervention at project sites and, (ii) selecting sites in a way that provides for strong inferential power rather than according to management priorities.

Adaptive management can be a powerful tool for capitalising on restoration projects to improve the knowledge base but they require a considerable level of commitment from management and scientific agencies and will not be feasible in many cases.

4.2.2 Conventional Monitoring

Not all projects that incorporate monitoring can be considered as adaptive management. If experimentation is of secondary importance to other management imperatives, monitoring and evaluation become an "add-on" to the project. In these projects, decisions regarding site selection and the works carried out at the project sites are based on conventional management priorities. Monitoring may be actively supported by the management agency but

EXAMPLE 1:

The North Johnstone River Catchment Riparian Zone Management Model

As an example, the first stage of adaptive management for riparian zone management model building, was undertaken by a group of Australian scientists who were interested in the effect of riparian zones on stream values (Wilson *et al.*, 1996). The North Johnstone River Catchment, Queensland was chosen as the case study for this modelling work. The model was developed during a workshop of all the stakeholders in the research project and other interested parties. It is a time-series simulation model that includes algorithms representing monthly runoff from 1 km^2 grid cells, sediment and nutrient generation, the effect of riparian vegetation on material trapping, stream hydraulics, bank erosion, temperature and stream habitat. The interest in this project was identifying knowledge gaps to stimulate a research program rather than guiding management experimentation. However, the project demonstrates that there is an adequate knowledge base to support adaptive management of riparian zones. The details of experimental design and analysis for such an experiment would depend on the outcomes of the modelling stage of the process and the commitment of the management agencies involved. It is likely that the design would be one of those discussed in Section 3.1 and may be similar to the dedicated experiments discussed in a later section.

EXAMPLE 2:

The Campaspe River Flow Manipulation Experiment

The Cooperative Research Centre for Freshwater Ecology initiated an adaptive management project involving environmental flow releases from Lake Eppalock on the Campaspe River. A multi-disciplinary team assisted in the planning of the environmental flow releases. Within the constraints of current commitments of water to consumptive uses, Goulburn-Murray Water was willing to provide the environmental flow as recommended by this group. This management agency had a strong commitment to learning rather than simply meeting their management responsibilities. Monitoring has been undertaken downstream of Lake Eppalock and in a control river, the Broken River, before and after implementation of the new environmental flow rules. The project has only recently moved into the post impact phase.

One of the main challenges of the Campaspe River project has been in maintaining support for the monitoring program, mainly because of a delay in implementation of the environmental flow rules because of a sequence of dry years. However, the project has already demonstrated that adaptive management can provide new knowledge. Preliminary analyses of biological data have resulted in the development of new hypotheses regarding the effect of flow regulation on fish populations. The results of interrogating the data being collected in this long-term and large-scale project are likely to provide a major contribution to stream ecology regardless of the outcomes of the study. Such a project would not have been possible without the integration of management and scientific interests.

the habitat reconstruction treatment is chosen for its suitability for the site rather than for the purpose of experimentation. A difficulty with such projects is that they are seldom based on a thorough consideration of the ecological processes involved. Time and funding constraints demand a simpler appraisal of the problem and the adoption of "best management practices". This approach can inhibit the monitoring and evaluation process. Some potential challenges with conventional monitoring projects are summarised here (For further discussion see Lake, 2001). Not all projects will be subject to these limitations:

Poor planning: It is common for habitat reconstruction projects to have unclear targets and fail to identify the reference condition that is the intended end point for the river being restored. This makes it difficult to establish and test hypotheses when evaluating the success of the project. Some projects overlook important factors that can override the effects of riparian restoration or adopt practices based on flawed assumptions. Monitoring is generally a costly exercise and there is little justification for monitoring a poorly planned project.

Complex projects: Most habitat reconstruction projects combine more than one technique of habitat reconstruction and sometimes include works carried out for purposes other than environmental improvement. For example, it is common for riparian restoration to be combined with bed and bank stabilisation works such as rock chute construction or the placement of rock on the stream banks. In these projects, it would be difficult to distinguish the effects of riparian restoration from other works carried out at the site. On-going management, particularly if it is poorly planned or inconsistently applied at the project sites or through time, can also confound any evaluation program.

Site selection: Habitat reconstruction projects may be conducted at sites that have quite unique characteristics. Sites close to urban centres may be restored because of their higher profile, or sites subject to flood damage or erosion may be restored because funding is available to address these problems. If these sites are not typical of sites within the region, it will be difficult to use the results of a conventional monitoring program to guide works elsewhere.

Timing: Sites for stream management works are rarely chosen more than one year in advance. This makes planning and implementing any effective monitoring before habitat reconstruction works nearly impossible. Given the individual nature of restoration projects, the collection of pre-rehabilitation data is crucial to any conventional monitoring project.

Remedial works: If the monitoring program reveals some problem associated with the habitat reconstruction work, it may be difficult to discourage management agencies from rectifying the situation. However, remedial works run the risk of invalidating the monitoring and evaluation program.

It is important to ask if conventional monitoring projects will provide useful information to guide the planning of future habitat reconstruction efforts. We recommend that conventional monitoring should only be undertaken when:

1. There is sound project planning, including the setting of clear targets,
2. The sites are not atypical of sites that might be considered for restoration in the future, and
3. There is sufficient time for the collection of data before rehabilitation works are implemented.

The monitoring of complex projects may be acceptable if the combination of works undertaken at the site is well planned and typical of projects undertaken elsewhere.

The use of 'before' monitoring and control sites is essential for making reliable conclusions regarding the performance of habitat reconstruction at the site. If several of these projects are completed, it may be possible to use some form of meta-analysis to pool the results and to make inferences regarding the performance of habitat reconstruction works. However, if the performance is inconsistent, it will be difficult to identify the reason for the inconsistency because of the large number of factors that will vary between the projects. Inconsistent results may suggest that habitat reconstruction is unreliable and discourage future work rather than providing insights regarding successful aspects of the work.

EXAMPLE 3:

Broken River and Ryans Creek Habitat Enhancement Project

A conventional monitoring project was carried out on two reaches in the Broken River catchment, one on the Broken River and one on Ryans Creek (Stewardson, 1999). This was one of the first documented studies in which the biological and physical performance of habitat reconstruction in an Australian stream was evaluated, and illustrated the challenges of conventional monitoring. Although biological monitoring began one year before the works were undertaken, physical monitoring was commissioned less than one month prior to restoration, allowing time for only a single survey to be conducted in the 'before' monitoring period. Insufficient time, funds and experience with this type of project meant that that no control sites were included in the monitoring program. A review of similar projects in the United States showed that it was common practice to monitor changes before and after restoration work but none of the studies included in the review used control sites.

Similar work was carried out at both sites. This work included the placement of large woody debris and boulders in the channel, channel stabilisation works, revegetating the riparian zone and stock exclusion. The habitat enhancement objective of the project was to increase physical habitat diversity. Despite the similarity of works at the two sites, the responses in the following year differed markedly, with habitat diversity increasing at the Broken River site and decreasing at the Ryans Creek site. It is possible that these changes occurred in spite of the work rather than as a result of it. The different responses at the two sites complicated the interpretation of the study and reduced its ability to advise management on future works. However, monitoring at the Ryans Creek site showed that the site had high habitat diversity prior to the works. This fact highlights the poor state of knowledge available to the management agency when planning this project. An assessment of habitat diversity before the work was carried out would have confirmed the high habitat diversity in Ryans Creek and that 'rehabilitation' was not required. This would have required the involvement of scientists with some knowledge of the ecology of the system and careful specification of management objectives. Resources are seldom made available for such detailed planning.

Despite the difficulty of making inferences from an experiment of this type, some suggestions could be made to guide future projects. Careful examination of the patterns of physical changes within the reaches suggested that placement of logs in shallow areas tended to result in deepening and narrowing of the channel and loss of shallow water habitats. This appears to have lead to the reduction in habitat diversity at the Ryans Creek site. As a consequence of this observation, the management authority involved does not place large woody debris on riffles. The project also indicated how project planning could be improved. More recently, the same management authority has undertaken an instream habitat reconstruction experiment in collaboration with scientists beginning with a very detailed and rigorous planning process to identify the cases of degradation. The more useful results of the study were not directly related to the gross-scale changes in habitat diversity, rather it was scrutiny of higher resolution data and the planning process that provided valuable insights. It is unlikely that observations at control sites would have substantially altered the recommendations of Stewardson's (1999) study.

4.3 Dedicated Experiment

The final approach to evaluating the effectiveness of habitat reconstruction is conducting a dedicated experiment designed to provide reliable and useful inferences regarding the performance of the habitat reconstruction. Scientists are best equipped to design and run such projects, in collaboration with management agencies. This type of experiment is designed to test clearly defined hypotheses and provide good statistical power within the constraints of available resources. Experiments focus on a small number of treatments, possibly limited to a single type of habitat reconstruction, preferably with a BACI type design. If more than one control or impact site is available, site selection should represent the range of conditions of rivers in the region. Randomised site selection is preferable but may not always be possible.

The advantage of a dedicated experiment is the ability to make inferences based on the experimental results and that some confidence can be placed in these inferences. A limitation is that, in order to achieve reasonable statistical power, the range of site types and methods of habitat reconstruction will necessarily be limited and monitoring costs may be quite high. In an extreme case, such experiments may be viewed as irrelevant by management agencies, which often carry out very complex projects at sites with a broad range of histories and with only limited resources.

Rigorous planning and a sound ecological basis means that data collected in dedicated experiments can be used to explore underlying mechanisms responsible for changes in the condition of the river, to generate hypotheses for further research, and to suggest improved management approaches. Funding for these projects may be difficult to obtain because they do not address an immediate management need and can take a number of years before their conclusions are available. In some cases, there may be a concern by management agencies that scientists are more concerned with advances in research than pursuing knowledge that is useful for management.

4.4 Summary

The following recommendations are made in regards to the evaluation approaches discussed in the chapter.

- There are insufficient suitable sites that have been previously subject to habitat reconstruction work to conduct post-project evaluation
- An adaptive management approach has some merit. However, it must be recognised that the results of a several projects will be required before we can assess the general performance of habitat reconstruction work. Whilst possible, comparing results across studies will be complicated by variations in the nature of the work carried out. High levels of confidence in results of these comparisons are not expected.
- Conventional monitoring is considered less useful than adaptive management because of a number of factors but in particular because of the possibility of poor project planning.
- A dedicated experiment is the most effective approach for improving our knowledge of the performance of habitat reconstruction. The limitation of this approach is that it is likely to be narrowly focused on a single type of stream and form of riparian restoration.

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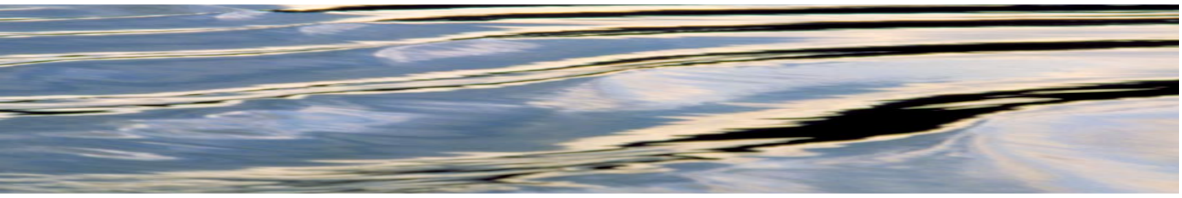

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