Evaluation of the Impact of Research Projects Relating to Australia's Natural Resources (Second Update, 1993 Group)

TEMTAC Pty Ltd

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Contents

List of Tables

List of Figures

Preface

In 1993, the Land and Water Resources Research and Development Corporation (LWRRDC) commissioned an independent evaluation of a number of projects receiving LWRRDC funding. At that time, most of the projects inherited by LWRRDC when it was formed in 1990 had been completed, and a new series of projects was commencing which reflected the Corporation's new purpose and research focus.

The procedure called 'life-of-project evaluation' has been designed to assess the cost–benefit performance of research projects, first at project commencement and then at approximately two-year intervals as research proceeds and adoption of research technical outputs takes place. The life-of-project evaluations are designed as a measure of accountability with respect to research funding, to provide planning information which will assist in project selection, and explore the extent to which economic evaluation is feasible and consistent over time.

A representative selection of seven projects from the LWRRDC portfolio was made in 1993; initial evaluations conducted at that time are reported by McGregor et al. (1994)[1]. At that time, the projects had recently commenced or were about to commence. An update of the evaluations was commissioned in 1995, with findings reported by Harrison and Tisdell (1997)[2].

This report describes the second update of the life-of-project evaluations, carried out over the period November 1998 to April 1999, ie. three years after the first update and nearly six years after the initial assessments. This update has been designed to review how the projects have proceeded relative to initial predictions, and to make revised estimates of technical outputs, project outcomes, economic performance and monitoring requirements. The update involves a reassessment of those matters dealt with in the earlier terms of reference, taking into account that the projects have now been completed and adoption of the technical outputs is in progress.

It is notable that, even at this time, the evaluation cannot be considered ex post, in the sense that technology transfer is still in progress and for some projects adoption is still at an early stage. The evaluation provides useful insights into a number of issues: how estimates of economic performance for projects change over time; effectiveness of technology transfer measures, and of adoption processes and progress in both the private sector and resource management agencies; and viability of monitoring technical outputs and practical outcomes.

The terms of reference for the current and earlier evaluations follow.

1. McGregor, M.J., Harrison, S.R. and Tisdell, C.A. (1993), *Assessing the Impact of Research Programs Related to Australia's Natural Resources*, LWRRDC Occasional Paper Series No. 08/94, Canberra.

2. Harrison, S.R. and Tisdell, J.G. (1997), *Evaluation of the Impacts of Research Programs Related to Australia's Natural Resources (1993 Group; Phase 2)*, LWRRDC Impacts of Research Series, No. IR03/97, Land and Water R&D Corporation, Canberra.

Terms of Reference for Current Study and Earlier Evaluations

Current Study

This report was prepared under the following terms of reference:

- Revise the assessment of technical outputs, risks, resource management linkages, adoption patterns and social cost-benefit payoff from each of the projects which were included in the earlier initial studies.
- Compare updated project performance characteristics against those predicted in the previous evaluations, and examine reasons for differences.
- Review the information (being) collected during the course of the projects (and program) and define any changes needed in information collection for any subsequent life-of-project evaluations.
- Report to the Corporation on each of the topics listed above.

This update will revise the technical outputs, risks, resource management linkages, adoption patterns and social payoffs of each project, as they can be observed now, and compare them against predictions in earlier evaluations. More specifically, updating will be carried out with respect to:

- research performance: researchers' aims, achievement of milestones, expenditure levels, variations negotiated with LWRRDC;
- technical outputs of the research: products, processes, improved management techniques, other information;
- development and adaptation of research to a form suitable for end users;
- extension activities;
- research, development and extension costs, including costs of both LWRRDC and host organistion;
- potential users, barriers to adoption, adoption rates;
- market and non-market benefits; and
- future monitoring requirements.

Earlier Evaluations

The terms of reference for the first update in 1995–96 were as follows:

1. Revise the assessment of technical outputs, risks, resource management linkages, adoption patterns and social cost–benefit payoff from each of the seven projects which were included in the initial evaluations.
2. Compare updated project performance characteristics against those predicted in the initial evaluations, and examine reasons for differences.
3. Review information being collected during the course of the projects and define any changes needed in information collection for any subsequent evaluations.
4. Report to the Corporation on each of the topics listed above.

The terms of reference for the initial evaluation in 1993 were:

1. The consultant is required to comment on the initial selection of projects and programs for impact assessment in the light of the total spread of projects funded by the Corporation.
2. The consultant is required to carry out an initial prospective (ex-ante) impact assessment analysis, including:
   - a definition of technical outputs expected (products, processes, improved management techniques or other information);
   - an assessment of the likelihood of the project/program achieving such technical outputs;
   - an examination of the linkages between the technical outputs projected and how they may be used to manage resources and to effect change;
   - an examination of the profiles of adoption of such technical outputs by resource users and managers in order to effect change; and
   - an examination of social investment criteria for each project, using the project cost and valuation of benefits through the market, or by using non-market valuations.

3. The consultant is required to identify information, which can be collected during the course of the project or program, that can be used in a final impact evaluation for each project. These data should refer not only to variables defined in the linkages stated in the prospective analysis, but also to others which may affect achievement of project outcomes.
4. The consultant is required to develop a set of guidelines to assist the analysis of benefits and costs of natural resource research and development, to be used by the Corporation, its stakeholders and research clients in formulating and assessing research and development projects/programs.
5. The consultant is required to report to the Corporation on each of the four topics listed above. It is intended that the report will form the basis for a process of life-of-project evaluation of the selected research and development.

Study Team

The current evaluations were carried out by Professor C.A. Tisdell, Dr J.G. Tisdell, Dr S.R. Harrison and Dr M.J. McGregor (all of whom had participated in the earlier evaluations but only Dr Harrison was involved in all three studies). Brief résumés of the authors follow:

Professor Clem Tisdell, BCom (Econ) (NSW), PhD (ANU), FASSA

Professor Tisdell is an internationally recognised environmental economist who specialises in applications of microeconomics to fields such as natural resource economics, managerial and decision economics, development economics, tourism economics and science and technology policy. He has been a consultant to the ILO, OECD, World Bank, Queensland Department of Environment and Heritage, ASTEC, ACIAR, LWRRDC, Queensland Commercial Fisherman's Organisation, Queensland Cement and Lime Corporation, the University of Brunei, and the University of the South Pacific, AusAID plus other bodies. Current research interests are in his main areas of expertise.

Dr Steve Harrison, QDA (UG Gatton), BAgrSc (Qld), BEcon (Qld), PhD (Qld)

Dr Harrison is Associate Professor of Economics in the Department of Economics at The University of Queensland, and member of the Cooperative Research Centre for Tropical Rainforest Ecology and Management. He specialises in natural resource and environmental economics, operations research and statistical methods. Dr Harrison was Economic Adviser to the Commission of Inquiry into the Conservation, Management and Use of Fraser Island and the Great Sandy Region. He has carried out research projects or consultancies for the International Rice Research Institute, GRM International, Queensland Department of Police and Emergency Services, Queensland Electricity Transmission Corporation, North Queensland Joint Afforestation Board, Queensland Commercial Fishermens' Organisation, Indicative Planning Council for the Housing Industry, Grains Research and Development Corporation, Rural Industries Research and Development Corporation, Australian Centre for International Agricultural Research and Australian International Development Assistance Bureau, and has served on project selection or review committees for the Australian Wheat Research Council and Land and Water Resources Research and Development Corporation. Current research interests include non-timber benefits of rainforest reforestation, and economics of animal health information systems.

Dr John Tisdell, BCom (Wollongong), PhD (Qld)

Dr Tisdell is Lecturer in Environmental Economics in the Faculty of Environmental Sciences at Griffith University. He specialises in natural resource economics (particularly water resources) and environmental economics. Current research interests include modelling trade in water markets, water rights and the establishment of instream water entitlements, Green National Accounting and the valuation of biodiversity.

Dr Murray McGregor, BAgrSc (Cant), MagrSc (Cant), PhD (Cant)

Dr McGregor is Director of the Curtin Institute, Muresk University, WA, and was previously Head of the Rural Systems and Management Department of the Scottish Agricultural College, and lectured at the University of Edinburgh. His areas of special competence include project appraisal, environmental and resource economics, socio-economic modelling and impact assessment. He has acted as consultant to the European Commission, Countryside Commission for Scotland, MAFF, Scottish Office of Agricultural and Fisheries, NZAID and New Zealand Ministry of Works and Development.

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Ms Heather Adams, Environmental/Salinity Officer, Department of Natural Resources and the Environment, Colac, Victoria.

Professor Angela Arthington, Centre for Instream Water Catchment Management, Griffith University, Brisbane.

Dr Paul Bailey, Dept. of Ecology and Evolutionary Biology, Monash University, Clayton, Vic.

Mr Wayne P. Chapman, Development/Extension Officer, Department of Natural Resources, Emerald, Qld.

Mr Fred Chudleigh, Department of Natural Resources, Emerald, Qld.

Mrs Averil Cook, Lecturer in Economics, Department of Economics, The University of Queensland, Brisbane.

Dr Norm Dudley, University Fellow, Centre for Water Policy Research, University of New England, Armidale (now retired).

Mr Tim Fisher, Wetlands Co-ordinator, Australian Conservation Foundation, Melbourne.

Ms Danielle Heffer, Salinity Officer, Department of Natural Resources and the Environment, Kerang, Victoria

Dr Ross Hyne, Principle Research Ecotoxicologist, New South Wales Environmental Protection Authority and University of Technology, Sydney.

Dr Anne Jensen, Habitat Co-ordinator, Wetland Care Australia, Department of Environment Heritage and Aboriginal Affairs, Adelaide.

Professor Ivan Kennedy, Department of Agricultural Chemistry and Soil Science, University of Sydney.

Ms Eleisha Keogh, Salinity/Environmental Officer, Department of Natural Resources and the Environment, Maffra, Victoria

Dr Rod Oliver, Murray–Darling Freshwater Research Centre, Albury.

Dr Bruce Radcliff, Department of Natural Resources, Biloela, Qld.

Dr Greg Raisin, Manager, Central West Region, Department of Land and Water Conservation, NSW

Ms Michelle Scoccimarro, Centre for Resource and Environmental Studies, Canberra.

Dr Bradley Scott, Centre for Water Policy Research, University of New England, Armidale.

Dr John Skerritt, Principal Research Scientist, CSIRO Plant Industry, Canberra.

Dr Jeff Tullberg, Farm Mechanisation Centre, Dept. of Plant Production, University of Queensland Gatton College, Gatton, Qld.

Dr Glen Walker, Water Resources, CSIRO, Canberra

Mr Pat Walsh, Commercial Manager, CSIRO Plant Industry, Canberra.

Mr Allan Williams, “Kia-Ora”, Narrabri, NSW.

Mr Nicholas Woods, Director, The Centre for Pesticide Application and Safety (C-PAS), University of Queensland, Gatton College, Gatton.

Dr Don Yule, Principal Soil Scientist, Department of Natural Resources, Rockhampton, Qld.

List of Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
B/C	benefit–cost or benefit–cost ratio
BGATF	Blue Green Algae Task Force
BPMM	Best Practice Management Manual
CBA	cost–benefit analysis
CEPA	Commonwealth Environmental Protection Agency
Cotton CRC	Cooperative Research Centre for Sustainable Cotton Production
CRCFE	Cooperative Research Centre in Freshwater Ecology
CRDC	Cotton Research and Development Corporation
CSIRO	Commonwealth Scientific, Industrial and Research Organisation
CVM	contingent valuation method
CWPR	Centre for Water Policy Research
DEH	Department of Environment and Heritage (Qld) (now Department of Environment)
DENR	Department of Environment and Natural Resources (SA)
DLWC	Department of Land and Water Conservation (NSW)
DME	Department of Mines and Energy (SA)
DPI	Department of Primary Industries (Qld, SA)
dse	dry sheep equivalent
DWR	Department of Water Resources (NSW, now DLWC)
EIS	environmental impact statement
EWS	Engineering and Water Supply Department (SA)
GL	gigalitre (one million litres)
IRR	internal rate of return
LWRRDC	Land and Water Resources Research and Development Corporation
MDBC	Murray–Darling Basin Commission
MDFRC	Murray–Darling Freshwater Research Centre
NLP	National Landcare Program
NOAA	National Oceanic and Atmospheric Administration, of the US Department of Commerce
NPV	net present value
NSWEPA	New South Wales Environmental Protection Authority
ppb	parts per billion
R&D	research and development
RAC	Resource Assessment Commission
tds	total dissolved salts
UC	University of California
UQ	The University of Queensland
WTP	willingness-to-pay

Summary and Recommendations

Current Status of Projects

Seven projects were selected in 1993 for life-of-project evaluations, and an update of the evaluation was performed in 1996[1]. This study represents the second update of the project evaluations. The research projects, along with their principal investigators, organisations and durations, are indicated in Table 1. All of the project research has now been completed, although the program is continuing.

Representativeness of the Sample Projects

Two of the sample projects are based in the Australian Capital Territory, two in New South Wales, and one in each of Queensland, South Australia and Victoria. Two of the projects associated with DEP1 are located in South Australia and one in Victoria. Before the first update, two principal investigators moved to Canberra (one from Adelaide and one from Sydney), and one moved from Albury to Melbourne. The spatial distribution of the case studies has remained wide (although Western Australia, Tasmania and the Northern Territory are not represented).

Most of the case studies have been concerned with surface and groundwater management, one (QPI14) dealing with land management and one (CWW18) dealing with vegetation in relation to groundwater balance. By comparison, approximately 60% of the total of about 300 projects in the LWRRDC portfolio are concerned with water management.

Since these life-of-project evaluations were commenced, there has been a major change in the LWRRDC portfolio, from individual projects under the "general call" to research programs, and in this respect the case studies have become less representative. However, it is to be noted that the programs are made up of a number of "program projects", so it is still necessary to examine the performance of individual projects. One of the case study projects (CWW18) was in fact incorporated within a program, the National Dryland Salinity Research, Development and Extension Program.

[1]. A second set of projects and programs was selected for life-of-project evaluation by ACIL in 1993, and a third set was subsequently commissioned.

As indicated in Table 2, two projects were approved additional LWRRDC funding after the initial evaluations. No information has been obtained about budget changes for LWRRDC projects and programs outside the case studies. Selected projects were initially larger than average in terms of LWRRDC funding amounts, so it is probable that this disparity has continued.

Summary of Results from Case Studies

Research progress, and achievements

All projects were found to have made sound progress towards meeting their agreed objectives; there have been no "failed" projects. However, one project (CWW18) has mainly had a decision-support role, in that alternative management measures began while the project was in progress.

Technology transfer and adoption progress

Technology transfer measures were built into the program design, and further measures were added in some cases, so that, in general, technology transfer was highly effective. For some projects — particularly CPI4, QPI14 and DEP1 — adoption rates have been more rapid than predicted. For others — including MDR 8 and UMO 18 — adoption has been slower than initially predicted. Indeed, for projects UNE11 and CWW18, little progress in adoption has yet taken place.

Economic performance criteria

Estimates of economic performance have been made for all projects, although those for two wetland projects (UMO18 and DEP1) can be regarded as indicative only. The estimates are summarised in Table 2. The net present value (at a 7% interest rate) is positive for all projects, or equivalently the benefit-to-cost ratio is greater than unity for all projects. That is, all projects have been found to be worthwhile in economic terms — and some are expected to generate very high returns. Estimated benefit-to-cost ratios consistently exceed about 2.0, and internal rates of return are typically greater than 15%.

The economic analyses, by necessity, do not take account of some of the potential benefit categories identified for the projects, and in this sense are likely to underestimate economic performance. A high degree of uncertainty is recognised in estimates, which is to some extent accounted for in sensitivity analysis.

Table 1. Summary detail of sample projects and program, and associated projects

Project title	LWRRDC code	Principal investigator	Organisation and location	Commencement date	Completion date	LWRRDC expenditure ($1000)	Est. total expenditure ($1000)
SAMPLE PROJECTS							
Effects of increased salinity on riverine and wetland biota	UMO 18	Dr P.C. Bailey	Dept. of Ecology & Evolutionary Biology, Monash Univ.	1-Jul-92	30-Dec-96	439.9	1493.3
Ecological processes for management of wetlands and floodplains - practical management systems	DEP 1	Dr A. Jensen	Dept. of Envir. & Natural Resources, Adelaide	1-Nov-92	1-Mar-96	133.0	491.6
Integration of wetlands water supply and demand management in a market environment using capacity sharing	UNE 11	Dr N. Dudley	Centre for Water Policy Research, Univ. of New England	1-Jul-92	30-Jun-94	580.9	1550.7
Management of a regional groundwater discharge zone in an area of dryland agriculture	CWW 18	Dr G.R. Walker	Division of Water Resources, CSIRO, Canberra	1-Jul-92	30-Jun-96	432.4	951.3
Nutrient limitations of algal growth: physiological assays and chemical analyses	MDR 8	Dr R.L. Oliver	CRC in Freshwater Ecology, Albury	1-Nov-92	31-Jan-96	262.3	517.8
On-site monitoring of agro-chemical residues — a valuable tool for irrigation management	CPI 4	Dr J.H. Skerritt	Division of Plant Industry, CSIRO, Canberra	1-Jul-92	30-Jun-95	170.2	984.2
Compaction control and repair practices for cropping lands in the sub-tropics	QPI 14	Dr D.F. Yule	Qld. Dept. of Primary Industries, Biloela	1-Jan-93	31-Dec-98	916.4	4908.2
ASSOCIATED PROJECTS							
Health of floodplain vegetation	CWS 2	Dr G.R. Walker and Dr I. Jolly	Division of Plant Industry, CSIRO, Glen Osmond	1-Jul-92	31-Jul-95	267.4	915.2
Productivity and decomposition	MRD 10	Dr P. I. Boon	Dept. of Environmental Mgt., Vic. Univ. of Tech.	1-Jul-92	30-Jun-96	294.5	758.5
Water level effects	UAD 6	Dr George Ganf Dr Keith Walker	Dept. of Botany, Univ. of Adelaide Dept. of Zoology, Univ. of Adelaide	1-Jul-92	30-Jun-97	246.5	542.2

Table 2. Summary of economic performance from case studies

Project title	Best estimate of performance			Comments
	NPV ($m)	IRR (%)	B/C ratio	
Effects of increased salinity on riverine and wetland biota (UM018)			2.05	Indicative estimate only. The breakeven benefit area is of the order of 40,000 ha.
Ecological processes for management of wetlands and floodplains — practical management systems (DEP1)			25.57	Indicative estimate only. The breakeven area benefit area appears to be less than 50,000 ha.
Integration of wetlands water supply and demand management in a market environment using capacity sharing (UNE11)	2.4		2.4	Difficult to isolate benefits from those of prior and following projects on capacity sharing.
Management of a regional groundwater discharge zone in an area of dryland agriculture (CWW18)	1.7	16.4	2.5	Closely linked with benefits from regional management plan.
Nutrient limitations of algal growth: physiological assays and chemical analyses (MDR8)	0.6	15.1	2.4	Based on reduction in algal damage and reduction in assay costs.
On-site monitoring of agro-chemical residues — a valuable tool for irrigation management (CPI4)	0.71	24.7	2.0	Based mainly on reduced research costs
Compaction control and repair practices for cropping lands in the sub-tropics (QP114)	41.2	40.9	8.5	Based on increased yields and more frequent opportunity cropping

Variations from Initial Evaluations and Reasons for these Variations

Method of analysis

In the main, the same method of economic analysis has been adopted as in the first update. The method of estimating breakeven payoff for two projects (UMO18 and DEP1) was continued.

Estimation issues

Project expenditure. Some further expenditure for technology transfer took place for QPI14 and UMO18. While non-LWRRDC funds were used, the activity supported was directed to achieving adoption and hence has been included as part of expenditure. Extra funding was obtained for technology transfer/extension programs in a follow-up program to UNE11 funded by LWRRDC.

Potential project benefit categories. The nature of the projects has become much clearer with the passage of time and the availability of milestone reports, project reviews, research publications and information provided directly in meetings with Principal Investigators. A wider list of potential benefits can now be identified. Core benefits remain:

- improved understanding of natural systems; and
- greater ability to manage natural resources in a sustainable way.

In two projects where prototype assays have been developed as alternatives to traditional chemical analysis methods (CPI4 and MDR8), these assays have proved of value in other research projects (including other LWRRDC projects). Computer models have been developed, eg. in CWW18, which could be valuable in future studies. In the one project for which products were developed and marketed by a commercial partner (CPI4), Australian sales and royalties proved disappointing.

Estimation of adoption timing and levels

Adoption is more readily observed now that research has been completed. While earlier estimates relied to a large extent on judgment by researchers, information on adoption is now available from resource managers, including government agencies and farmers. For one project (CPI4), probably most of the adoption has already taken place.

Timing of project benefits

Time lags to generation of project benefits have been increased for UMO18 and UNE11, while adoption has been more rapid than expected in CPI4, DP1 and QPI14.

Magnitudes of project benefits and estimated levels of performance criteria

The number of potential sources of project benefit categories identified tended to increase at the first update, but has now stabilised or reduced. Similarly, while estimated benefits fell considerably at the first update, relative to the ex ante evaluations, they have tended to fall slightly or stabilise in this update. Changes in relative magnitudes of project benefits are again notable, as adoption practicalities have emerged and expectations of benefits in some directions have been dampened.

Uncertainty

The level of uncertainty with respect to achievement of project benefits has clearly been reduced relative to earlier evaluations for most projects. Exceptions are UNE11 and UMO18, where large-scale adoption has not yet taken place. Other research has provided improved information about wetland values.

Random versus systematic changes

While in the earlier update systematic changes in research and adoption timing and expenditure were observed, changes in estimated performance relative to earlier estimates appears to have been random in this update. Agricultural commodity prices have decreased, but this has affected mainly project QPI14 for which adopters are private landholders. Little can be read into the fact that the largest project (QPI14) has the greatest benefit–cost ratio.

Usefulness and Recommended Timing of a Further Update

For some projects (CP4, CWW18, DEP1), ex post performance is now reasonably well determined, and little new information would be gained in a further evaluation. For another (QPI14), a rapid rate of technology adoption is taking place and, in the sense that this project can be regarded as a success, any further evaluation would provide information mainly on adoption patterns and processes rather than clarify economic performance. However, for some projects — particularly UNE11, UMO18, and MDR8 — there is a case for a further evaluation to determine economic performance in a more reliable way and to examine appropriateness of technology transfer methods. For the three projects, in that adoption would be gradual, it would probably be preferable be most cost-effective to delay a further evaluation for three years.

Recent Developments in Evaluation Methods of Research Projects Related to Management of Natural Resources

Methods of non-market valuation are continuing to evolve. There is greater recognition of the necessity to use benefit transfer methods, and greater acceptance of the contingent valuation method, and recommended practices for use of these techniques have evolved. A good deal of expectation is held for choice modelling as an improvement over contingent valuation, but as yet this must be viewed as a difficult and unconfirmed approach.

The importance of other methods for estimating economic impacts or research, such as the replacement or opportunity cost approach, and cost and revenue variation, must also be recognised. While less novel in their application, these approaches are widely used, as in the case studies reported here.

Issues in Adoption of Research Outputs and Products

The development of research results to the applied stage and their transfer and adoption involves complicated processes and is usually much more costly than the initial research itself. The same is true for other areas of R&D. In manufacturing, for example, transfer and adoption costs are typically of the order of 80% of the total cost of the introduction of new products.

Processes of the development of techniques, and the extension and adoption of results can be quite varied. Most of the literature is concerned with these processes in relation to private agents (which involves a focus on private goods) rather than on adoption by public (or corporatised) resource-management agencies and by community groups. The latter are usually concerned with the supply of social or collective goods or with the supply of commodities which have partly a private and partly a social or collective dimension. A minority of LWRRDC-supported projects reviewed here involve adoption by private agents.

Transferring technology which depends on social or collective demands for its application is extremely complicated (much more complicated than in the case where adoption depends purely, or mainly, on private demand and private agents), as this review illustrates. In the case of technology with social or collective application, client groups may be diverse and difficult to identify, and new groups may form or need to form to agitate politically for adoption of the new technology. Application of new technology affecting the supply of social or collective commodities inevitably involves social and political processes. Consequently, the spread of adoption of similar new technologies may be slower in the public arena than in the private arena. Comparatively little literature exists on the adoption of new techniques of with social or collective implications. From a social point of view, it is appropriate that LWRRDC support be given to research projects likely to result in the introduction of techniques with social or collective application since it is in this area that market failure in R&D is likely to be most marked.

However, in relation to technologies with social or collective applications, many LWRRDC-supported researchers have been hampered in the development and transfer of technologies by changes in their target ‘clients’ brought on by restructuring of government agencies. At crucial times, researchers have, as a consequence, lost previously existing networks which could have been helpful in providing guidance for development of applied aspects of their research and have lost channels to communicate their research results to potential adopters. During the performance of most of the research projects reviewed here, the structure of government and government agencies has been in a state of flux. As a result, significant gaps in extension and communication networks have emerged. Public policies have been directed to downsizing government, introducing the user-pays principle wherever possible, and employing competitive and market mechanisms more widely in relation to the business of government agencies. In addition, there have been moves towards regionalisation and privatisation of government services in line with structural adjustment policies. It may take some time to fill the information and communication gaps which have emerged in relation to land and water resources.

In cases where private industry is the main beneficiary of LWRRDC-supported research, the path to adoption and diffusion of new technology is the least complicated, as in the case of the soil compaction project of relevance to agriculturists whose soils are particularly prone to that problem. Economic agents will normally act in their collective economic interest only when it is in their private interest to do so. So private incentives for adoption need to be considered in order to assess this case. On the other hand, in the case of soil compaction, many agriculturists can obtain economic benefits individually from adopting the controlled traffic farming techniques. Economic incentives for adoption are strong in this case, and adoption has been relatively rapid.

The progress of adoption of new techniques involving social or collective commodities has been, as one might expect, slower and more variable than in the case of industry-focused techniques. Progress in adoption of the former techniques seems to have been fastest where comparatively effective administrative and political action has been instituted, supported by community groups (and by the formation of community groups), as in the case of DEP1, which indirectly has provided benefits to Wetland Care Australia.

The extent to which LWRRDC should support technology transfer, financially and otherwise, is uncertain. However, the approach of LWRRDC lending support to proposals to obtain funding for technology transfer from other agencies seems to have worked well in the case of QPI14.

If the project is large enough, and an integrated management package can be developed, then the employment of full-time extension officers may be justified, and is likely to lead to favourable adoption outcomes.

Commercialisation of Research Products

In one project (CPI4), research products had been further developed and marketed by a commercial partner. The desirability of commercialisation, but also the need to protect the interests of Australian users and achieve equitable shares of innovation rents when products are controlled overseas, was discussed in the previous update. It is now clear that the royalty revenue generated is low, and may not even cover the transaction costs of ensuring ownership of intellectual property. This raises issues concerning legal and royalty sharing arrangements for commercialised products.

Information Requirements and Monitoring Responsibilities

Assessment of the technical and economic performance of research projects has heavy information demands. A variety of information sources was accessed for this update, important among which were meetings with Principal Investigators, reading research and conference publications, and discussions with potential and actual adopters.

Where new life-of-project evaluations are commissioned, a more formal approach to monitoring may be desirable. The most appropriate person to assist with this is the researcher, and it must be recognised that this will impose some time costs. It is not difficult to develop a 'wish list' of information requirements, but for practical purposes a minimal critical data set may need to be negotiated with researchers. From an evaluation viewpoint, it is most useful to be able to identify all publications arising from research projects, to have sighted the most recent milestone reports, and to be familiar with the extent and nature of other current research on related topics. Where product commercialisation has taken place, the practical difficulties of monitoring sales needs to be recognised.

The Life-of-Project Evaluation and Update Process

Carrying out life-of-project evaluations and updates is an interesting and challenging task. A large amount of scientific investigation has to be comprehended, sometimes including a substantial volume of research publications. Judgments have to be made about the uniqueness, new insights provided and general worth of research outputs.

Once project research has been completed, it is more difficult for researchers to provide up-to-date information, and they have less incentive to do so unless they have continued funding. At the same time, greater access to views from resource managers is required.

For some projects, a major problem arises in separating out the contribution to resource management, relative to other projects dealing with related issues. This is a particular problem with successor projects by the same researcher (and even with further LWRRDC funding), in which case it may be most appropriate to group the research as a single project.

Where projects generate environmental benefits such as better wetland management and salinity control, estimation of benefits will remain difficult and speculative.

Recommendations

The recommendations made in the discussion chapters of this report are summarised here:

Project monitoring measures

1. For future projects subject to continuing socio-economic evaluation, a formal request for monitoring should be made to Principal Investigators, and the primary variables to be monitored and frequency of recording should be negotiated with them.
2. If researchers or resource managers who are not recipients of funding for a project are asked to monitor adoption or other variables for the project or a regular basis, then a formal agreement and financial support should be provided for this activity.

Technology transfer and adoption

1. If there is an expectation of technology transfer from a LWRRDC research project, the Corporation in the original agreement should give greater attention to how and by whom that is to be achieved and in what time frame.

2. LWRRDC needs to provide sufficient funding for development and transfer unless there is assured funding by other parties, bearing in mind that this expense is often the most costly part of a project. If other parties are willing to contribute to transfer, their role should be determined as far as possible in advance.
3. It would appear that one cannot always predict when findings of research projects are to be transferred. The findings of research cannot be predetermined. This applied both to the nature of results and the likely time of their discovery. When research projects have a duration of only 4–5 years, transferable results may emerge only towards the end of the project. Possibly at this stage a second agreement could be entered into regarding development and transfer. This suggests a two-stage funding process.
4. Early advice should be sought about the possibilities of transferring predicted research results from a social and economic point of view. Natural scientists are not always in the best position to advise on this.
5. The role which LWRRDC ought to play in the communication process should be carefully assessed. The extent to which legal risks prevent it from being effective in helping to transfer intellectual knowledge requires investigation.
6. Early contact between researchers and all potential client groups (not just resource managers and funders) seems desirable for transfer of the research results. Such contacts involve costs and these should be allowed for.

Commercialisation of research products

1. Where possible, products resulting from LWRRDC research should be manufactured in Australia.
2. Greater incentives might be provided to researchers to engage in technology transfer eg. via payment of consulting monies for this purpose.
3. When products of research funded in whole or part by LWRRDC are commercialised, consideration be given to arrangements which ensure royalty sharing but do not require sharing in ownership of intellectual property.

Desirability and timing of a further evaluation update

1. A further update should be undertaken for some projects UMO18, UNE11 and MRD8 but not necessarily for DEP1, CPI4, CWW18 and QPI14.
2. The update should be carried out in approximately three years time.

Desirability of a workshop on evaluation of research projects

1. A workshop should be convened to discuss the methods, progress, findings and desirability of life-of-project evaluation, and make recommendations concerning further implementation of this process.
2. Participants in the various groups undertaking life-of-project evaluations, some Principal Investigators of projects and programs subject to evaluation, and some recognised experts on non-market valuation, should be invited to attend the workshop and make presentations.

1 Outline of the Report

Seven research projects chosen by LWRRDC for life-of-project evaluations and reviewed in 1993 and 1996 were again examined. The tasks to be covered by this update are described in the terms of reference. This chapter contains an outline of the report.

Chapter 2 reviews recent developments in the evaluation of projects related to the management, use and conservation of natural resources. Particular attention is paid to estimation of non-market values, including benefit transfer methodology and stated preference techniques. The use of replacement and opportunity cost, and cost and revenue variation, is also examined. Chapter 3 reviews the literature on comparisons of ex ante and ex post evaluations of projects relating to use of natural resources, and examines potential sources of 'slippage' in ex post evaluation. Chapter 4 sets out the objectives and methods of the evaluation update. Various aspects of the application of cost–benefit analysis to natural resource projects were reviewed in the earlier evaluations, and these are not repeated here.

Chapters 3 to 10 contain the details of the updated evaluations for each of the case-study projects, which are listed in Table 1-1. Relative to the first update, less material is provided on background and research progress in each project, and more emphasis is placed on technology transfer and adoption. Expenditure and benefit estimates are made, leading to estimates of performance criteria, which are compared with estimates in the initial evaluations. Comments are made on information that would be required for further evaluations.

Chapter 11 reviews the findings of the update with those of the initial evaluations. Overall economic performance levels, relative importance of various benefit categories and extent of uncertainty in estimations are compared with those of earlier evaluations.

In that research activities for the projects are mostly completed, and completed more than three years ago for two projects, this update has provided an opportunity to review technology transfer mechanisms and examine adoption rates and patterns. In Chapter 12, theoretical and conceptual issues concerning technology transfer and adoption of projects dealing with natural resource management are discussed, with reference to the sample projects.

Chapter 13 discusses project monitoring to provide information for economic evaluation. The need for further monitoring of the sample projects is discussed. Also, implications are drawn from the experience of this series of life-of-project evaluations for future monitoring of LWRRDC-supported projects. In Chapter 14, the major findings and conclusions of this study are reviewed.

Table 1-1. The projects selected for life-of-project evaluation

Effects of Increased Salinity on Riverine and Wetland Biota (UM018)
Ecological Processes for the Management of Wetlands and Floodplains: Practical Management Systems (DEP1)
The Integration of Wetlands Water Supply and Demand Management in a Market Environment Using Capacity Sharing (UNE11)
Management of a Regional Groundwater Discharge Zone in an Area of Dryland Agriculture (CWW18)
Nutrient Limitation of Algal Growth: Physiological Assays and Chemical Analyses (MDR8)
On-Site Monitoring of Agro-Chemical Residues: a Valuable Tool for Irrigation Water Management (CPI4)
Compaction Control and Repair Practices for Cropping Lands in the Sub-tropics (QPI14)

2 Recent Developments in Evaluation of Research Projects Related to Management of Natural Resources

Evaluation of research concerning management of natural resources involves use of a variety of market and non-market valuation estimation techniques. With growth in community concern over natural resource and environmental values, there has been a growing demand for improved valuation methods, driven by the needs of resource managers and, in some cases, environmental litigation. This chapter reviews some of the recent developments in valuation methods, and briefly comments on the relevance of these techniques to the current life-of-project evaluation.

A vast literature has arisen on the problems of non-market valuation, such as sources of bias, how to improve estimates, identifying specific value components, transferring value estimates between applications, and citizenship as against economic rationalist behaviour. Major efforts have been made to refine existing techniques or develop alternatives which overcome some of the limitations. The large attendance (nearly 1000 delegates) and large number of papers (about 600) at the First World Congress of Environmental and Resource Economists in Venice in June 1998 is indicative of the growth in the environmental economics specialisation.

As noted by Sterner and van den Bergh (1998, p. 249) as editors of *Frontiers of Environmental and Resource Economics: Testing the Theories*,

> "The proportion of valuation research in total publications in [the Journal of Environmental Economics and Management] shows the highest increase of all areas over the period 1974–1996 … there are still many reasons why the numbers generated are not very reliable …"

A similar view was presented by Deacon et al. (1998, p. 388):

> "It is doubtful that anyone could have anticipated the explosion of research on non-market valuation that has taken place in the last 25 years. … Basically, the profession is not yet entirely comfortable with the numbers it is producing. … several economists have questioned consumers' ability to make consistent and reliable choices with any new goods …"

The recent effort by Costanza et al. (1998) to place a value on the world's ecosystem services and natural capital has further promoted the active debate on non-market valuation methodology. This chapter reviews progress in development of estimation methods for non-market values, drawing on material from Harrison 1999.

Valuation Methods

A convenient economic framework for valuation efforts is provided by the 'total economic value' (TEV) concept, as summarised in Table 2-1, based on Pearce and Moran (1994). While some variations arise in how the types of benefits are classified or grouped, the TEV is being accepted increasingly by economists and environmentalists as a framework for viewing values of natural systems and protection of the environment. When placing values on research concerned with prevention of resource degradation, the concern typically is with degradation costs or reduction in TEV which can be prevented.

Table 2-1. TEV framework for evaluation of environmental goods

TEV = UV + NUV = (DUV + IUV + OV) + (BV + EV)

where TEV is total economic value

UV is use value, which consists of

- DUV = direct use value — products, recreation
- IUV = indirect use value — services provided by a resource
- OV = option value — safeguarding the asset for future use

NUV is non-use value, which consists of

- BV = bequest value, of keeping asset available for future generations
- EV = existence value, a value independent of human wants

A variety of techniques is employed to estimate TEV and various components of it, some of the more important of which are summarised in Table 2-2. Greatest interest has focused on stated preference techniques and benefit transfer methods. Morrison et al. (1996, p. 1) argued that revealed preference techniques have limited usefulness because they are retrospective and therefore not able to value changes that have not been experienced, and cannot estimate 'non-use' values.

Table 2-2 Methods of estimating benefits of improved resource management

Modelling approaches	Bioeconomic simulation models
Direct methods	Experiments
	Surveys (stated preferences, hypothetical choices) Contingent valuation (CVM) Contingent rating Contingent ranking Paired comparison Choice modelling (CM)
Indirect methods (revealed preferences, actual choices)	Surrogate markets (behavioural trail)
	Travel cost method (TCM) Hedonic price method (HPM)
	Conventional market
	Dose-response techniques Replacement cost Opportunity cost
Practical expedients	Delphi method Benefit transfer methodology (BT) Cost variation Revenue variation

Source: Based in part on Pearce and Moran (1994) and Morrison et al. (1996).

Stated preference techniques, including contingent valuation

A number of stated preference (SP) techniques — including contingent valuation, contingent rating, contingent ranking, paired comparison and choice modelling — have been reviewed by Morrison et al. (1996); they concluded that contingent rating, contingent ranking and paired comparison have weak theoretical bases and do not produce economically valid valuation estimates.

Contingent valuation has certainly been the most widely used SP technique. Morrison et al. (1996, p. 2) refer to a bibliography of CVM studies by Carson et al. (1994) with 1674 entries. CVM has been given some standing in environmental litigation in the USA, subject to best practice use (Bennett, 1996). There has, however, been continued concern about the potential biases of this technique (and other SP techniques), and of limitations such as valuing a complex multifaceted resource on an all-or-nothing basis.

Contingent valuation would have been an suitable approach for estimation of values of protecting wetlands in relation to some of the projects considered here, including CWW18, DEP1, UMO18, and UNE11. However, application of this technique would have been beyond the time frame and resources available for this update.

Choice modelling or choice experiments

Boxall et al. (1996) and Hanley et al. (1998) reviewed applications of choice experiments for estimating environmental values. The alternative names "choice modelling" (Morrison et al., 1996), "environmental choice modelling" (Blamey et al., 1997) and "choice experiments" (Hanley et al., 1998) have been used to refer to the same form of conjoint analysis. These authors have identified various advantages of choice modelling over CVM. The former is more suitable for placing values on individual attributes (hence more suitable for benefit transfer), is easier for respondents (who do not have to make an 'all or nothing' choice) and is less prone to bias than CVM (overcomes the embedding problem and allows internal consistency checks).

Choice modelling is not a simple technique to apply. Focus groups are normally used to identify characteristics to be valued. Questionnaire design can be complex and requires considerable skill. A large number of questions may be required, with long interviews during which it is difficult to hold the attention and concentration of the respondent.

The Delphi method for obtaining a consensus of expert opinion

The Delphi method is an approach to obtaining consensus estimates from a group of experts, which can be applied to estimate environmental values. This can be a rapid and moderately inexpensive practical expedient. It is, in effect, a method of summarising the collective wisdom of those most likely to have an understanding of resource and environmental values in the particular situation. The process can involve a meeting of experts or postal survey, but experts are asked to make estimates independently of each other, to avoid undue influence of those with employment seniority or dominant personalities. Two or more survey rounds may be implemented, with respondents provided with summaries of findings of previous rounds and invited to revise estimates. Harrison and Sutherst (1998) trialed use of the Delphi method in development of a socio-economic model of eucalypt dieback under climate change, and noted the practical problem of finding a sufficient number of experts who have confidence to make value estimates.

Other non-market valuation methods

The travel cost method (TCM) is now well accepted for estimation of recreation values, and is considered to provide reasonably reliable estimates. However, in that recreation value is only one component of use value, this approach is limited when studying total costs of resource degradation. The hedonic price method (HPM) provides statistically acceptable values of environmental characteristics of traded assets or products, but has the limitation that suitable records of transactions relevant to evaluation of research into management of natural resources are typically not available which are.

Two further valuation approaches — benefit transfer methodology and replacement or opportunity cost methods — do have wide applicability for LWRRDC-funded research projects, and will now be reviewed in greater detail, because of their emerging importance and recognition.

Benefit Transfer Methodology

In recent years, considerable attention has been devoted to benefit transfer methodology[1]. Benefit transfer has been defined as "an application of a data set that was developed for one particular use to a quite distinct alternative application" (Brookshire and Neill 1992, p. 651), and "the transfer of existing estimates of non-market values to a new study which is different from the study for which the values were originally estimated. In essence, this is simply the application of secondary data to a new policy issue" (Boyle and Bergstrom 1992, p. 657). Kirchloff et al. (1997) refer to the locations as the "study site" and the "policy site".

Loomis (1992) considered the benefit transfer (BT) process to be one of obtaining benefit estimates for an unstudied recreational resource by applying an existing demand curve from a similar site, while Smith (1993, p. 7) defined benefit transfer as the process of "adapting existing models or value estimates to construct valuations for resources that are different in type or location from the one originally studied". Morrison et al. (1998, p. 2) note that the use of existing data is not something new in economics but the novelty of benefit transfer is that "data that are believed to be sensitive to changes in the context in which they were collected, and subject to various uncertainties, are being used."

Boyle and Bergstrom (1992) note three distinct philosophical orientations towards benefit transfer held by resource economists. The 'pragmatists' believe that benefit transfer is valid, and the quality of data for benefit transfer studies is improving because of the increasing number of valuation studies being conducted, and so the number and diversity of benefit transfer studies should be expanded. Proponents of the 'impossibility myth' believe that, because of different technical attributes and different individual preferences between sites, the transfer of value estimates is impossible. The 'idealists' believe that benefit transfer is possible but that strict standards are necessary, in terms of the validity and reliability of estimates. Boyle and Bergstrom (1992, p. 662) believe there is no future in either the overly optimistic or pessimistic views, so "we should move forward with benefit transfer, including validation studies that are adequately funded and meet conditions for publication in scholarly journals".

Use of benefit transfers in the USA was stimulated by Executive Order 12291 signed by President Reagan in 1981, requiring that all new major regulations be subject to cost–benefit analysis. 'Guidelines for Performing Regulatory Impact Analyses' developed by the US Environmental Protection Agency acknowledge that limited budgets and often severe time constraints often dictate that "… off-the-shelf methodologies and studies can serve as the basis for benefit and cost analyses. In other cases, more analysis is necessary to fill conceptual and empirical gaps" (quoted in Freeman 1984, p. 169). That is, where possible, benefits and costs should be inferred from the results of previous research studies. There is no doubt that performing new studies can be highly costly in terms of time as well as funding and so benefit transfer has become an attractive policy evaluation alternative (Desvousges et al. 1992).

Initially, from the demand equation estimated at the study site, researchers sought to transfer average net willingness to pay to new sites. However, economists soon realised that a more conceptually sound approach to benefit prediction at the policy site resulted from transferring the entire demand equation (Loomis 1992). The coefficients from the demand equation estimated at the existing site could be used with the values of independent variables at the policy site to estimate both the use and benefits of the new site. An early famous example of this technique was its application by Cicchetti et al. (1976) to estimate the benefits of a proposed new ski resort at Mineral King based on demand functions for existing ski areas. 'Benefit function transfer', as it is now called, is expected to produce a more unbiased estimate of total recreation site benefits than simply transferring the average benefit per person per day.

[1] The review material on benefit transfer methodology presented here draws extensively on a draft thesis chapter kindly made available by Mrs Averil Cook of the Department of Economics of The University of Queensland.

Brookshire and Neill (1992) group benefit transfer studies into three classes.

- Estimates based on expert opinion: the unit-day value approach (based on 'reasonableness'). This is a measurement by proxy, which is often used in courtrooms where the assessment of resource damage needs to be valued.
- Estimates based on observed behaviour: where an entire demand equation from a travel cost analysis is transferred.
- Estimates based on preference elicitation mechanisms: Brookshire and Neill (1992, p. 652) stated that "There are a number of contingent valuation studies that are potential candidates for benefit transfer application" but they identified only one study where this had been done and the court had disallowed the evidence. They concluded that regardless of this one result, "it is probably only a matter of time before such an effort is successful" (p. 652). Since that time, many benefit transfer studies have been completed using choice modelling, random utility models (RUM), multinomial logit regression estimation for TCM (Loomis and Walsh 1997, p. 157), and contingent valuation models (CVM) (eg. Parsons and Kealy, 1994; Downing and Ozuna, 1996; Morrison et al., 1998).

Some basic criteria for selecting studies which can be used for benefit transfer have been compiled. Better quality transfer estimates will occur the more similar the study and policy sites are to each other. Studies should be based on adequate data, sound economic methods and correct empirical techniques, and have estimated the correct demand model. The environmental good and its various provision levels at different sites should be similar. Sites should have visitor populations with similar characteristics. The markets should be the same at each site. The assignment of property rights at both sites must lead to the same theoretically appropriate welfare measure, eg. WTP versus willingness-to-accept compensation (WTAC).

Boyle and Bergstrom (1992, p. 661) comment that "If benefit transfer is going to become accepted by sceptics as a reasonable means of developing nonmarket values in the face of budget and time constraints, a careful research agenda must be developed to examine the validity of benefit transfer studies." It has been suggested that four sets of hypotheses should be tested to analyse benefit transfer validity (Bergland et al., 1995). First, the equality of the average willingness-to-pay (WTP) amounts, or more rigorously the equality of the distribution of WTP amounts, at the two sites can be tested. Secondly, the calculated WTP (or distribution) at the policy site is compared with the observed WTP at the policy site. The third hypothesis compares the estimated benefit functions at the two sites and the fourth hypothesis compares the estimated models with their pooled model and tests whether the estimated benefit functions originate from a common underlying function. The fourth test is slightly weaker than the third since it does not really evaluate whether the coefficients of the two models are equal, just if they are equal to the pooled model (Brouwer and Spaninks, 1998, p. 7).

Without doubt, benefit transfer is the most widely used non-market valuation method, because of the imperative to come up with estimates reasonably quickly, and the high cost and time requirements and sometimes controversy over the findings of specific purpose surveys. It would be simply impossible to undertake a stated preference survey every time a non-market value was required. Such studies can be highly expensive, eg. an Australia-wide CVM survey on willingness-to-pay to prevent mining at Coronation Hill in the Northern Territory would have cost more than $A0.5M. While more streamlined survey procedures can be devised, it inevitable that BT will continue to be used. Even when a survey is conducted, resort to BT is desirable as a reality check. Benefit transfers were used in this study, particularly for the estimation of environmental values such as those of wetland protection in DEP1 and UMO18.

This is not to underestimate the difficulties with BT. In any difficult valuation situation, there are likely to be few studies of similar resource situations available from which to obtain comparable estimates. Hence, findings from a small number of studies tend to be widely used elsewhere. An example concerns conservation value of wetlands; estimates from a single study by Stone in 1992 were used (with modification) in various valuation studies — including those of McGregor et al. (1994) and Harrison and Tisdell (1997)[2].

Replacement or Opportunity Cost Method of Resource Evaluation and Cost Variation Methods

The economic value of a resource is sometimes measured by the cost of replacing its desired services by the least costly alternative. For example, the costs of compensating for the loss of wetlands in purifying water might be measured by the cost of the engineering alternative of reducing effluent input into the water or the cost of sufficient treatment to render the water suitable for its various uses. These replacement costs represent the opportunity cost arising from the loss of the cleansing

2. Recognising this information shortage, the Australian Bureau of Agricultural and Resource Economics commissioned a wetland valuation study by Bennett et al. (1997).

services provided naturally by wetlands. Nevertheless, caution must be exercised when using this method. Depending on circumstances, this method can undervalue or overvalue the resource subject to loss (Pearce 1993, p. 107).

When the demand for the services of a resource is less than the cost of replacing the resource by alternatives to provide its services, this method overvalues the resource. On the other hand, if the willingness to pay for the services of a resource exceeds its replacement cost, replacement cost will undervalue the resource from an economic viewpoint. Nevertheless, in this case replacement cost (less any costs involved in maintaining the original resource) will provide a lower limit to the value of the original resource.

The opportunity or replacement cost method has not been used in these reviews to value the benefit of retaining natural resources such as wetlands, but use has been made of cost variation methods for valuation purposes. For example, in relation to new methods or tests for determining water quality (project CPI4 and MDR8), the reduced costs of carrying out tests is used as an indicator of the economic benefits from the technical advances supported by funding from LWRRDC. If the demand for undertaking these tests is inelastic, then this will be an accurate indicator of economic benefit and will be a closer approximation the more inelastic is demand.

For example, in Figure 2-1, suppose that line EFG represents the pre-innovation per unit cost of carrying out a scientific water tests and that ABC represents the per-unit cost after innovation. If the demand for tests is inelastic, as indicated by the vertical demand curve marked DD, the total cost savings as represented by the area of rectangle ABF accurately reflect the private economic value of the new technique. On the other hand, if the demand curve exhibits some responsiveness to the price of tests, some own-price elasticity, the demand curve may be as illustrated by the line marked D^1D^1. In that case, the private economic value of the new techniques consists of the economic benefit due to cost reduction (area of rectangle ABFE) plus the economic value of stemming demand because of the lower price (area of triangle FBC). If in estimating the economic value of the new test, cost reduction is used as the sole indicator, the private economic benefit will be understated if the number of tests before the use of the new technique (X_1) is used. They are understated by an amount equivalent to the area of the triangle BCF, the stemming benefits. On the other hand, if cost savings are used an indicator of value on the basis of the number of tests after the introduction of the new technique, the private economic benefit from the new technique will be overstated by the area of triangle CGF. In both cases, errors are greater the more elastic is demand.

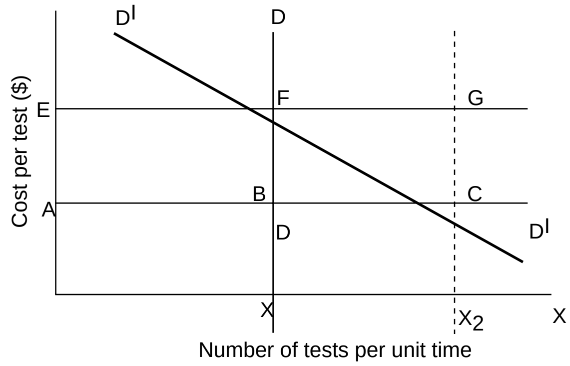

Figure 2-1 Assessment of the economic benefits of a cost-reducing test for water quality

In practice, economic assessment can be more difficult than indicated above. For example, the quality of the earlier and the new technique for water-testing may differ. Furthermore, the demand for use of tests by scientists and resource-managers may not reflect the full social value of the use of the new tests, due for example to favourable environmental consequences from the testing. A further complication can be a shift in the demand curve during the period for which the economic evaluation is being performed. This can, however, be allowed for in principle.

Reliability and Credibility of Value Estimates

Non-market valuation techniques have been subject to considerable criticism because of their potential as sources of error. It must be kept in mind that economic information is only one input to public sector decision-making, to be used against a backdrop of various other social and political considerations. What is required by policy-makers is an indication of the order of magnitude of environmental costs; often, a high degree of precision is neither expected nor required. Nevertherless, credibility of non-market values is critical to their acceptance for policy purposes, hence a number of criticisms need to be noted:

Non-response bias

A common source of error is non-response bias, where people who provide information differ in their WTP to non-respondents; this is a particular problem in postal surveys where a response rate of less than 50% is typical. Experience suggests that people who place highest values on conservation are most likely to return questionnaires in environmental surveys.

Bias in WTP surveys

Even when the sample is representative, and CVM is applied with the greatest of care, various sources of bias have been recognised (including strategic, information, hypothetical, initial bid, bid-vehicle and framing bias). Strategic bias in particular has a tendency to produce high rather than low estimates. Procedures such as those recommended by the NOAA Panel (Arrow et al., 1993) can reduce these biases.

Purchase of moral satisfaction or a warm inner glow

Some critics of SP techniques (eg. Kahneman and Knetsch 1992) argue that these techniques do not measure consumer surplus for environmental goods so much as the value of moral satisfaction from providing a politically correct response.

Citizenship behaviour

Respondents may answer questions in their role as citizens rather than as consumers; that is, they provide responses which the regard as appropriate for the community good rather than for maximisation of their private utility (Blamey et al., 1995; Blamey, 1996).

Imperative for 'good figures'

There is sometimes a strong incentive to come up with figures which will be perceived as a satisfactory result, particularly when the valuation is carried out by a consultant for a client with a vested interest in the valuation outcome. There may be an implicit understanding by the consultant as to the value the proponent of a project would like to see obtained. Because a wide variety of benefit categories can be recognised under the TEV framework, and benefits in these categories could take a wide range of values, it is possible to come up with very large numbers. In the extreme case, if one uses non-market valuation unscrupulously, it becomes possible to support any argument or investment proposal.

National CVM surveys in Australia have produced particularly high values, which has led to skepticism about their reliability. The estimated values of approximately $600M a year to not log Fraser Island and also $600M a year to not mine Coronation Hill appear suspiciously high. The Coronation Hill study provoked the mining industry to raise the question "Will the play money drive out the real money?". In effect, this implies a lower value weight for consumer surplus relative to producer surplus. If a government considers that producer surplus is more valuable than consumer surplus (eg. that mining has externalities with regard to infrastructure development), then this can be accommodated by shadow pricing or placing a loading the former values (but not by excluding consumer values altogether).

Recent Developments in Application of Valuation Techniques

As research progresses, a better understanding of the strengths and weaknesses of non-market valuation techniques is being gained, and guidelines for the application of these techniques are evolving.

There has been considerable effort to define which techniques are most suitable to which application areas. For example, Schuele et al. (1997) examine choice of technique for valuing recreational fishing. Similarly, Driml (1998, pers. comm.) prepared guidelines for the Queensland Department of Environment (now Environmental Protection Agency) on matching valuation techniques with applications.

Given that non-market valuation techniques tend to have relatively high estimation errors and are prone to bias, it is important to delineate conditions when estimates are reliable and when errors are most likely to occur. Harrison identifies the following factors as likely to lead to difficulties in estimation of values:

'Distance' from market goods

It is generally considered that the nearer a good to a market good, the more able are people to place a value on it. Outdoor recreation is close to fee-paying recreation, and valuation is relatively straightforward and values reasonably well accepted. Items far removed from markets — such as the value of an endangered species or maintaining peace of mind — require respondents to deal in markets where they lack experience. In general, non-use values pose greatest problems for valuation.

Time until value will be realised

Where items are potentially of high value, but have little value at present, there will be high uncertainty as to estimates. This is the case, for example, with option values such as gene pool and pharmaceutical values of native plants.

Heterogeneity of the population

The more heterogeneous the population — eg. in terms of culture, socio-economic status and attitudes — the more variable are values elicited likely to be.

Complexity of ecological or social systems

Typically, systems which are highly complex will not be well understood, which may contribute to high uncertainty as to their values.

Size of spatial distribution

Where a resource to be valued is spread over a wide area, such as a district or State, the level of system complexity and the heterogeneity of the affected population is likely to be high, and value estimation difficult.

Extent of community knowledge about the item to be valued
Items which do not currently exist, or which are not well known, present particular valuation difficulties. Cameron (1997) found a positive relationship between respondents' amount of experience with environmental goods and their value estimates from CVM.

Particular problems in developing countries
In developing countries, markets are often less developed, placing values on the environment may be a less accepted, fewer comparable studies will be available for benefit transfer, and WTP surveys may be more difficult to carry out, eg. due to lack of people trained in this methodology and less supporting infrastructure.

As well as development of new techniques, and refinement of existing ones, researchers have experimented with use of combined techniques for valuation of a particular resource. For example, Schuele et al. (1997) suggest a combination of the travel cost method and contingent valuation for estimation of recreational values for fishing.

Some Difficult Estimation Areas

Many examples arise where estimation of values is difficult.

Values of non-existent or not-well-known environmental goods

As indicated above, a resource which is unknown or not well known by the community is difficult to value. People will not hold a value to preserve resources the existence of which they are unaware, and may have difficulty placing a value on a proposed resource. Thus, a proposed walking track, or a wetland that few people had heard about, might attract low value estimates. A further problem is that value estimates can be highly sensitive to the information provided to respondents. In this context, it is useful to include questions about respondents' prior knowledge of the information provided, in the survey instrument.

Genetic resources and pharmaceutical values of plant species

The question is often posed as to what is the value of a species, ie. how much would a national or the global community lose if a species became extinct. This is highly variable, from important food crops to pests and diseases for which eradication programs imply large negative values. An important component of species conservation is option value eg. of plants for medicinal products and as a gene pool for agriculture. Pearce and Moran (1994) explored these values, raising some cautionary issues. First, the probability that any individual (threatened) species will be the source of an important drug is small — estimated by Principe (1991) as between 1/1000 and 1/10000. Second, the 'resource rents' or benefits of these drugs may not go to the general community or even to the country where the plants are found. Third, interest in exploiting these drug sources may be limited. According to Ehrenfeld (1988, p. 213), "It used to be said that the myriad plants and animals of the world's remaining tropical moist forests contain a great many chemical compounds of potential benefit to human health — everything from safe contraceptives to cures for cancer. ... Pharmaceutical researchers now believe, rightly or wrongly, that they can get new drugs faster and cheaper by computer modeling of the molecular structures they find promising on theoretical grounds followed by organic synthesis ... including genetic engineering. There is no need, they claim, to waste time slogging around in the jungle". Ehrenfeld (1988, pp. 214–215) goes on to argue that the species which are the most rare are the ones least likely to be missed by the biosphere. Wild species provide a store of both genetic material and genetic information for future plant breeding to aid pest and disease resistance. In this context, Randall (1994, p. 275) observed "It is not yet clear whether the emerging technologies of bioengineering will enhance the value of naturally occurring genetic material or merely substitute for it". Evenson (1981) noted that the estimation of genetic values is extremely difficult.

Visual disamenity cost

When land degradation takes place, as well as loss of productivity there can be severe visual disamenity, such as unsightly algal blooms, salt scalds and gully erosion, the value of which may need to be estimated. Many studies have valued attractive landscapes, good views, recreation sites, value of 'visibility' and opportunities for viewing wildlife. However, when examining the "visual disamenity cost" of high-voltage overhead transmission lines, Harrison et al. (1995) found there was surprisingly limited information about the reduction in value from deterioration in appearance or "eyesores". Personal discussions and email consultations with a wide spectrum of environmental economists at that time revealed only one study which placed a disamenity cost on electricity transmission, and this involved a subjective assessment by the appraiser rather than a community survey. Whether this indicates that visual disamenity is difficult to value, or there is a lack of interest in such values, is not clear, although the latter explanation seems improbable. Another study concerning visual disamenity relates to the cost of tree dieback. This phenomenon has been observed in many countries (Harrison and Sutherst, 1998). In Australia, one the areas most severely affected is the New England Tableland, where attempts have been made to carry out a socio-economic evaluation of this phenomenon. Again, the valuation was found to be difficult and controversial.

The cost of anxiety and value of peace of mind

Non-market valuation appears to have concentrated on environmental values, somewhat to the neglect of social values. Yet, environmental issues often are proxies for personal and family anxiety and the desire to avoid change. Evidence suggests that anxiety can have a high cost to individuals, and peace of mind can have a high value. A guide to values for medical and mental conditions is provided by court awards. In a recent Australian case, a policewoman was awarded $A750,000 damages for lack of support from her employer in relation to work-induced stress concerning child abuse cases (Ogg and Miranda, 1998). This amount presumably includes loss of earnings from ceasing employment with the Police Service. Social impacts have also been examined in valuation of food safety (Caswell, 1995).

In the visual disamenity study of Harrison et al. (1995), a major concern of people living near the proposed high-voltage overhead power line was possible adverse health effects of electric and magnetic fields (EMF). Scientific evidence suggests this is not a serious risk for people living 100 m or further away from the lines (although some doubt remains), and wires can be configured to minimise the EMFs. However, even if there is no health risk from the EMFs, there is still a cost to residents near the line in terms of anxiety, which should be factored in as a negative externality in cost–benefit analysis.

The Value of Information Systems

Modern information systems making use of computers, databases and geographical information system (GIS) packages are being used increasingly in environmental research, eg. Poh-chin et al. (1998). These systems replace paper-based or more piecemeal electronic information systems. The valuation of GIS systems presents a number of difficulties. One approach which has been used widely is to estimate the cost saving that can be achieved by the electronic system relative to the labour cost of an existing and largely paper-based system. While this is likely to yield a favourable benefit to cost ratio, it is hardly a fair comparison. For one reason, the tasks carried out by a GIS probably would not be attempted with a more traditional system. For another, the GIS creates both the opportunity and the awareness to perform new functions. The difficulty is that valuation of the additional functions of the information system is extremely difficult. In addition, prediction of the roles which a GIS will perform is not a simple task, and there are often unrealistic expectations of what can be achieved, as noted in the context of an animal health information system by Harrison et al. (1999).

Economic Impacts of Climate Change

Considerable effort is being made to estimate the economic implications of climate change, such estimates being relevant to national and global greenhouse gas mitigation measures. Climate change presents perhaps the most costly externality with which environmental economists are confronted. Sterner and van den Bergh (1988, p. 252) reported that "[i]n this volume we have chosen to include no less than four articles on global warming, which reflects how important this subject is perceived to be." From a valuation perspective, a difficulty arises in that climate change scenarios remain rather speculative, depending on a variety of assumptions, which may be referred as an uncertainty explosion (Henderson-Sellers, 1993). Any economic valuation based on these scenarios multiplies the uncertainty even further. Harrison and Sutherst (1998) examined the feasibility of making cost–benefit estimates of the impact of climate change on tree dieback in Australia's New England region, concluding that tentative estimates of policy relevance could be derived. A problem in this valuation was the need to predict what adaptive behaviour will take place in response to climate change, eg. whether landholders will attempt to ameliorate microclimates or change enterprises so as to reduce climate-change costs.

Degradation and Depletion of Natural Resources Nationally

'Green' national accounting introduces a need to make estimates of the change in value of natural resources at a national level. The large spatial extent and range of resource types of such estimates raises estimation problems. Common and Sanyal (1998) made estimates of the decline over time in values of Australia's mineral resources, and concluded that different estimation methods yield strikingly different valuations, hence this task is fraught with difficulty.

> "It has become clear that, to say the least, producing accurate numbers for sustainable national income will be a difficult, and costly, exercise" (Common and Sanyal, 1998, p. 23)

The Value of the World's Ecosystems and Natural Capital

In a brave effort to value the services of natural systems globally, Costanza et al. (1998) produced a figure of $US33 trillion for these services. When this paper was reproduced in Ecological Economics, there has been a good deal of cynicism in the journal about these values, with paper titles along the lines "Pricing the invaluable", "Why not calculate the value …" and "Next, the value of God …", and comments such as "There is little that can usefully be done with a serious underestimate of infinity". Criticisms of the Costanza et al. effort can be divided into three types:

- concern over specific detail in the estimation methods, such as the reliability of national accounts and the possibility of double counting;
- broader concerns over the acceptability of the valuation approach, such as whether it is valid to use observed prices from non-sustainable economic systems; and
- objections to attempt to value these resources at all (eg. that they are beyond value, or that valuation from a human-centred perspective is immoral). In this context, Hammon (1998) asks, "How might nature value man".

Future Prognosis and Concluding Comments

One may ask where research into valuation of impacts relating to natural resources and the environment is heading. It seems probable that interest in this field will continue, driven by the various demand factors discussed above. At the same time, a high degree of cynicism for some of the valuation efforts will remain. Research will no doubt continue into alternative non-market valuation methods which overcome some of the recognised risks associated with CVM, particularly with respect to bias and the 'all or nothing' basis of valuation. Choice modelling (choice experiments) currently appears to be the most promising alternative, and further research on this approach can be expected.

Further work can also be expected on benefit transfer methodology, because of the practical utility of this approach. Developments which can be expected include:

- creation of databases of environmental (and perhaps social) values. These involve collation of non-market values from the literature, and standardisation to a common basis of measurement (eg. common year, per head basis). An early example has been provided by the Morrison's Envalue database (NSWEPA, 1995), which is now publicly available on the Internet. Other such databases are now under construction, and these will become more useful as the number of items in them increases; and
- exploration of the circumstances in which benefit transfers are appropriate, and the way in which estimates from other sites can be adjusted to make them usable.

The development of valuation techniques and progress of benefit transfer methodology are not independent activities. Choice modelling offers the prospect of providing estimates of individual components of total economic value, which may be particularly useful for benefit transfer applications involving intractable values. The placing of economic values on social impacts and social change is a further possible area of research focus. There is much scope for economists and social impact specialists to work together to value social costs.

To date, there has been limited progress in placing a level of uncertainty on non-market value estimates, which will in many cases mean admitting to wide and perhaps subjective confidence intervals. However, it would appear to be a reasonable request for economists to provide an indication of the level of uncertainty in their estimates, eg. through explicit sensitivity or risk analyses.

Another area where progress is commencing is the matching of estimation techniques with valuation problems. It is unlikely that any single approach will be preferable for all valuation cases, so guidance is needed on what method should be applied in what situation. In broad terms, the stated preference approaches are more appropriate when the task is to estimate non-use or total economic value. Even then, a decision will need to be made about whether to undertake a survey approach (and say choose between CVM and CM), or whether to adapt estimates if available from similar studies (BT).

In spite of great enthusiasm about non-market values by some proponents, general acceptance is a slow process, and evolves through peer review in published literature, testing in a number of practical decision-making situations, receiving legal standing and building up a tradition of use. Recognition of difficult or intractable valuation cases, and exploration of suitable approaches for them, is an essential component of this process. It is to be expected that policy-makers will have increasing acceptance of non-market valuations, with respectability conferred by a growing tradition of use and critical evaluation, and by partial acceptance in courts in damage evaluation. Hopefully, at the same time a better appreciation will be gained about the viability of non-market valuation, confidence bounds of estimates, and situations where estimates are unreliable, and the weight to be placed on these values relative to other information.

The progress of these developments will obviously depend on the extent of interdisciplinary cooperation — between economists, other social scientists and ecologists. Value estimates are likely to be more realistic if linked to an understanding of the natural system. Further scientific research leading to greater understanding of systems is likely to lead to improved community understanding, better information in WTP surveys, and more reliable valuations.

In summary, no doubt economic researchers will continue to develop new valuation methods, and refine existing ones, and apply validation tests to these methods. As these methods are improved, it should be possible to achieve greater reliability in evaluation of research projects relating to natural resource management, and estimates can be expected to have greater standing. However, in research evaluation, only infrequently will special purpose valuation studies be possible, hence continued use of benefit transfer methods will be required. Accumulation of greater numbers of case studies in databases of environmental values and availability of greater detail of benefit generation processes rather than simply value estimates will help here.

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3 Case Study 1: Effects of Increased Salinity on Riverine and Wetland Biota (UMO18)

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Executive Summary

Rising salinity levels both in riverine and wetland environments constitute a serious environmental problem in Australia. Increasing salinity is a threat to native biodiversity, and can reduce the range and values of ecological services provided by wetlands and riverine environments. The debilitating impact of increasing salinity on wetlands can be reduced by improved management of water flows. Improving management requires the effects of increasing levels of salinity on non-halophytic (salt intolerant) biota to be known, as well as the salinity and the timing of the occurrence of salinity in waterbodies to be controlled. This study was designed to explore this subject and provide a database on salt sensitivity of non-halophytic organisms common to waterways and wetlands in southern Australia. The project took longer to complete than originally planned and significant transfer of intellectual knowledge to water managers could not be achieved during its course. Only after completion did noticeable transfer seem to occur as the result of a workshop. Difficulties in technology transfer are to a considerable extent a consequence of major changes in government administration in Victoria. Some further development and varied presentation of the database would be useful for improving transfer, to regional water managers, of the knowledge obtained.

It is impossible to provide benefit–cost ratios for this project with a high degree of confidence but a benefit–cost ratio of over two seems achievable.

All water managers interviewed believe that this research is helping to fill a significant gap in their knowledge about the ecological impacts of water management, and that the project can assist them in their water management, especially in their monitoring of improvements in the health of ecosystems in wetlands and riverine areas.

Background

Increasing salinity is not only a major threat to Australian agriculture, but is impacting adversely on riverine biota. The problem is especially serious in Victoria as pointed out by Harrison and Tisdell (1997, p. 37), but is also of major concern in New South Wales, Western Australia, and parts of South Australia, and is developing as a problem in Queensland.

Basically, increased salinity of surface or near-surface water in Australia arises from two sources (Wilson, 1995):

- clearing vegetation such as trees for dryland agriculture which reduces the evapotranspiration of underground water via deep-rooted vegetation and thereby causes underground watertables to rise bringing salts to or near the soil-surface; and
- rises in watertables due to irrigation, mostly combined with removal of deep-rooted vegetation.

Bailey and James (1998) report:

> "Secondary salinisation currently affects almost 3 million hectares in Australia and appears to be expanding at 3–5% annually. In the recent Assessment of the National Dryland Salinity R,D&E Program, Hayes (1997) concluded that, 'if comprehensive data was available on all costs associated with dryland salinity, it is likely that dryland salinity would probably represent Australia's most serious longer-term natural resource management issue' (p. 32).

Two key findings from the same report are that:

- the full costs of dryland salinity at the national level are not known but we estimate that they are at least $270M per year. Although agricultural costs have received most attention in the past they are likely to be over-shadowed by other costs, particularly infrastructure costs, including costs of deteriorating water quality and environmental costs; and
- the environmental spillover effect from dryland salinity will impact on some of the nation's most valuable environmental resources and threaten the stability of important ecosystems.

Harrison and Tisdell (1997, p. 37) point out that "Rising saline watertables in floodplains and ephemeral wetlands can be expected to impose salinity stress on plant and animal biota, and reduce survival rates between floods. A major method of control of rising saline watertables is pumping of groundwater into watercourses, which has implications of riverine water salinity and salt-sensitive biota". Not only can such saline discharges adversely effect riverine biota but, if they find their way into wetlands, they can adversely affect ecological health and undermine the valuable ecological services of wetlands. The latter are listed in Table CS3-2 (Case Study 3).

Little basic research has been undertaken in Australia on the relationship between salinity and the abundance and nature of biota in streams and wetlands. This is particularly so in relation to the duration of salinity stress and the timing of salinity stress in relation to the life-cycles of biota. UMO18 was especially designed to generate basic scientific information about such matters. All water managers who were interviewed in relation to this subject commented on the paucity of knowledge about this subject, particularly before the completion of this project.

Aims of the Project and Performance

The agreed objectives of this project were to:

- quantify the effect of increasing levels of salinity on non-halophytic (salt intolerant) macrophytes, macroinvertebrates, amphibians and fish inhabiting riverine and associated wetlands, by measuring changes in community structure, abundance, physiological responses and behaviour;
- develop a database of salt sensitivity of non-halophytic organisms common to riverine and associated wetlands in southern Australia, and
- prepare management guidelines on the timing and concentration of saline wastewater discharges to riverine and wetland ecosystems.

The technical outputs expected from this project, as identified in the LWRRDC review of April 1995 and summarised by Harrison and Tisdell (1997, p. 39), were:

- assessment of the effects of salinity on riverine and wetland fauna and flora in the range 1,000–2,000 mg/L NaCl;
- assessment of the different impacts from continuous versus pulsed salinity increases;
- effects of salt concentration on ephemeral wetlands;
- identification of wetland acidification and increases in mosquito populations as a consequence of, or somehow related to, increasing salinity of wetlands;
- impacts of the lethal and sublethal effects of salinity on macrophytes at various life stages and consequences for further populations; and
- guidelines for the release of saline waters into rivers and wetlands.'

As mentioned in the review update by Harrison and Tisdell (1997), several obstacles were encountered with this project. There were staff changes, construction delays at field sites, loss of equipment because of flooding at one site, vandalism, and drought in 1994–95 at Raftery's Swamp which meant that experiments at this site had to be delayed for a year. As a result, the size of the budget for the project as at the 1997 review had expanded from $0.84M to $1.4M, in which the contribution of LWRRDC rose from $285,000 to $439,900. However, the total budget expanded beyond this level because the project was extended by one year with the permission of LWRRDC, but with no extra funding from it. The extra funds for the additional year were provided by Monash University. [Although requested, the amount of the extra sum provided by Monash University in 1997–98 was not available to us at the time of the writing of this report.]

Studies were undertaken at two field sites and in the laboratory:

- studies of instream effects of salinity variation on biota were undertaken at Hughes Creek near Seymour; and
- salinity impacts on plants and mostly invertebrates were examined at the Raftery's Swamp near Shepparton. Glasshouse experiments were conducted at Monash University to determine the metabolic responses of three species of wetland macrophytes to increased salinity.

From the above studies (and those of other researchers), a salt sensitivity database for biota was prepared. In addition, it was observed that in wetlands the timing of increased salinity levels is crucial for the reproduction of several species. For instance, high salinity levels at the time when macrophyte species with low salt tolerance are developing their tubers and propagules can be expected to adversely affect their reproduction and their future presence in wetlands. Timing of saline releases in relation to biotic stages is an important issue. Instream pulsed releases of salinity are, on average, less favourable to species diversity and the preservation of species than continuous releases of similar magnitudes. Some species or groups, including gastropods, show greater sensitivity to salt than do others. The more sensitive species can be used as indicator or marker species. Each of the above three main findings have important water management implications, but translating them into specific guidelines is a difficult task because conditions can vary from locality to locality. Furthermore, the research undertaken is pioneering and has not been replicated to any extent either at the sites where the experiments have been conducted or elsewhere. Therefore, extension of results has to be approached with some caution.

Technical Outputs of the Project: Products, Processes, Improved Management Techniques, Other Information

The principal output of this project is intellectual knowledge useful for managerial purposes, rather than a patentable product or process. The physical incorporation of this knowledge is in published documents.

Recent, or relatively recent items, include:

Bailey, P. and Warwick, N. (1998), 'Salinity, a Threat to our Streams and Wetlands', Water, May/June, pp. 20–21.

Warwick, N.W.M. and Bailey, P.C.E. (1998), 'The effect of time of exposure to NaCl on leaf demography and growth for two non-halophytic wetland macrophytes, Potamogeton tricarinaturs. F. Muell and A. Benn. Ex A. Benn and Triglochin procera R. Br., Aquatic Botany' 62: 19–31.

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Warwick, N. and Bailey, P. (1996), 'Salinity in Wetlands: Detrimental Effects of the Growth and Development of Ephemeral Wetland Macrophytes', Danthonia, 5(2), 3–5, Australian National Botanic Gardens, Canberra.

Anon. (1996), 'Salinity Damages Wetland Plants and Animals', Victorian Landcare, 1(1), 23.

Warwick, N. and Bailey, P. (1995), 'The Effect of Increasing Salinity on Wetlands', Trees and Natural Resources, September, pp. 9–10.

In addition to the above, 7–9 papers, stemming from the project, are in preparation.

An extremely important output arising from this project is 'A Database of Salt Sensitivity of Non-halophytic Organisms'. It consists of 1,500 entries covering 1,049 different taxa. It is comprised of common and scientific names of the organisms covered, their range of sensitivity to salt, the source and quality of the data on which the sensitivity estimates are based and the geographical location where the sensitivities were observed.

From 1–2 December 1998, Dr Paul Bailey in conjunction with Dr Paul Boon conducted a Workshop at Maffra, Victoria, on 'Salinity Wetland Monitoring Program' and prepared extensive amounts of material for communication. Participants were regional water managers in Victoria, including salinity officers. This workshop provided a vehicle to communicate the main findings from UMO18 to water managers.

Dr Bailey would like to further the communication component of UMO18 by developing and installing an interactive database website (at Monash University) using salt sensitivity information about aquatic biota. He has not yet been able to obtain additional funding for this purpose, but he has prepared a proposal.

The skills and knowledge about Australian wetlands and riverine environments of the researchers in UMO18 increased as a result of the project. This enhanced human capital has assisted the following:

- The report for LWRRDC on Riverine and Wetland Salinity Impacts – Assessment of R & D Needs by Dr Paul Bailey and Dr Kimberley James, August, 1998 (to be published as LWRRDC Occasional Paper No. 25/99).
- The proposal for review articles involving Dr Paul Bailey and other authors entitled 'Novel approaches to monitoring wetland health' to celebrate the 50th issue of Marine and Freshwater Research.

Development and Adaptation of Research to a Form Suitable for End-Users

UMO18 extended over six years, although LWRRDC funded it for only five. While six years may seem a long period for a research project, compared with research for many industrial projects, it is a comparatively short time, especially bearing in mind that much of the research undertaken was of a relatively fundamental nature. There were also inevitable delays with this project mainly because of problems at field sites. Hence, as is to be expected in such research, a long gestation period exists before substantial scientific results can be communicated to end-users.

Furthermore, care must be exercised when research results depend on inductive methods in order to avoid possibly unwarranted generalisations on the basis of limited experimentation both geographically and serially. A balance must be struck between premature reporting and overcautious behaviour in this regard. A degree of risk is involved and, furthermore, where inappropriate advice is given, legal action for damages is always a possibility.

It appears that adaptation of research in a form suitable for end-users did not occur until 1996 when publications appeared in magazines, journals of special public interest groups (eg. in a publication of the Natural Resources Conservation League of Victoria), and in the Landcare Victoria journal. Publication for the scientific community first appeared in 1997 (Aquatic Botany). Water managers may have taken note of some of the earlier publications, but it seems to have been the Maffra Salinity Workshop in early December 1998 which had a major impact on regional water managers in Victoria. Material from UMO18 was adapted for this workshop and valuable interaction took place between researchers and regional water managers.

Further communication of the results from this project could eventuate. Sally Berridge Communication Consultancy (Canberra) was in contact with Dr Bailey (at the suggestion of LWRRDC) towards the end of 1998 to explore the possibility for assisting with some science communication for project UMO18. In further discussion in 1999, she suggested the possibility of preparing fact sheets for distribution to interested end-users, but mentioned that for legal reasons it would be wise to avoid the communication of management guidelines. Thus, even if detailed “management guidelines on the timing and concentration of saline wastewater discharges to riverine and wetland ecosystems” (objective 3 of UMO18) had been drawn up, there might have been legal impediments to their communication. In practice, only general guidelines have been suggested so far in relation to the biotic effects of timing and concentration of salinity discharges.

Potential Users, Actual Users, Barriers to Adoption, Adoption Rates

Harrison and Tisdell (1997) identified the Victorian Department of Conservation and Natural Resources (now Natural Resources and the Environment), regional water and drainage authorities and the Murray–Darling Basin Commission (MDBC) as the potential adopters of the research results from UMO18. These are potential users for managerial purposes. But in a wider sense, there may be many other users of the research results. These could include:

- landholders who with to conserve wetland on their properties;
- community wetland action groups such as Landcare and Wetland Care;
- Parks Victoria;
- Victoria Field and Game Association, with its interest in duck hunting — such associations sometimes help fund wetland rehabilitation;
- local councils with an interest in using wetlands for tourism and outdoor recreation; and
- bodies with a general conservation interest such as the Australian Conservation Foundation, and the Natural Resources Conservation League of Victoria.

Of course, counterparts of the above in other Australian States would also have an interest in the results of this research. Furthermore, the wetlands research community (including academic and non-academic institutions) will be users of this research, which is a bridge to further research findings in this area.

In Victoria, since water management has now been largely decentralised to the regional level, it is regional salinity/environmental officers of the Department of Natural Resources and the Environment who are likely to be the main end-users of the results from UMO18. Nevertheless, improving or sustaining the ecological health of wetlands and riverine areas largely involves the provision of a social or collective commodity or benefit. Public servants must be guided, through their relevant ministries, by public demands for such commodities. Therefore, communications with those likely to demand such commodities or benefits (‘pressure-groups’) may be as important, or more important, than communication and transfer of techniques to water managers. In the case of the transfer of management strategies relating to social or collective goods, a more diffuse communication strategy is required to facilitate adoption than in the case of private goods. In the latter case, communication with only the end-user of the technology or intellectual knowledge, such as a business enterprise, is required.

There appear to be no water managers as yet using the results from UMO18 but several are on the verge of doing so and some have been sensitised to the management issues raised as a result of UMO18. Hence, adoption rates of results from this research so far are low or near zero. This is mainly because the results are only just starting to become known to many water managers. In Victoria, the Maffra Salinity Workshop held in early December 1998 appears to have been a watershed. Regional water managers in Victoria became aware for the first time of the potential relevance of the results from UMO18 for their management

A severe barrier to the transfer and adoption of results from this research was the substantial changes made in public administration in Victoria during the life of the research project. This reorganisation meant that Dr Bailey lost his original network in the Victorian Department of Conservation and Natural Resources and with continual changes found it impossible to re-establish an effective network during the project. This had two consequences: (a) reduced input from resource managers as to features that would be useful to develop in the project from a managerial perspective with the unfolding of research results, and (b) the absence of a conduit for transferring research results to resource managers. An gap appeared between the researchers and water managers.

This gap could not be filled until the institutional structure of the Victorian Government evolved to a more stable state. As mentioned earlier, a more decentralised structure has evolved than previously. In December 1998, Dr Bailey was able to establish contact with the regional water managers through the Maffra workshop, and develop an interaction. This augurs well for any follow-up activity to UMO18 or for any new wetland research projects involving Dr Bailey and other researchers, such as the joint research project with Associate Professor Boon on wetland eutrophication and algal blooms.

It should also be repeated here that, since relatively basic research was being undertaken and because there were delays due to inescapable problems in the field, there was little intellectual knowledge to transfer early in their project. It is unrealistic to expect technology transfer in research of this nature until some considerable time after a research project has commenced. Furthermore, the costs of technology transfer and adaptation are generally quite high and call for special skills which many researchers do not have. In most industrial projects the cost of developing research and actually applying it are much greater than initial research costs. Therefore, LWRRDC may have had unrealistic expectations about the transfer of intellectual knowledge and associated technology to the applied managerial stage in relation to projects such as this, particularly given the climate of institutional change which the project faced.

The regional water managers involved in the Maffra Salinity Workshop were all of the view that the salt sensitivity results from UMO18 were of great value to them. There is obviously great demand for the salt-sensitivity biota database from water managers.

There may be several reasons for this. Regional catchment salinity/environmental officers of DNRE are required by the State legislature to monitor and report on changes in the ecological health of wetlands and waterways and, if possible, improve the health of these. The salt sensitivity database compiled as a result of UMO18 can be a considerable help in this regard. In a communication to Dr Bailey dated 4 January, 1997, Eleisha Keogh, Salinity/Environmental Officer, Lake Wellington Catchment District, thanked him for his contribution to the Maffra workshop and suggested ways in which the database might be manipulated and presented to make it more useful to water managers in the field. She also suggested (letter of Eleisha Keogh to Dr P. Bailey, dated 4/1/99) that the database could have the following managerial uses:

> "To predict the impact of an increase in salinity concentrations in a wetland/river on the biological environment (sub-lethal effects, and effects of continuous, pulsed or gradual increased are relevant here). The impact on significant species would be of particular interest.
>
> To develop salinity concentration objectives for a wetland or river in order to conserve, enhance or rehabilitate particular values.
>
> To choose salt-sensitive species that may be useful as indicators in a monitoring program for a particular site.
>
> As a guide to revegetation works."

In order to assess the possible use by water managers of results from UMO18, four water managers (identified by Dr Paul Bailey) were interviewed by telephone, namely:

- Eleisha Keogh, Salinity/Environmental Officer, Lake Wellington Area, Vic.
- Danielle Hefter, Salinity Officer, Kerang–Swan Hill Area, Vic.
- Heather Adams, Environmental Officer, Lake Corangamite Area, Vic.
- Dr Greg Raisin, Manager, Central West Region, Department of Land and Water Conservation, NSW.

All of these resource-managers said that results from research undertaken for UMO18 are of value to them. Regions vary in relation to the salt management problems which they face, as the following information reveals.

In the Lake Wellington area (in Gippsland) rising watertables are causing saline intrusion into freshwater wetlands. Rising watertables are a consequence both of irrigation and dryland agriculture. Several pumps are operated in the area by Southern Rural Water, a Victorian Government Corporation. New pumps must be approved by the Victorian Environmental Protection Agency (EAP). Electric pumps discharge water into irrigation return drains from which it flows to the river. None of the saline water being pumped is dumped in wetlands. Pumps are designed to operate at constant speed 365 days a year, but are sometimes turned off when farmers want to irrigate from irrigation return drains. The aim is on average to keep the watertables two metres below the surface in dryland areas and one metre below the surface in irrigated areas.

Although of the pumps are operated by Southern Rural Water, management is by the Wellington Salinity Group, a local community group of which the DNRE Salinity Control Officer is a member.

In deciding whether to grant a permit for an additional pump, the EPA takes into account the quality of the water in the stretch of the river or stream into which the water is to be discharged. All beneficial users are to be considered and a balance is to be struck by the EPA in making its decision. Varying levels of environmental protection are therefore applied, but Australian Water Guidelines for Protection of Ecosystems are taken into account.

Apart from saline intrusion into wetlands as a result of rising watertables, a most serious problem in this region is the transport of sea salt to inland waterways as a result of the opening of Lakes Entrance. This has increased salinity in Lake Wellington and in several other lakes and wetland areas.

There is considerable interest in rehabilitating the ecological health of wetlands in this region. The Lakes Entrance Council would like to use wetlands to attract both domestic and international tourists. Consideration is being given to installing some pumps in the future near wetlands to prevent saline groundwater from seeping into these. Rehabilitation of wetlands is of particular interest in this region.

UMO18 was described as a useful study from a managerial view point. It was said to be value-adding. Of particular interest is information about the salt tolerance of different species, importance of the timing of exposure of biota to salinity and the effect of sub-lethal doses of salinity on populations of species. The following additional points were made about this research:

- the research indicates that several factors affecting water quality may be interlinked, eg. salinity with acidity, salinity with high nutrient-loads and so with the occurrence of cynobacteria (blue-green algal blooms) – high-nutrient loads may occur because of reduced population of macrophytes;
- the research is especially useful because it does not rely purely on glasshouse experiments;
- in some regions, attention needs to be given not only to the environmental impacts of NaCl, but also to other salts in water;
- this research is of particular interest because it involved the study of sub-lethal as well as lethal effects on biota of salinity; and
- research of this type takes considerable time, as does the transfer of its findings.

Few extension and similar support services appear to be available to regional water managers in Victoria. This may be a relatively widespread problem in Australia and has been commented on by Dr Anne Jensen (see Case Study 3). It seems to be a consequence of government restructuring.

Considerable demand exists for extension work and communication products. The extent to which LWRRDC should fill this gap is unclear. It was suggested that the following would be of value:

- a manual for salinity management based on the results of the range of available scientific findings (not just those from UMO18);
- further development of the salinity database; and
- modification of the database so as to simplify it for use in the field — from the point of view of water managers, this may be more important than putting the database on the Internet, but this is not incompatible with Internet entry.

In the Kerang–Swan Hill region, salinity was described as the major water problem. Groundwater is considered to be too saline for pumping for disposal. Some wetlands in the region are permanently inundated as a result of weirs on the Murray River (compare Case Study 3) or now permanently dry or mostly so because of reduction in the fluctuations in the water-levels of the Murray. Considerable effort to rehabilitate wetlands is being made in the Kerang–Swan Hill area.

A major problem in this area is the intrusion of saline groundwater into wetlands. Flushing with freshwater is being trialed as a means to reduce saline build-up in some wetlands connected to the Murray. The timing of the flushing may be of importance for the composition of biota in a wetland. Findings from UMO18 are relevant in this respect.

There are several highly significant wetlands in this region, many of which are RAMSAR listed. The latter are managed by Parks Victoria but DNRE carries out monitoring for them. Priorities for water management by DNRE in the region are determined by internal discussions and discussions with community stakeholders. The Victorian Game and Field Association has provided some funds for wetland rehabilitation in this area.

Results from UMO18 are likely to be of importance in this region for monitoring salinity impacts on biota, particularly information about the salt tolerance of macrophytes and invertebrates. These data will be especially important in monitoring for signs of biota recovery as salinity management plans are instituted.

Furthermore, it was suggested that information from UMO18 could be useful for the management of some wetlands on private land. In some areas, community surface drainage networks have been established and the run-off from high rainfall events is stored in dams. Some water could be diverted to private wetlands at critical times so as to reduce salinity levels in wetlands. Changes in surface drainage can affect salinity conditions in those wetlands which receive a considerable amount of local run-off of water.

The south-west region of Victoria is well endowed with wetlands and lakes, but many of its lakes are naturally saline to varying degrees. Lake Corangamite and Lake Colac are both saline. Lakes are as a rule formed by the movement of groundwater in this region from west to east. However, salinity levels and problems in waterbodies in this region have escalated.

Reasons for this include:

- removal of tree cover for agriculture; and
- diversion of rivers and streams feeding lakes, eg. the diversion of waters normally entering Lake Colac to the Barwon River — water diversion is usually practised with little consideration for its impacts on wetlands.

In the Corangamite region, pumping of subsurface water is not practised. While tree planting has been encouraged or undertaken as a remedial action in the past, it has not been on a sufficient scale to be effective. At least 25–30% tree cover is required to have any noticeable impact on watertables. Tree planting by DNRE has mostly been of a 'cosmetic' nature — planting in unsightly areas showing salt scald. However, it is possible that commercial factors may play a positive role in the future as more landholders begin to grow eucalypts for the pulp industry.

The presence of blue-green algae is a serous problem in the Corangamite area. In 1992, 60,000 ha of lakes and wetlands were affected. Increasing eutrophication of waterbodies in this region seems to have go hand in hand with rising salinities.

As mentioned earlier, the Corangamite area has many wetlands and lakes. The smaller ephemeral wetlands are often overlooked in conservation policy but they have an important role as support systems for some species, eg. brolgas.

Catchment authorities are basically responsible for the management of surface water. Victoria has been divided into nine catchment regions. Good management requires that surface and underground water management be co-ordinated.

In relation to UMO18, the Maffra Salinity Workshop was described as a turning point. It helped to provide some useful guidelines for wetland management. Water managers of DNRE are required to pursue effective wetland and water monitoring policies, but have been given little guidance as to how to best achieve this. UMO18 gives some pointers as to how monitoring might be done. For example, in the past macrophytes were not monitored in the Corangamite region.

A side-result of the research in UMO18 is the suggestion that there is a close connection between the presence of macrophytes and the absence of blue-green algal blooms. If increased salinity reduces macrophyte abundance, the frequency of blue-green algal blooms increases According to Heather Adams, this observation is supported by experience in the Corangamite area.

The Maffra workshop was especially appreciated by the regional water managers participating in it because it gave a chance for networking and involved a two-way flow of information between researchers and water managers. Long-term research with effective communication and networking is required to improve water management.

Discussion with Dr Greg Raisin, Manager for the Central West Region for the Department of Land and Water Conservation, NSW (stationed in Orange), indicates that results from UMO18 have application outside Victoria and are relevant to some water management problems in his region. The Central West includes rivers such as the Macquarie, Brogan and the Lachlan. These terminate in wetlands and the waters now rarely reach the Murray–Darling system, because of high levels of water offtake for irrigation.

Salinity problems are increasing in the central west of NSW mainly because of dryland salinity in the headwaters of the rivers flowing through this region. Salinity monitoring stations have now been established on rivers in the central west and a freshwater quota for salinity dilution has been established.

A number of species in the salt sensitivity database of UMO18 occur in this region. The database will be useful for monitoring these and helpful in deciding when to draw on freshwater stocks for the purposes of diluting salinity of water.

Dr Greg Raisin stated that there is an urgent need for greater support for research into salinity issues given their current and growing importance.

Research, Development and Extension Costs, Including Costs of LWRRDC and Host Organisations

Expenditure on this project is set out in Table CS1-1. The upper half of the table is definitive but the entry for 1997–98 is an 'estimate'. Despite requests, no estimate had been supplied by Monash University at the time of writing. Continuation of the project in 1997–98 was entirely funded by Monash University. Its outlay in 1997–98 is assumed to be somewhat less than that for 1996–97, namely just over $105,000. Thus, total outlays on this project were of the order of $1.5M undiscounted. Discounted to the commencement of the project at 7%

per annum this amounts to just over $0.95M of total outlays.

Market and Non-Market Benefits

Virtually all the benefits from this project are non-market benefits. They are the same type of benefits as can be expected generally from having ecologically healthy wetlands. These benefits are specified in Table CS3-2 (see Case Study 3). A particularly important aspect in this case is that preservation of many types of salt-sensitive biota appears to play a positive role in reducing eutrophication and the occurrence of blue-green algal blooms.

Benefit–Cost Ratios

It is extremely difficult to estimate the likely benefit–cost ratios from this project with accuracy. However, if the same assumptions are adopted as in Harrison and Tisdell (1997) and costs are adjusted for the expenditure of Monash University in the extra year (1997–98) for which the project was extended, benefit–cost ratios are as set out in Table CS1-2. As in Harrison and Tisdell (1997), a discount rate of 7%. Only in those situations in which the benefit–cost ratio exceeds unity is the project economic. In such cases, the discounted stream of benefits exceed the discounted stream of costs. As in the previous report, a planning horizon of 20 years is assumed to apply from the same time as in that report.

Harrison and Tisdell (1997) were of the view that 10% of wetlands in Victoria (about 40,000 ha) would benefit from this research and that its application to management would, on average, conserve 10% of their annual value per hectare, estimated to be $10 pa. Allowing for the additional costs incurred in 1997–98 on this project, this indicated a benefit cost ratio of 2.05 assuming an eight-year lag from mid-1997 before adoption in a one-step process. For the purposes of approximation, these authors assumed all adoption would be delayed until the eighth (or alternatively the fifth) year from project completion. In either of these cases, the project is economic. However, there are also some circumstances in which discounted benefits are less than discounted costs. Furthermore, some additional expenditure may be needed to improve the transfer of this knowledge, eg. improvements in the preservation of the salt-sensitivity database to enhance its use in the field.

It should, however, be noted that the benefits of this research are unlikely to be confined to Victoria. Furthermore, given low current interest rates, a discount rate of 7% may be on the high side. Allowance for such factors would tend to increase estimated benefit–cost ratios. On the other hand, costs of varying water management to achieve target salinity-levels should be deducted from benefits received. The nature of these water management variations is less clear than for Case Study 3. However, in the Gippsland region consideration is being given to installing groundwater pumps near some

Table CS1-1 Project expenditure for UM018 ($'000)

Year	LWRRDC funds	Research organisation (Monash Univ.)	Third party	Total funds
1992–93	91.0	149.7	47.1[a]	287.8
1993–94	119.9	201.9		321.8
1994–95	118.5	168.3		286.7
1995–96	61.7	254.3		316.0
1996–97	48.8	127.1		175.9
Total	439.9	901.3	47.1	1,388.2
1997–98	–	105.1[b]	–	105.1
Total	439.9	1006.4	47.1	1493.3

[a] Salinity Bureau of Victoria
[b] Estimated.

Table CS1-2 Benefit–cost ratios of project UM018 in relation to rate and time of adoption and fraction of wetland value protected

Fraction of area (%) Years to adoption	5 5	5 8	10 5	10 8	15 5	15 8	20 5	20 8
Fraction of wetland value protected	5	0.52	0.29	1.33	0.88	2.14	1.46	1.94
	10	1.33	0.88	2.95	2.05	4.57	3.22	6.19
	15	2.14	1.46	4.57	3.22	7.00	4.98	9.44
	20	2.95	2.05	6.19	4.39	9.44	6.73	12.70

wetlands to reduce watertables to prevent salt intrusion. In the Central West of NSW, a strategic freshwater quota is available which can be used to dilute saline water. Environmental water quotas are available in some other areas, eg. at Kerang, for flushing some wetlands in the Murray. In some other cases, eg. Corangamite, less diversion of streams is possible. Pumping of saline underground water to the sea rather than disposal into wetlands such as the Tilley Swamp and the Southern Coorong in South Australia has been considered.

Bennett et al. (1997), using the contingent valuation method, estimated that the total value of not pumping underground water into the Tilley Swamp and the Southern Coorong and so avoiding ecological damage to these would be of the order of at least $10M. The costs of the water diversion and the management of it would need to be offset against any such benefit.

One of the benefits of this project which is difficult to quantify is its contribution to other research projects and ideas. For example, there appears to be a connection between increased salinity, reduced presence of biota such as macrophytes and the occurrence of blue-green algal blooms.

Further Monitoring Requirements

While a case could be made out for continuing to monitor the transfer of intellectual knowledge from this project, the case for doing this is likely to be stronger if funding becomes available for developing the salt-sensitivity database so its practical value is increased. If the database is put on the Internet, access can be monitored. However, it seems that some water managers would prefer to have simplified field guides.

Monitoring takes time. It requires the Principal Researcher to provide data and information to the individual doing the monitoring. Several days of work can be involved. It is, for example, estimated that the Principal Researcher for UMO18 would have spent 5–6 days preparing materials and making contacts for his review. This came at a time when teaching and fieldwork demands on his time were high. The opportunity cost to researchers can be high when they have other activities to which they must also attend. The benefits of additional monitoring must be weighed against such costs.

Concluding Observations

Greater interaction between water managers (particularly at the regional level) and researchers involved in this project both before its commencement and during its execution would have been desirable. This way the project might have been designed so that it related more clearly to management objectives, and transfer of knowledge (a two-way process) could have occurred as the project unfolded. In fact, effective interaction with regional water resource managers did not occur until after the completion of the project. In part, the problem of inadequate liaison with water resource managers has its roots in major changes in government institutions in Victoria during the period of research.

The public service structure changed from a relatively centralised to a more decentralised one. Consequently, original contacts and networks in the Department of Conservation and Natural Resources were lost by the researchers. These contacts were in Melbourne rather than at the local level. The new structure for managing Victoria's water resources took some time to evolve and become operational. At this stage, regional officers seem to lack support services and are keen to take advantage of any information and data which will help to guide them in their management of water resources. Therefore, they are eager to take advantage of whatever guidelines can be provided by the results from UMO18, particularly in relation to salt-sensitivity of biota. This is especially so since water managers are required by legislation in Victoria to monitor wetlands and report on their ecological health.

The absence of clear operational public objectives for the conservation of wetlands and riverine environments hampers the assessment of research projects designed to improve the management of the ecosystems involved. Much decision-making in this area seems to involve ad hoc political processes. Management objectives often appear to be open-ended (to some extent, vague) and not holistic in nature, eg. fail for example to take account of all interdependencies and demands of ecological services. This may be unavoidable to some extent because social processes and knowledge evolve and are dynamic rather than static.

Management guidelines on timing and concentration of salinity in riverine and wetland ecosystems have not been developed in great detail from this project. It has concentrated mostly on basic research and general guidelines. While the results can be linked to actual water management problems (field problems), to do this requires the involvement of water managers, not just the natural science researchers. Application of the results in different types of management and environmental systems and situations needs to be specifically explored. An interdisciplinary approach (possibly involving ecological economists) and a side-by-side approach (Tisdell, 1995, 1999) is likely to be beneficial in this regard.

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4 Case Study 2: Ecological Processes for Management of Wetlands and Floodplains — Practical Management Systems (DEP1)

Research Organisation
Department of Environment and Land Management (now Department Environment, Heritage and Aboriginal Affairs)

Principal Investigator
Dr A.E. Jensen (now on leave as Habitat Co-ordinator, Wetland Care Australia)

Executive Summary

The main purpose of this project was to promote technology transfer and foster the adoption of management strategies to improve the ecological health of wetlands and floodplains, although there was also a small experimental component in this project. The project concentrated on processes of critical importance for the ecology of Australian wetlands and floodplains. Analysis of this project indicates the significant influence of social and political factors on adoption rates. This is not surprising, since the provision of social or collective commodities, rather than private goods, is involved in changed water management techniques. Furthermore, the study highlights the problem of how to attribute benefits to different projects and initiatives which may have contributed to the accretion of relevant knowledge and its transfer. In most cases, credit cannot be totally assigned to one project or initiative. Despite such issues, there is strong evidence that this has been a very successful project in achieving its objectives and that it has a benefit–cost ratio is well in excess of unity.

Background

Inland economic developments in Australia, mainly for agricultural purposes, have reduced oscillations in the water levels of many inland Australian rivers and have reduced their water quality as evidenced by elevated salt-levels, increased nutrient loads and additions to water turbidity. All of these factors impact adversely on the ecological health of wetlands and floodplains, but reduced fluctuations in the flow of rivers is of major importance.

Reduced fluctuations in river levels are pronounced on the Murray River, especially below Wentworth in New South Wales, because of the large number of weirs in this stretch, intended to maintain water levels at controlled heights. The weirs were built before World War II, initially to improve navigation but are also used now as a source of irrigation water. They have changed the Murray below Wentworth into a series of relatively static connected pools behind the weirs, some of them up to 88 km long. There are 10 locks (weirs) below the junction of the Darling and the Murray, six of them in South Australia. There are 15 locks below Euston in New South Wales. Furthermore, barrages below Blanchetown have altered the originally brackish waters of the lower Murray system. According to K. Walker (1996), these human 'developments' have changed the ecology of the lower Murray and are a threat to the conservation of the Murray's native biodiversity.

In addition to the weirs, reservoirs in the headwaters of most major rivers flowing into the Murray–Darling system have helped reduce fluctuations of river levels. Consequently, the combined impact of weirs and reservoirs and greater offtake of water for irrigation and other uses, is that some former floodplains and wetlands are no longer inundated or rarely so, and their normal wetting and drying cycles are eliminated or impeded. This changed pattern has undermined the reproduction of floodplain and wetland biota, eg. the regeneration of river gum and black box depends on such cycles. Animal reproduction also is adversely affected, eg. shortened periods of floodplain inundation adversely affect the breeding of ducks.

At the same time as some former wetlands are no longer flooded or rarely so, other wetlands on the Murray are permanently inundated or inundated for much longer than previously, because of the impoundment of water by the weirs. Thus, the normal wetting and drying cycles of these wetlands have disappeared and much Australian biota dependent on these cycles eliminated. Riverine biota has been favoured at the expense of wetland biota.

Changes in water quality, such as increased salinity, have adversely affected some biota. Species which are intolerant of salinity are disappearing. Nutrient enrichment is stimulating growth of undesirable aquatic organisms such as blue-green algae. Increased turbidity also causes problems. For example, the waters of the Darling are dirty and those of the Murray are relatively clear. The impoundment of peak flows of the Darling in Lake Victoria and the gradual release of these waters maintains the turbidity of the Murray below that lake for much longer than was previously so. Increased turbidity reduces the penetration of water by sunlight. This reduces the growth of macrophytes in the Murray below Wentworth. In time, this, combined with high nutrient loads, may favour the growth of blue-green algae.

Thus, the reduced frequency and size of fluctuations in many inland rivers is reducing biodiversity along and around watercourses, threatening the continued existence of some native species, and is generally reducing the ecological health of riverine systems, particularly floodplains and wetlands. According to Jensen et al. (1996, p. 1), “wetlands are the kidneys of river systems – if they are healthy, the rivers will be healthy for all users”.

DEP1 is relevant to all the above major issues. Its primary purpose was to develop practical management systems to rehabilitate and sustain the biota of wetlands and floodplains, and to ensure the transfer of such management systems. DEP1 was linked with three other, basically biological/ecological projects. As explained in Harrison and Tisdell (1997), these were: CWS2, concerned with the health of vegetation on the Chowilla floodplain (principal researchers, Dr Glen Walker and Dr Ian Jolly, CSIRO Division of Water Resources); MRD10, dealing with macrophyte productivity and decomposition processes and their contributions to wetland food webs in Murray Valley billabongs (principal researcher, Dr Paul Boon, Victoria University of Technology) and UAD6, responses of aquatic plants to water-level fluctuations along the lower reaches of the River Murray and in Bool Lagoon (principal researchers, Dr George Grant and Dr Keith Walker, University of Adelaide).

Aims and Performance of the Project

The basic purpose of this project was, on the basis of available scientific data, and on results from CWS2, MRD10 and UAD6, to develop practical management systems for improving the ecological health of wetlands and floodplains. Specific objectives were to:

- promote and facilitate the coordination of LWRRDC-funded projects on the ecological basis for the management of wetlands and floodplains and assist the principal investigators with the communications components of these projects; coordinate and implement an information transfer package to ensure that results from these projects are taken up in management practices;
- liaise with other researchers and R&D institutions investigating wetland and floodplain processes (including those funded by LWRRDC), and with individuals, agencies and community groups that have management responsibilities and interests for these areas, in order to develop linkages and two-way information exchange between clients and researchers;
- develop and publicise practical guidelines for the rehabilitation and management of wetlands, aimed at both public and private users/managers and appropriate areas in the Murray Valley and elsewhere in southern Australia; and
- arrange a national seminar for presentation of the results of the ecological projects and others related directly to floodplains/wetlands management.

As pointed out in the previous review (Harrison and Tisdell, 1997), DEP1 was jointly pursued with a small project (M32291) funded by the Murray–Darling Basin Commission (MDBC) and concerned with developing a flow management strategy for the lower River Murray. That project was entitled ‘Hydrological Manipulations and Procedures for Instream and Wetland Management’. Considerable synergies existed between it project and DEP1 with a degree of overlap, such that the independent contributions of the two projects cannot be identified. The research results are joint ones and research involving the two sources of funds was pursued jointly. This was a sensible procedure. The project provided a bridge to the MDBC and therefore increased the likelihood of managerial transfer of results from both projects. Because of complementarity, research productivity was enhanced by having both projects proceed simultaneously.

As pointed out in the previous report (Harrison and Tisdell, 1997), actual transfer from projects CWS2, MRD10 and UAD6 may have been less than LWRRDC initially envisaged, partly because LWRRDC’s expectations were unrealistic. For example, only limited results were available from these other projects for possible transfer in the time frame set for project DEP1. In addition, realistic management policies had to be based on a wider body of knowledge and this was in fact done. A one-year time lag was involved in completing this project but LWRRDC provided no additional funding for the final year. This type of time lag seems to be not uncommon among LWRRDC projects.

Technical Outputs of the Project: Products, Processes, Improved Management Techniques, Other Information

The main purpose of this project was not to provide physical products as such, but to draw on scientific information and develop practical plans for the management of wetlands and floodplains and ensure transfer of information to potential users which would facilitate this. However, a number of physical products (mainly publications) and processes helped to facilitate this. These are listed in detail in the Final Report to LWRRDC on this project, submitted in 1996. Perusal of this report indicates that all the objectives of this project were in fact met, even if not all were met as quickly as originally anticipated. Although some results could be transferred from project UAD6 and from CWS2, it appears that little transfer occurred from MRD10 in the time frame of DEP1. MRD10 is not mentioned in the final report prepared for DEP1, no publications of Dr Boon are included in its reference list and Dr Boon was not involved in the 1996 regional seminar involving the LWRRDC partners of DEP1. This outcome was possibly a result of the short period of overlap of MRD10 with DEP1, the greater geographical distance of Dr Boon from Adelaide and lack of funding for Dr Boon for travel to the regional seminar. In any case, as mentioned earlier, the management strategies devised as a result of DEP1 draw on a wider scientific base than that provided by the three associated projects.

As for technical outputs, these do not neatly fall within the various categories suggested for this report, but the suggested classification can act as a guide.

Physical outputs for this project include the following:

Jensen, A. and Nicholls, K. (1997), Flow Management Options for the Lower Murray below Wentworth: Technical Paper for the Lower Murray Flow Management Working Group, Department of Environment and Natural Resources, Adelaide, 19 pp.

Jensen, A., Nicholls, K. and Nicolson, C. (1997), Flow Management Options for the Lower Murray below Wentworth: Analysis of Options and Impacts for Each Reach, Department of Environment and Natural Resources, Adelaide, 23 pp.

Jensen, A., Paton, P., Mowbray, T., Simpson, D., Kinnear, S. and Nicholls, S. (1996), Wetlands as a Basis for Integrated Catchment Management, Department of Environment and Natural Resources, Adelaide. A major work.

Jensen, A., Nichols, S., Nicholls, K. and Seaman, R. eds (1996), Adding a Few Pieces to the 'Mysteries of the Murray' Jigsaw: Proceedings from a Seminar presenting Results from recent Projects on the Murray Valley, Department of Environment, Heritage and Aboriginal Affairs, Adelaide, 66 pp.

Jensen, A. (1996), 'Identifying and Redressing the Ecological Consequences of River Regulation in the Lower River Murray' in I. Rutherford and M. Walker (eds) Proceedings of First National Conference on Stream Management in Australia.

Jensen, A., Paton, P., Mowbray, T., Simpson, D., Kinnear, S. and Nicholls, S. (1996), Wetlands Atlas of the South Australian Murray Valley: A Summary of Current Knowledge of Murray Valley Wetlands as a Basis for Integrated Catchment Management, Department of Environment and Natural Resources, Adelaide.

Jensen, A., Nicolson, C. and Carter, J. (1996), Restoration Techniques for Wetland Systems: A Case Study in the South Australian River Murray Valley, Department of Environment and Natural Resources, Adelaide.

Jensen, A., Nicolson, C. and Carter J. (1994), 'Preservation and management of natural wetlands in the South Australian Murray Valley', Water Science Technology, 29(4): 325–333.

Nicolson C. and Carter, J. (1993), Wetland Management: A Manual for Wetlands of the River Murray in South Australia, South Australian Department of Environment and Land Resources, Adelaide.

Carter, J. and Nicolson, C. (1992) Managing Wetlands of the River Murray in South Australia: A Guide to Communities of Common Concern, South Australian Department of Environment and Planning, Adelaide.

This is not an exhaustive list of publications stemming from DEP1. In addition, various pamphlets, fact sheets and so on were prepared, and contributions were made to a video and a television program.

As for processes, most of the publications mentioned above are concerned with outlining managerial processes which, if adopted, would improve the ecological health of wetlands and floodplains in the lower Murray. Their main purpose is to encourage or foster the introduction of improved water management techniques for the purpose just mentioned. Various methods were adopted to increase the likelihood of adoption of such techniques. For example, a network system of those interested or involved in management of wetlands was established as a result of this project. The principal researcher, both through her senior position at the Department of Environment and Natural Resources and her contacts at different levels, has been in a position to influence resource decision-makers to consider adoption of a number of the managerial recommendations made and has pursued this objective steadfastly. She continues to do this in her current position in Wetland Care Australia. However, as explained below, the process of adoption of improved management techniques is a slow one in this area because of conflicts of interest and political considerations.

Development and Adaptation of Research to a Form Suitable for End-Users

Examination of the materials produced indicates that considerable attention was given to the development and adaptation of this research so that it would be in a form suitable for end-users. Material was provided in different forms to suit different audiences. Target groups included members of the general public, community groups, and authorities directly responsible for water management, including working parties and subgroups within these authorities. Some of the targeted groups, however, were not end-users in the sense of being those who might actually carry out the managerial functions. Nevertheless, as explained below, communication with those who may be in a position politically to demand changes in water management can be important for the adoption of managerial methods to improve the ecological health of wetlands and floodplains. Effective transfer of managerial systems of water management often depends on appropriate communication with all stakeholders, not just those actually making decisions.

Potential Users, Actual Users, Barriers to Adoption, Adoption Rates

The adoption of new methods of water management often involves socio-political factors, because social or collective resources rather than private resources are frequently at issue. In this respect, the transfer of technical outputs from DEP1 is very different to technological transfer in industry. In the latter case, the potential industrial user has only to be convinced that the adoption of the new technique is in his or her private interest — that it would for example increase the net profitability of his or her enterprise.

The position is much more complex as far as changes in the management of social or collective resources is concerned. For example, responsibility for managing such a resource, as in the case of water in the Murray–Darling Basin, may depend on several bodies, even though the MDBC may have a major implementation role. Changes in water management are liable to have different impacts on users of the Basin. Social conflict may arise because some can gain and others lose as result of changed water policies. In altering water management regimes, public authorities can be expected to be influenced by public demands as expressed through political processes. Ironically, therefore, effective transfer in this area often requires the activation of political processes through pressure groups.

Nominally, the potential users of the results of DEP1 are:

- MDBC and associated controllers of weir flows such as lockmasters;
- State bodies having responsibilities in relation to water flows and quality in the Murray–Darling system;
- catchment management authorities; and
- community wetlands management groups.
- Apart from the above groups with an interest in wetland management, others include:
- duck hunters;
- conservationist groups generally;
- in certain cases, local councils and tourist associations wishing to use rehabilitated wetlands and floodplains as tourist attractions;
- farmers and other water-users wanting improved water quality and reduce the occurrence of cynobacteria (blue-green algae); and
- fishers.

Several barriers to adoption of the new management techniques exist. These include:

- in some cases, lack of awareness of current and growing environmental problems. This project has made considerable progress in overcoming this knowledge gap;
- socio-political inertia. Because many different parties have an interest and involvement in managing the resources in the Murray–Darling system, change is likely to be slow;
- social conflict increases barriers to change. Not everyone will benefit, for instance, from greater variations in water levels. For example, some areas, which have been developed on the expectation of little risk of flooding, may be more frequently flooded and for longer periods, eg. caravan parks and low-lying agricultural land;
- wetting and drying cycles have been normal in Australia's inland wetlands. Attempts to reinstate such cycles to restore the ecological health of wetlands now permanently flooded will please most duck-hunters, conservationists and some other special interest groups, but not necessarily adjacent farmers irrigating from the wetland. Instigating the wetting and drying cycles will leave the latter without their traditional water source in the dry phase of the wetland;
- extra allocation of fresh water for flushing wetlands may be opposed by some irrigators who see the cost to them as being less water available for irrigation. Consequently, the extra allocation of such water is often involves a protracted political process.

Thus, it is clear that changes in water management will come slowly. Nevertheless, this project has set in force processes which are helping to bring about such change. While there is virtually no chance of returning to patterns of flows that existed before European settlement, moderate manipulation of water levels to improve the ecological health of wetlands and floodplains may be politically achievable in the not too distant future.

In the meantime, small-scale adoption of management processes outlined in DEP1 is occurring. For example, Wetland Care Australia (formerly Ducks Unlimited Australia) has adopted practices similar to some recommended in DEP1 for rehabilitation of wetlands. Projects have been completed for both private landholders and in conjunction with government bodies. For example, Wetland Care Australia currently has a project beside Gurra Gurra Lakes. A demonstration project has commenced at Little Duck Lagoon adjacent to these lakes. Little Duck Lagoon has been flooded since Lock 4 was constructed in the 1930s, but now its wetting and drying cycles are being reintroduced and European carp are being excluded from it.

Because Anne Jensen has been appointed Habitat Planning Coordinator with Wetland Care Australia for a fixed period, on leave from her position as Manager, Wetland Management Program of the S.A. Department of Environment, Heritage and Aboriginal Affairs, this directly assists with transfer of techniques from DEP1. Moreover, she has been a national board member of Wetland Care Australia (WCA) and its predecessor for several years. She has therefore been able to have a direct influence on the wetlands rehabilitation policies of WCA for a considerable period of time.

WCA will continue to exert influence through local action planning groups, its own Wetland Care Group, through Catchment Water Management Boards and other avenues to ensure the adoption of improved management strategies for restoring the ecological health of wetlands and floodplains.

Furthermore, considerable effort is planned by WCA in the near future to accelerate and extend wetlands rehabilitation work (Jensen, 1998). Jensen (1988, p. 4) reports "Funding from the Natural Heritage Trust is enabling Wetland Care Australia's first long-term strategic program. The formal title of the program is 'Strategic Wetland Management in River Murray Local Action Planning (LAP) Areas'. The new program provides funding direct to Wetland Care Australia to operate in partnership with community groups and landholders on rehabilitation projects".

For example, WCA is establishing a National Wetland Community Network because many agencies involved with wetland management have been left with little technical support as a result of changing government policies. In addition, WCA is hoping also to be able to rehabilitate the whole 3000 hectares of Gurra Gurra Lakes near Berri.

A considerable amount of the transfer from DEP1 has arisen both through the official public service position of Dr Jensen and her personal affiliation with the WCA. This has been extremely fortuitous. Adoption rates may well have been much slower without the latter connection.

Relatively rapid progress is being made with wetland rehabilitation at the micro- or individual wetland level. Slower progress is being made in adoption of management strategies involving manipulation of water levels in the Murray as a whole and in making available extra water for flushing wetlands. Politically that is not surprising. Sufficient social demand must be generated before such variations are likely to occur. The extent to which LWRRDC should be expected to generate such demand is uncertain. However, demand for increased variation of water levels appears to be growing.

Research, Development and Extension Costs, Including Costs of LWRRDC and Host Organisation

The relevant costs are as set out in Table CS2-1, and are the same as in the previous review.

Note that funding from LWRRDC terminated one-year before completion of the project and so any extension work after 1996 was funded from sources other than LWRRDC.

Table CS2-1 Project expenditure for DEP1 ($'000)

Year	LWRRDC funds	NRMS funds	Research organisation (SA DENR)	Total funds
1992–93	33.1	13.3	65.3	111.7
1993–64	52.0	26.2	100.6	178.8
1994–95	47.9	20.0	103.2	171.1
1995–96		21.0	8.0	29.0
Total	133.0	80.5	277.1	491.6

Market and Non-Market Benefits

Virtually all the benefits from this project are non-market benefits, though some of the publications resulting from this project, such as the Wetland Atlas, are being sold. The actual non-market benefits have not been quantified because this would be a major task in itself involving additional scientific research.

Table CS2-2 sets out the type of benefits which can be obtained from improved ecological health of wetlands and, in particular cases, floodplains. It includes functions outlined in Turner and Jones (1991), in Pearce (1993, p. 71), Harrison and Tisdell (1997, p. 56) plus additional ecological benefits.

As can be seen from Table CS2-2, the potential benefits from restoration of the ecological health of wetlands and floodplains are considerable. However, restoration is usually not without cost. Costs will include costs of direct activities (set-up and maintenance) required for the restoration of wetlands and floodplains, eg. cost of organising action or community groups, construction work where required, costs of coordinating flow variations, and indirect costs, eg. depending on restoration techniques, loss by some farms of water-intake points for irrigation during the drying phase of a wetland, greater frequency of flooding of lower land used for agriculture, caravan parks, etc. if the amplitude of river-levels is increased. The nature and size of benefits from wetland and floodplain restoration as well as costs depend very much upon the technique(s) used for the restoration. Often techniques can also be used in combination.

Table CS2-2 Benefits from wetland and, in certain cases, floodplain restoration

Preservation of wetland and floodplain biota.	This includes some possibly endangered Australian native biota, eg. the small mammal, Giles' planigale, *Planigale gilesi* and species used for commercial purposes, eg. river red gums for honey collection, and for recreation eg. ducks. The presence of some species and ecosystems may be valued for their own sake (existence value).
Water cleansing functions.	Well functioning wetlands help to remove excess nutrients from waterbodies which may come from fertilisers and sediments. Macrophytes play an important function in this process. Their presence reduces the likelihood of cyanobacteria (blue-green algae) taking advantage of nutrient-enrichment to multiply and cause serious water quality problems.
Nutrient cycling and flushing and associated support for food webs both local and extended.	This can be expected to increase the ecological productivity of riverine systems, eg. increase the abundance of fish and ducks.
Control of pest species.	Appropriate restoration can result in reduced populations of unwanted wetland and riverine biota. For example, cynobacteria production may be reduced by creating conditions which favour the growth of macrophytes and re-instituting wetting-and-drying cycles for wetlands. Some wetland restoration projects include European carp exclusion devices. Carp interfere with the natural ecological processes of Australian wetlands.
Provision of carbon dioxide sinks.	Floodplain trees such as river red gums and black box act as carbon sinks. Restoration of water regimes which allow populations of these trees to reproduce and increase their current populations will help sustain carbon sinks.
Recreation benefits.	Riverine environments and wetlands are important foci for recreation eg. Barmah Forest in Victoria. They can be used for picnicking, camping, fishing, duck shooting, photography and so on. They may have particularly high values in some areas in inland Australia where few natural aquatic environments remain. Outdoor recreational opportunities provide economic benefits to individuals often measured by consumer surplus. In addition, recreational activities create demand for commodities used in recreational activities, such as photographic equipment, and this adds to the incomes of traders.

Table CS2-2 (cont'd) Benefits from wetland and, in certain cases, floodplain restoration

Commercial benefits.	Producers can obtain a number of benefits. Commercial fishers may benefit by greater fish abundance, suppliers of recreational commodities by greater sales, honey producers by greater supplies, farmers by improved water quality and councils by reduced cost of water treatment for urban use.
Water savings.	Water savings are possible from some forms of wetland restoration, eg. those which involve reduction in size of water impoundment of weirs during a drying cycle. The reduced surface area will reduce evaporation and seepage of water. The water saved could be used for agricultural and other purposes, and possibly a flushing water credit for wetlands could be established.

Basically, three techniques are highlighted in the work of Jensen:

- isolation of a portion of a permanently flooded wetland for restoration by artificially restoring wetting and drying cycles, eg. the procedure adopted in Little Duck Lagoon and proposed for the Gurra Gurra Lakes. This may be combined with a flushing strategy as well;
- alteration in patterns of river heights so to restore 'natural' flooding and wetting and drying cycles. The impacts are likely to be widespread. Various alternative regimes have been outlined by Jensen and Nicholls, (1997) and Jensen et al., (1997). These are likely to have differing patterns and magnitudes of costs and benefits; and
- flushing of salts, detritus, etc. from wetlands can be important for their ecological health. Natural flushing may be restored by changed river-level management or rights to an environmental flushing quota of water may be considered. The latter will have its own cost–benefit aspects.

To estimate all the possible costs and benefits associated with the abovementioned, management techniques would be a major research task and beyond the scope of this review, but further study of these aspects is justifiable. Detailed analysis along these lines has not as yet been undertaken.

Benefit–Cost Ratios

Several major assumptions are required to obtain cost–benefit ratios for this project. The assumptions made by Harrison and Tisdell (1997) provide a reasonable basis for estimating benefit–cost ratios in this case. Their scenarios can be modified in the light of ex post adoption rates.

They estimate that approximately 500,000 ha of wetland and floodplains on the South Australian stretch of the Murray could benefit from this project. In addition, although not allowed for in their calculations, some areas in New South Wales and Victoria could benefit. They estimate that the value of fully functioning wetland and floodplain services are, on average, equal to $100 per year and suggest that the application of management techniques recommended by DEP1 will add between $5 and $20 per ha in ecological and other services from wetland and floodplain areas to which they are applied. These are highly conservative allowances given that many wetland and floodplains are severely degraded. They consider the possibility of the application of restoration methods to the alternatives of 10, 20%, 30 and 40% of total wetland/floodplain area with a lag of either five or eight years from completion of the project (DEP1) in mid-1996.

The following can be observed:

1. The assumed per hectare increases in value of wetlands and floodplains services are moderate. They appear to be on the low side because, depending on the actual set of techniques chosen, some wetlands which are either non-functioning now or seriously debilitated will be restored. The actual benefits in such cases could be close to $100 per hectare per annum.
2. The percentage of wetland area improved by these management techniques will vary depending on the techniques selected from the suite available in DEP1. River flow variation is capable of restoring an extensive area of wetland, the size of which will vary with the degree of manipulation adopted. Other techniques such as impounding stretches of water retained by weirs and subjecting these areas to wetting-and-drying cycles are likely to impact on a smaller area.
3. Benefits are expressed in a generalised way. To obtain social net benefit, costs associated with the management schemes would need to be deducted, eg. any losses in the net value of agricultural production due to increased flooding of low-lying land. Specification of benefits and costs in detail would constitute a major research project. Because the net benefit figures assumed by Harrison and Tisdell (1997) are very modest, they are unlikely to be an overestimate even when specific costs are accounted for.

4. Social benefit–cost analysis as a rule does not give much attention to the distributional consequences of environmental changes. It is appropriate to give consideration to these because they have welfare and political implications and are likely to influence the rate of adoption of techniques which have social or collective impacts.

Table CS2-3 presents in terms of benefit–cost ratios rather than NPV the results reported by Harrison and Tisdell (1997) in CS2-2. Their approach of only considering expenditure on DEP1 as the cost element is adopted and a discount rate of 7% is assumed. As can be seen, all of these ratios are well above unity, indicating particularly high net benefits from this project relative to costs. Given the above considerations, it seems probably that the payoff would be in the mid range of these values, with a benefit–cost ratio of between approximately 6 and 20.

Harrison and Tisdell (1997), as an approximation, assume a one-step process of adoption but depending upon the technique adopted, a multi-stage process may be involved. For example, although changes in flooding regimes by river-level manipulation may be a one-stage process, wetland flushing and embayment of waterbodies trapped by weirs in order to reinstate wetting-and-drying cycles for reclaimed wetlands are likely to be processes staged over a several periods.

Reclamation of wetland by embayment and reinstitution of wetting-and-drying cycles has already begun. It seems likely that the Gurra Gurra Lakes reclamation project will proceed soon. This will recover 3,000 ha of currently drowned wetland. At least 5,000 ha of wetland should be reclaimed by this method on the Murray of South Australia by mid-2001. It also seems highly likely that new flow regimes will be instituted by then. Thus, considerable benefits can be expected to flow within five years of the completion of this project , supporting the prediction of Harrison and Tisdell (1997) that this project has a high benefit–cost ratio.

It is interesting to note that, to the extent that the Gurra Gurra Lakes restoration project has benefited from this study (DEP1), it alone would more than recoup the original outlay on DEP1. The cost of Gurra Gurra Lakes restoration is estimated to be $300 per ha, and the lakes will be valued at around $2,000 per ha after restoration, probably an added value of around $1,500 per ha (Anne Jensen, pers. comm.). Net of restoration cost, added value per hectare would then be $1,200 or $3.6M in total. Even after discounting and allowing for the fact that not all the credit for this restoration can be assigned to DEP1, the net benefits from the Gurra Gurra Lakes project alone would much more than cover the costs of DEP1.

Future Monitoring Requirements

There seems little point in continuing to monitor this project although it would be of interest to identify any policy changes in relation to river-flow variations and freshwater allocations for flushing wetlands which may have been catalysed by this project. As time passes, it becomes increasingly difficult to decide where to apportion credit for such policy changes. It is clear that they are not solely attributable to one project or initiative. In any case, there can be little doubt now that this project has achieved its main objective.

Concluding Observations

Transfer of technology and intellectual knowledge when it is to be applied to social or collective commodity, as is mainly the case in relation to wetland and floodplain restoration, is an extremely complicated process, more so than in the case of transfer of technology or intellectual knowledge to private business. This has been highlighted by this case study. Because of her public service position, well established networks, administrative input and personal commitment to wetlands restoration, Dr Jensen has been able to foster technology transfer through this project most effectively. Her ability to do this has recently been reinforced by her secondment to Wetland Care Australia.

Table CS2-3 Benefit–cost ratios in relation to rate and time of adoption and fraction of wetland value protected, DEP1

Fraction of area (%) Years to adoption	a/	10 5	10 8	20 5	20 8	30 5	30 8	40 5	40 8
	Fraction of wetland value protected (%)								
	5	3.9	2.5	9.0	6.2	14.2	9.9	19.3	13.6
	10	9.0	6.2	19.3	13.6	29.5	20.0	39.8	28.4
	15	14.2	9.9	29.5	20.0	44.9	32.1	60.3	43.2
	20	19.3	13.6	39.8	28.4	60.3	43.2	88.8	57.0

a/ A potential benefit area of 500,000 ha and annual wetland value of $100/ha is assumed. Based on Harrison and Tisdell (1997, p. 58).

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5 Case Study 3: The Integration of Wetland Water Supply and Demand Management in a Market Environment Using Capacity Sharing (UNE 11)

Research Organisations:
Centre for Water Policy Research, University of New England, Armidale, NSW

Principal Researcher:
Dr N.J. Dudley (now retired)

Executive Summary

This project explores the trade-off between the supply of water to wetlands and net revenue from irrigation, given a capacity share system of water management. Capacity sharing gives each water user a share of the storage capacity of the dam, evaporation losses and water inflows. In effect it transfers the management of the water from the water authority to the water users. This process opens up opportunities for managers of wetlands to participate in acquiring water for wetland needs. This project has explored the ability to account for the environmental needs of wetlands under capacity sharing. The project is essentially a simulation study aimed at expanding the theoretical underpinnings necessary for implementing capacity sharing. To date, the adoption of the research has been primarily by researchers further developing the principles of capacity sharing. Urban and rural water managers, irrigation associations and environmental groups are showing interest in capacity sharing and the underlying constructs of capacity sharing are beginning to be adopted. Based on simulated outcomes, the project has an estimated net present value of $2.4M and benefit–cost ratio of 2.4.

Background

Water in rivers and streams has historically been seen as a resource for extractive use and the demand for water for extractive use has resulted in little being available for environmental use. Unfortunately, the neglect of the needs of the environment has resulted in the deterioration of riverine ecosystems and wetland environments. Outbreaks of blue-green algae have prompted public concern for the health of riverine environments, and water legislation in various States of Australia is addressing the need for environmental flows. These actions are based on traditional methods of water allocation.

The research conducted in UNE11 is grounded on ‘capacity sharing’, an alternative to traditional methods of water management . Capacity sharing is an institutional arrangement and property rights structure for allocating water among multiple uses, including the environment. In contrast to the current arrangements which give users an annual allocation of water, capacity sharing provides each water user with a long-term right to a percentage of reservoir inflows and a percentage of total reservoir capacity or space in which to store those inflows, and from which to control releases. Each user is also given a right to a percentage of unregulated downstream inflows. The argument for capacity sharing is the premise that the separation of the management of emission and evaporation losses from extractive use decisions may lead to less efficient water use. Further, annually announced allocations lead to short-term planning horizons for water users and bulk allocations for environmental use which may not be cost-effective management. The benefits and efficiency gains from adopting capacity sharing as a water resource allocation system are security of access and the encouragement of long-term water management strategies by users.

Traditional methods of water allocation have depended on the water authority accounting for storage and transportation losses in the supply of irrigation water. Those promoting capacity sharing argue that inefficiencies in the use of water arise because of the separation of management decisions concerning extractive use and transmission and storage losses. By adopting capacity sharing, the management decision-making is centralised on the final user and potentially all the costs associated with water use are incurred by the final user. In essence, “capacity sharing is an approach to reservoir management which provides each user with a percentage of reservoir inflows, a percentage of reservoir space for storage of the inflows and a right to manage release of this percentage of inflows as desired. Such an approach to reservoir management transfers the management of risk and supply reliability preferences to the individual capacity shareholder, allowing them to adjust their risks according to their risk preferences" (Dudley et al., 1993. p. ix).

Aims of the Project and Performance

This project involves modelling the supply and demand for water by cotton growers and the wetlands during a water year, simulated over many years. The project adapted existing computer simulation and stochastic dynamic programming models of irrigated cotton production to integrate the management of wetland water supplies. Irrigated cotton production is seen as the major competitor to the environment for water in many broadacre agricultural regions. The water requirements of cotton are highly variable, and by trading in water though the season and allowing water for the environment in a capacity-sharing system, the research demonstrates that it could be possible to meet the environmental needs in a budget neutral manner. The study explores these trade-off issues between extractive and environmental use of water under a capacity-sharing regime of water management, using the lower Gwydir Valley of New South Wales as a case study for the analysis.

Technical Outputs of the Project: Processes, Improved Management Techniques, Other Information

The first technical output was the development of the programming models. The models generate trade-off curves that reflect the cost-effectiveness of meeting the requirements of wetlands. Methodologically, the study provides:

- insight into methods of measuring environmental effects in terms of judging regulation over releases. The researchers argue that, under capacity sharing, environmental flow decision-making becomes transparent and better managed. The research associated with UNE11 is seen as important in supplying information to the process of community-based decision-making concerning the trade-offs between extractive and environmental use;
- a basis for modelling the management of environmental and social objectives with respect to daily optimisation within nested monthly optimisation models; and
- a basis for the development of further analysis of capacity sharing. The findings of UNE11 have provided the building blocks for research projects UNE15 and UNE19. UNE15 attempts to measure benefits, given various soil and crop types and trade in water. The study has found a 10–11% increase in farm annualised net revenue as a result of the adoption of capacity sharing and associated concern for the water demands of wetlands. UNE19 extends the current stochastic optimisation models to give greater guidance to stream quality managers to follow when operating the capacity share under their control. The study develops the work of UNE11 in that it improves the definition of streamflow requirements (Dudley et al., 1998).

The work on capacity sharing began in the early 1970s and mid-1980s with a LWRRDC-funded project, UNE6. This project integrated irrigation water supply and demand management in highly unpredictable environments to maximise irrigation net benefits. The project was followed by UNE11, which developed the trade-off curve for maximising the average commercial net benefits against environmental effectiveness.

The research of UNE11, and associated reporting to LWRRDC, have been completed. The project produced a frontier that provides information concerning the trade-off of irrigation net revenue and water supply to wetlands under capacity sharing, as shown in Figure CS3-1. In systems using capacity sharing such analysis provides a mechanism for evaluating the effectiveness of water use between irrigation and wetlands, and the costs associated with policy decisions concerning the use of water for extractive and environmental use. While the results are specifically associated with capacity sharing, they also provide a basis for debate of current wetland water allocation regulations.

In Figure CS3-1, the horizontal axis represents the increasing average annual net benefits with decreased volumes of water allocated to the environment. Similarly, the vertical axis shows the increased environmental effectiveness of meeting the water requirements of the environment as more water is allocated to environmental use. When sufficient water is available, both commercial and environmental objectives can be achieved at the zero trade-off point (AB).

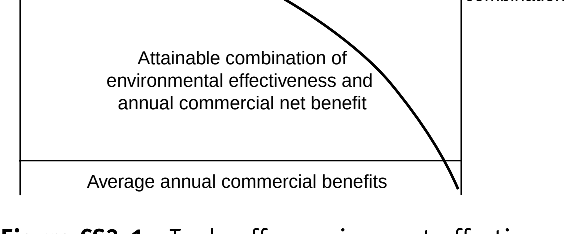

Figure CS3-1. Trade-off curve in a cost-effectiveness framework. Source: Dudley et al. (1998, p.2).

Development and Technical Transfer of Research to a Form Suitable for End-Users

The staff at the Centre for Water Policy Research have been active in running workshops and short consultancies to explore and develop the principles of capacity sharing and the benefits of developing systems to achieve optimal points on the frontier of the trade-off curve developed in UNE11. Many of the stakeholders are exploring continuous accounting as a mid-point between traditional methods of allocation and full capacity sharing.

Movement towards capacity sharing — continuous accounting

Water managers are exploring continuous accounting as a response to accountability and the concept of capacity sharing. Continuous accounting, as the name suggests, involves a form of banking where irrigators can 'deposit' water and make 'withdrawals' of that water across water years. The principle of continuous accounting is that irrigators may choose to carry over a proportion of their allocation to the following year. While its adopts some of the principles of capacity sharing, it still relies on an annual allocation of water.

The adoption of continuous accounting is seen as a movement towards capacity sharing as it gives farmers increased responsibility for managing their stock of water. It also moves away from the rigid structure of 'use-it-or-lose-it' within a water year which is endemic in current methods of annual water allocation. Continuous accounting allows for changes in long-term farm investment strategies, especially in terms of on-farm storage facilities. On-farm water storage may not be needed because farmers could carry over unused allocated water that would have otherwise lost at the end of the water year. This could lead to significant changes in farm management and on-farm infrastructure expenditure. Increased efficiency may also result from reduced evaporation losses because on-farm storage in ring tanks results in higher evaporative losses than larger dams. There is also the opportunity cost of land required for on-farm storage.

Under traditional methods of water allocation, the full capacity of the storage is not shared and so water users are not able to manage their share of the resource. The useable capacity of water is reduced as a result of operational and transmission losses. Making the final water users accountable for these losses is seen as a critical component of capacity sharing and essential for efficient use of the resource. In other words, irrigators under continuous accounting are not responsible for their losses, which is seen as a significant source of inefficiency in the use of the resource.

Potential Users, Actual Users, Barriers to Adoption and Adoption Rates

UNE11 is part of a series of projects dealing with the concepts underlying capacity sharing. UNE11 is completed but its results have yet to be adopted. The principle and associated researchers believe that once capacity sharing is adopted in one region there will be greater certainty in the methodology and adoption in other regions will follow. At present there are, in the eastern States of Australia, three stakeholder groups that are seriously interested in capacity sharing. For each of these stakeholder groups the Centre for Water Policy Research has been involved in evaluating the potential of adopting the results of UNE11. The three groups are:

1. Sydney Water

This agency, the supplier of urban water to Sydney, is exploring the possibilities of adopting capacity sharing to manage conflicts between urban, rural and environmental demands for water. Licensing arrangements are currently being reviewed for domestic water and a key concern is the environmental flow rules and the certainty of supply. The researchers see certainty of supply through a clear specification of property rights as a key benefit of capacity sharing. As part of UNE15, the staff of the Centre have conducted a short consultancy for Sydney Water to examine capacity sharing options for the management of Sydney water.

2. NSW Department of Land and Water Conservation

Water managers in the NSW Department of Land and Water Conservation are exploring continuous accounting as a mechanism for more flexible water management. In the first instance, the Department is proposing to trial this system in the Namoi and Gwydir rivers in the 1998–99 water year. Irrigators will have up to a 100% combination of carryover and announced allocation. Irrigators will have the option of carryover of 30% of allocation. In the future, there are possibilities to develop a database for continuous accounting, and a model to shadow water allocation outcomes with capacity sharing.

3. Queensland Department of Natural Resources

The Queensland Department of Natural Resources is considering full introduction of a capacity-share system in the Boondooma Dam system. The system essentially would give each sector — irrigation, industrial, urban and environment — a share of the capacity of the dam and some autonomy over its use. There is also a proposal to implement an individual capacity share program in the St George region in the immediate future. The initial proposal for the St George region may have a resource cap and maintain nominal allocations of water without carryover or forward draws. There are indications that the movement from traditional methods of water allocation to continuous accounting may be a step towards the adoption of capacity sharing.

Adoption of the research in other research projects

A complementary project, UNE15, funded a PhD scholarship whose holder further explored and developed stochastic models for deriving and implementing opportunity costs of environmental uses of water. The work of UNE15 and the research which preceded it produced a manual explaining how to implement capacity sharing and evaluate the trade-off between environmental effectiveness and commercial net benefits (Dudley et al., 1994). UNE19 is exploring alternative measures of environmental effectiveness. These projects expand the principles of capacity sharing developed by Associate Professor Norm Dudley in the early 1980s (Dudley, 1988). UNE19 adopted a holistic approach and refined the trade-off framework, resulting in a 'Generalized Environmental–Social–Commercial Cost-Effective Trade-Off Model' (GESCCETOM).

> "The GESCCETOM framework should provide a very useful aid to structuring property rights/institutional arrangements and decision aiding models to derive trade-off frontiers to summarize the long-run impacts of alternative allotting of scarce water resources between competing uses. Moreover, as well as providing the trade-off curves which summarize the effects of different allotment options, GESCCETOM provides detailed through-time sequences of the effects of alternative options to fine-tune the allotting decisions" (Dudley et al., 1998, p. 23).

Adoption of the research at the farm level

At the farm level, adoption of capacity sharing may change farm practices in terms of on-farm storage and the tendency to plant opportunist crops. The notion of improving the flow regime may in fact reduce the flow regime by farmers moving to these opportunistic cropping strategies. Under capacity sharing, the farmers have a drought-proofing method. Under the traditional methods of water allocation it is likely that trade will result in single crop valleys and concentrated water use. Farm management practices may change in response to changes in water management strategies. The need for on-farm storage will change as farmers realise the benefits of large upstream storage and do not have to avoid the use-it-or-lose-it problem associated with single-water-year water allocations. The farm management changes in the long term depend on:

- adoption of the trade-off curve — movement to the trade-off frontier and extension beyond to form new trade-off frontiers. Before UNE11 there were provisions for capacity sharing in the Victorian water legislation. But there was little account for the environment and the cost of possible trade-offs with extractive users;
- long-term farm investment in on-farm storage;
- sustainability— determining the appropriate volume of water for environmental use solely by regulation reduces the level of flexibility to achieve sustainability goals; and
- expectations of financial institutions — increased flexibility and control over the water and associated property rights may increase farm values and so the ability to borrow for further development.

Capacity sharing may result in trade in regulated water upstream and unregulated water downstream, which may well have positive environmental flow implications. Increased variety of crops in the valley is a better risk management tool and shelters the valley from market and to some extent rainfall fluctuations.

Adoption of the research at the national and international levels

Capacity sharing could also potentially be adopted on a national level. Given the benefits estimated for the Barker–Barambah catchment and the Gwydir Valley, the benefits of wide adoption of capacity sharing could be significant not just for improved wetlands but also for urban water supply management. Australia has significant wetland regions of international importance, including the Macquarie Marshes, Barmah Forest, "Riverland", and the Coorong and Lower Lakes. The environmental benefits and savings in riverine losses and restoration costs could be considerable. Managers of large urban water supplies, such as Sydney Water, have taken an interest in capacity sharing urban/environmental flow conflicts, and see it as a possible solution to current rural/environmental conflicts over water.

The Healthy Rivers Commission in NSW has defined a healthy river in terms of economic, social and environmental aspirations. The Healthy Rivers Commission points out that if information is not available on all aspects of these dimensions it is impossible for society to make such decisions. Models of the interaction of the components of a healthy river need to be transparent, yet most models developed for water managers are not readily available or understandable by the general community. To date, such models have been largely hydrologically based and have not been constructed to evaluate the economic and social dimensions of water management. These models also do not — and were never meant to — consider economic and social impacts. Irrigators argue that it may be possible to modify the capacity-sharing models to address better the conflicting economic, hydrological and social demands placed on water management.

At an international level, benefits of the research are being realised in Brazil. If the benefits of being able to assist other countries in adopting the research outcomes of UNE11 were seen as forms of foreign aid, then the benefits to such countries arising from the adoption of UNE11 could be included in a cost–benefit analysis of this nature.

Institutional limitations on adoption

Irrigators in NSW have questioned the rights of the water authorities at the Independent Pricing and Regulatory Tribunal, the National Competition Council, and the Productivity Commission. The NSW Irrigators' Council argues that the Council of Australian Governments (COAG) was about fundamental reform as much as it was about cost recovery and other administrative matters. While reform has occurred in cost recovery, reform on the supply side has not occurred and there is no opportunity for the private sector to supply water and manage water infrastructure. The Council considers that the move towards establishing a more secure right has not been forthcoming. The Council considers infrastructure access rights (or capacity sharing) provides for the necessary preconditions for efficient water use and trading. Once these rights are in place, the irrigators feel that the economic benefits to them and the State can be demonstrated.

The NSW Irrigators' Council is encouraged by the interest shown by the Australian Bureau of Agricultural and Resource Economics (ABARE) in infrastructure-based water allocation methods, because ABARE is seen as a body independent from State government departments. However, the Council concedes that the adoption of capacity sharing may be restricted by the desire of water authorities to maintain their power base through the current method of water allocation. Further, without that irrigators' power base it has been difficult to progress the research into technology transfer domestically. Irrigatorsinterviewed have in general been supportive of the concept of capacity sharing as a method of achieving the water efficiencies and economic improvements in water reform suggested under COAG.

Technology Transfer Items of the Project: Products, Processes and Improved Management Techniques, Other Information

The main method used to communicate technical output of the project has been to publish papers in refereed journals and reports. Papers and reports arising from the research include:

Dudley, N. (1988), A Single Decision maker Approach to Irrigation Reservoir and Farm Management, Water Resources Research, 24(5) 663–640

Dudley, N., Coellli, M., and Pigram, J. (1993), An Integrated Approach to Tradeable Discharge Permits and capacity Sharing under Australian Conditions, Discussion paper prepared for the Environmental Research Trust and the Sydney Water Board, Centre for Water Policy Research, Armidale.

Dudley, N., Scott, B. and Coellli, M. (1994), Trade-offs Between Effectiveness and Opportunity Costs of Water Supplies to Wetlands: An Explanatory Manual, Centre for Water Policy Research, Armidale.

Dudley, N.J., Arthington, A.H., Scott, B.W. and van der Lee, J.J. (1998), Integrating Environmental and Irrigation Water Allocation under Uncertainty, LWRRDC UNE19 Detailed Report, Volume 1: Introduction and Background. Centre for Water Policy Research, Armidale.

Economic Evaluation

Research, development and extension costs, including costs to LWRRDC and host organisation

The research in UNE11 is part of a series of projects developing the concept of capacity sharing, including UNE6, UNE8, UNE11, UNE15 and UNE19. Partitioning of the benefits of such integrated research is difficult and based on a number of assumptions that need to be realised when analysing the results of this study. It is argued by the Principal Researcher that, without the research of UNE11, project UNE19 would not have been possible and the final adoption of capacity sharing and the benefits or costs of capacity sharing may not be realised and accounted (UNE15 and UNE11 was conducted simultaneously). As a result, the costs and benefits of UNE11 and UNE19 have been included in this analysis.

While these projects have resulted in considerable interest in capacity sharing, adoption of capacity sharing is limited and occurring in different forms, such as continuous accounting.

Project expenditure

The project was completed before the previous life-of-project update. As a result the project expenditure for UNE 11 has not changed and is presented for reference in Table CS3-1. In this update, the costs associated with UNE19 have also been included.

Benefit–cost ratios

The modelling conducted during UNE11 demonstrated the direct benefits to the Gwydir Valley of adopting capacity sharing and trade-off between environmental and extractive uses of water. In the previous update, research conducted by McCosker and Duggin (1993) was used to estimate the value of improvements in the wetlands effectiveness achieved through capacity sharing. The estimated total wetland benefit per percentage point wetlands effectiveness in the previous update was $60,410. Applied to the improvements in wetlands effectiveness from the modelling of UNE11, this equated to $20,200 in wetland benefits if trade occurred in a budgetary neutral manner.

The research conducted in UNE11 is an important component of the development of knowledge on capacity sharing. The direct contribution of UNE11 was to UNE19. UNE19 "Integrating Environmental and Irrigation Water Allocation Under Uncertainty" further refined the definition of environmental effectiveness, developing the work conducted under UNE11 and developed the Generalised Environmental-Social-Commercial Cost-Effective Trade-off Model (GESCCETM).

The realised developmental benefits of UNE11 lie in part in the outcomes of UNE19. The modelling in UNE19 involved two different types of irrigation enterprises varying by soil type and the environment. A summary of the results of the modelling conducted in UNE19 is presented in Table CS3-2 below.

The modelling conducted on the trade-off between environmental effectiveness and net farm revenue suggested an increase in wetland effectiveness from 6.73 GL/yr to 6.75 GL/yr, an increase of 0.02 GL/yr (or 0.2972%). This amounts to an annual increase in wetlands effectiveness of $17,952.00 ($6.041 M ´ 0.2972). The change in net revenue from trade represents the benefits to irrigators. In UNE19, before trade the revenue to irrigators was $0.85 M/yr compared with $0.94 M/yr after trade, amounting to an irrigation benefit of $90,000. The potential benefits of UNE19 for the Barker–Barambah catchment total $107,952/yr.

Table CS3-3 presents an analysis in which it is assumed that the Gwydir system adopts capacity sharing and associated trade between irrigators in the 2003/2004 water year with 40% of the benefit stream realised between 2003 and 2005; 60% realised between 2005 and 2007; and full realisation after 2007. Similarly, it is assumed that capacity sharing is adopted in the Barker–Barambah catchments in 2005 with 60% realisation between 2005 and 2008, and full realisation after 2008. The net present value of the combined direct benefit of the research is $2.39 M, given a discount rate of 7%.

Table CS3-4 presents the NVP at discount rates of 4, 7 and 10%. The net present value of the project ranges from $1.22 M to $4.31 M.

Limitations of the analysis

Benefits beyond the economic analysis of this study include those of infrastructure sharing (a derivative of capacity sharing) estimated by the Australian Bureau of Agricultural and Resource Economics (ABARE), the costs and efficiency benefits of changes to farm practices resulting from the adoption of capacity sharing, possible

Table CS3-1 Project expenditure, UNE11 ('1000)

Year	Project	LWRRDC funding	Host organisation	Other	Total funding
1992–93	UNE11	80.4	142.6	0.0	223.0
1993–94	UNE11	97.4	131.6	0.0	229.0
1994–95	UNE19	146.3	256.4	22.0	424.7
1995–96	UNE19	256.8	414.2	3.0	674.1
Total		580.9	944.8	25.0	1550.7

Table CS3-2 Simulated of income and environmental flows from UNE19

Trade-off criteria	No trade	Trade between irrigators	Trade between irrigators and environment	Trade-off criteria
Income	Mean	$0.85 M/yr	$0.94 M/yr	$0.95 M/yr
	Median	$1.00 M/yr	$1.06 M/yr	$1.16 M/yr
Environmental flow	Mean	6.73 GL/yr	6.75 GL/yr	6.7 GL/yr
	Median	1.09 GL/yr	1.09 GL/yr	1.09 GL/yr

adoption of capacity sharing at a national level, and meeting the modelling needs of the Healthy Rivers Commission.

ABARE has analysed water reform in Australia and the conflicts between extractive and environmental use of water. The Bureau found three aspects common to the management of natural resources — physical and infrastructure constraints, institutional constraints, and variability of resource prices. They also highlighted the uncertainty surrounding risk and environmental impacts of alternative water policies. Beare et al. (1998) developed a regional irrigation model of capacity sharing to assess the optimal value of water under supply and demand uncertainty for the Murrumbidgee catchment of the southern Murray–Darling Basin. Two reports by ABARE in 1998 pointed out the benefits of moving to a capacity sharing system or infrastructure access rights in the Murrumbidgee River. ABARE estimated the discounted benefit to growers over 30 years to be $700 million.

As with any of these case studies, this analysis of UNE11 is a valuation of the immediate benefits and costs foreseeable at this time. The level of uncertainty concerning the adoption of capacity sharing is high. Over time, actual adoption rates of capacity sharing and any benefits arising from such adoption will be realised. At that time it will be possible to more accurately estimate the benefit stream arising from the research.

Future Monitoring Requirements

As the predicted benefits of this project are not yet assured, further monitoring of the technology transfer over the next 3–5 years would be desirable. Variables that could be monitored to provide a more complete evaluation of the worth of UNE11 include:

- the adoption of capacity sharing in river basins;
- the structure and management of environmental components of a capacity share regime;
- the development of water markets and the rights of environmental managers to trade in the market; and
- the change in farm management as a result of the introduction of environmental flow regimes and capacity sharing.

Discussion and Conclusions

UNE11 has been part of the continuing research into and development of capacity sharing as a method of water management in Australia. To date, the adoption of capacity sharing and the associated need to explore the

Table CS3-3 Annual cash flows and economic performance estimates, UNE11 and UNE19

Year	Project costs ($1000)	Gwydir Valley ('1000)	Barker–Barambah Catchments ('1000)	Total ('1000)
1992–93	–229.0	0	0	–229.0
1993–94	–223.0	0	0	–223.0
1994–95	–424.6	0	0	–424.6
1995–96	–674.1	0	0	–674.1
1996–03	0	0	0	0
2003–05	0	808.1	0	808.1
2005–07	0	1212.1	64.7	1276.9
2007–08	0	2020.2	64.7	2085.0
2008–10	0	2020.2	107.9	2128.2
NPV ($M) 2.39; IRR (%) 16.5; B/C ratio 2.36				

Table CS3-4 Net present value at various interest rates, UNE11

Discount rate (%)	NPV ($M)
4	4.31
7	2.39
10	1.22

trade-offs between wetland and irrigation water requirements has been limited. Interest in capacity sharing by water authorities (both rural and urban) irrigators and Federal Government authorities has been strong. Capacity sharing appears to have enough potential support from the irrigation community and growing support from water authorities to result in a major change in water management in Australia. If such a shift in water management occurs, the research conducted in UNE11 will be critical in exploring the trade-offs between extractive and environmental uses of water.

The results of this study have yet to be adopted. Potential adopters are still evaluating the results, and implementation of capacity sharing will depend on the ability of such a management regime to deal with the complex problems associated with water management in a mature water economy. Dealing with the trade-off between environmental and extractive use of water is a major component of that development. The marginal value of each project which developed on the basic principles of capacity sharing is difficult to determine, because the value of research projects often sum to greater than the value of the individual units of knowledge acquired from each project.

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6 Case Study 4: Management of a Regional Groundwater Discharge Zone in an Area of Dryland Agriculture (CWW18)

Research Organisations:
Division of Water Resources, CSIRO, Canberra

Principal Researcher:
Dr G Walker, Principal Research Scientist

Executive Summary

Dryland salinity is a problem in all States of Australia. In South Australia, the largest region at risk is the Upper South East Region, where approximately 250,000 ha are salt affected and another 175,000 ha are at risk of salinisation (Walker, 1997). The research project is technically highly complex. It involved adaptation of a groundwater model originally developed in the USA, to investigate net discharge rate and rates of salt accumulation under various land management practices in the study area. Associated research has analysed plant water uptake and the saltland agronomy practices; the outcomes of which were entered into the computer model.

There has been a high level of collaboration between the research team, local farmers and staff of the South Australian Department of Primary Industries and. Technology transfer was facilitated through a farm extension and planning program in the early part of the project and more latterly through the implementation process of the catchment management plan.

The research project has shown that, even within a regional groundwater discharge zone, local land management to increase groundwater discharge can have a significant effect on the rate of land salinisation. It was also shown that biological approaches alone would not be sufficient, especially in the short term, to arrest current rates of land salinisation. Major drainage work would be required.

Estimation of the benefits flowing from the research project have been complicated by the fact that the research focus was within a catchment management scheme where major drainage works and revegetation efforts have commenced during the life of the project. While the project has contributed to the decision-making associated with the implementation of the catchment management plan it is impossible to isolate this impact without a detailed survey of participants in the decision-making process including farmers, researchers, extension agents, engineers, wildlife officers and politicians. This was beyond the scope of this analysis.

Estimates of the contribution of the project to increased production, recreational value and wetland conservation indicate a positive net present value at a real discount rate of 7% and an IRR of between 7 and 25%.

Background

Dryland salinisation is a major problem facing agricultural production and wetlands in the Upper South East Region (USER) of South Australia. Current estimates show that out of an area of 680,000 ha, approximately 250,000 ha are affected by salt and another 175,000 ha are at risk of salinisation (Walker, 1997). If this is left to occur it would lead to significant losses in agricultural production from the area and also to the loss of a valuable wetland habitat, leading later to significant losses of social and physical infrastructure to the region.

Two broad options are available for managers in regional groundwater discharge areas (Walker, 1997), viz. large-scale land retirement and hence learning to live with salinity; or development of a comprehensive catchment management plan which includes drainage, pumping, revegetation and saltland agronomy.

The pattern of increasing salinisation in the case of the USER has led to the development of a catchment plan which will cost $70 M but is expected to return benefits of the order of $100 M by arresting the decline in agricultural production, restoring lost production and preserving valuable wetlands. The proposed catchment management plan has been subjected to a detailed environmental impact statement (Upper South East Dryland Salinity and Flood Management Steering Committee, 1993). A number of additional papers that investigated the economic implications of the proposed modifications in land use and drainage for the USER have been prepared as part of the overall environmental impact statement. These include a study by Jensen (1993) that investigates the wetland values for the area; a study by Walsh et al. (1993) that reviews the regional economic impact of the proposed changes; and a paper by Heinjus (1992) that describes the development of a farm plan for the selection and adoption of land management practices by a specific farmer.

The five key elements of the catchment plan are:

- surface drainage;
- revegetation with perennial vegetation;
- saltland agronomy;
- wetland management; and
- community involvement and funding.

The research project analysed here forms an integral part of the proposal to provide drainage and flood management schemes in the area. The research project was developed to address key knowledge gaps in developing a comprehensive management plan. The knowledge gaps identified included (Walker, 1997):

- an understanding of the water use by crops and native vegetation in areas of shallow, possibly saline, groundwater and implications for sustaining these systems;
- the role of surface flows in recharging (or discharging) the groundwater system and flushing wetland systems; and
- predicting the long-term impacts of total catchment management on the groundwater system.

This led to the three major research and one extension objectives shown in the next section.

Nature of the Project

The project objectives agreed between the Principal Investigator and LWRRDC were as follows:

- Develop techniques for the estimation of groundwater discharge under a range of land uses and different landscape situations when the groundwater is moderately saline (TDS > 10,000 mg/L) and close to the surface.

This was achieved by:

- investigating water use and health of Melaleuca halmaturorum;
- examining groundwater use by salt-tolerant grasses;
- investigating vegetation water-use strategies; and
- modelling the relationships: of water and salt fluxes to depth to watertable, transpiration etc; between transpiration and water availability; between growth and long-term water availability; and impacts of surface water regulation and climate variability.

The expected research outputs were:

- development and assessment of techniques for the estimation of groundwater discharge in areas of moderately saline groundwater;
- estimates of groundwater discharge in a range of conditions and land use; and
- some steps towards understanding the interaction of native vegetation and shallow groundwater.
- Predict likely trends in groundwater levels and salinities, and implications for land salinisation in the upper south east of South Australia.
- Show the effect of changed land use and engineering schemes on these same trends.

Objectives 2 and 3 were achieved by:

- recharge studies;
- groundwater modelling; and
- using the models to investigate a range of recharge options.

The expected research outputs for objectives 2 and 3 were:

- comparisons of recharge for different land uses in the region;
- development of a methodology for including these recharge estimates and discharge estimates in a sub-regional groundwater model; and
- understanding of the fate of salt.
- Facilitate the extension of the research results through the transfer of data onto GIS and LAD systems and the preparation of farm plans.

In addition, the adoption of the research was to be encouraged by the South Australian Department of Agriculture through the establishment of farm paddock demonstration plots, conducting workshops to assist farmers to prepare property plans, and extension to farmer groups through Landcare.

The achievement criteria for this objective were:

- model documentation is received and accepted by stakeholders;
- evaluation of input/output interfaces undertaken and documented;
- wetland management plan incorporates project results; and

- initial assessment of extension activity and adoption provided to LWRRDC.

Technical Outputs

The technical outputs indicated by the Principal Investigator in the application for the grant for this project were:

A regional groundwater model to:

- predict salinisation in the upper south east of South Australia (and other regions of Australia) leading to the development of improved land and water management practices;
- indicate the fate of similar regional groundwater discharge areas in other parts of Australia;
- determine realistic values for the long-term drainage options under investigation in the environmental impact statement for the upper south east region (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993);
- provide a database from which to plan the protection of wetlands and vegetation resources in the upper south east of South Australia; and
- provide data to support the development of farm plans and adoption of appropriate land management practices.

Run workshops to assist farmers to prepare property plans which:

- improve drainage and reduce surface flooding on farms;
- reduce the rate at which land is lost to dryland salinity;
- maintain or improve farm profitability;
- improve wetland values; and
- reduce off-site impacts of salinity.

Research Achievements

The Principal Researcher has described the research achievements provided by this research project (Walker, 1997; Walker and Mensforth, 1998). The following summarises these achievements.

Objective 1

Melaleuca *species*

Water management regimes were found to play a major part in maintaining the sustainability of ephemeral wetlands and in particular the maintenance of *Melaleuca halmaturorum*. The research revealed that trees were able to survive in the saline conditions although there was evidence at one research site that prolonged waterlogging prevented root growth below 20 cm, even when the watertable was low. In addition, it was found that flushing of the soil profile with winter rainfall and associated flooding was key in the survival of melaleucas.

Salt-tolerant grasses

Before this research project there had been little research on how plants used saline water in shallow watertables. Puccinella and wheat grasses were analysed in the study.

A report by Walker and Mensforth (1998) concluded that:

> "There was considerable difference in the root distribution between wheatgrass and Puccinella with the latter having a dense shallow root system while the former had deep roots.
>
> Puccinella showed no propensity to use ground water while the tall wheatgrass used some in the late summer before senescing.
>
> Both plants senesced well before maximum soil salinity levels were reached.
>
> The grasses will make a difference to local groundwater levels by reducing recharge and hence decreasing the need for additional discharge elsewhere."

This suggests that salt-tolerant grasses are not capable of controlling groundwater levels.

The research also raised the issue of sustainability of salt-land agronomy especially its sustainability on salt flats. In particular, questions were raised about the impact of continuing rises in groundwater and the spatial impacts of salt on productivity of pastures, especially when no drains are installed. These issues will need to be monitored as the current catchment management plan is implemented.

General outcomes

The EIS (Walsh et al. 1993) stated that the whole catchment management plan was reliant on the success of salt-land agronomy. The research project has shown that with appropriate water management regimes the production of salt-tolerant grasses can be maximised and Melaleuca species maintained if they do not become waterlogged. The latter is important in maintaining suitable sites for bird breeding.

The salt-land agronomy work has been supplemented by on-farm research carried out by a local farmer. Both research efforts have been a key component in the implementation of the EIS and provided confidence to those planning and implementing the catchment management plan.

The management of plants in shallow groundwater systems has also led to benefits in other areas of eastern Australia. In particular it has aided in developing guidelines for forestry and agroforestry systems in similar dryland salinity environments. The same outcomes have led to more informed decisions being made for ecosystem sustainability management criteria and management.

Objectives 2 and 3

Lucerne versus natural vegetation

The research compared water use of lucerne and native vegetation, and was unique in that it was the only study of this sort done in a regional groundwater discharge zone in an area of dryland agriculture. The research clearly revealed that lucerne is effective in recharge reduction control and that its impact is indistinguishable from the water use of native vegetation. Because lucerne was shown to have the same level of water extraction as native vegetation, it should be a more attractive land use for farmers as it provides an economic return.

A major problem has been non-acceptance of lucerne by farmers because of establishment risk, fear of aphid attack despite new aphid-resistant varieties, and problems of persistence on non-wetting sands. It is clear that farmers were not factoring the off-site benefits, such as reduction of water flows from discharge zones, into their decision-making. However, the full impact of lucerne establishment on recharge control will be dependent on the area planted and development of suitable agronomy. The research outcomes have meant that once there was confidence in the use of lucerne as a recharge reducing agent it could be recommended for use by farmers with confidence.

Groundwater modelling

The regional groundwater modelling studies showed that a reduction of recharge in the dune ranges (net recharge areas) will have a significant impact on salt accumulation in the associated discharge areas (Walker and Mensforth, 1998). The results also revealed that that there would be little impact on groundwater levels in the discharge areas.

This had already been recognised by the local geo-hydrologist and led to the decision to continue with the drainage options in the catchment management plan. The results therefore provided a sound scientific basis for going ahead with the drainage work but were not influential in making the decision to commence the drainage project.

There were considerable problems encountered in the modelling phase of the research project. Simulation of local water intake and discharge — including seasonal intake and plant evaporation — within a regional discharge zone is a novel application of groundwater models. While the model proved to be a reliable predictor of groundwater levels over the regional transects, the scale has been found to be less satisfactory for small area simulations. Local groundwater is highly sensitive to topography. This necessitated additional effort in modelling research, which led to the development of a non-linear evaporation module for MODFLOW and a purpose-designed pre-processor to allow variation in water extraction depth.

The modelling studies therefore provided new information for the modelling community as well as support for the implementation of the drainage systems.

Technology Transfer and Adoption

Objective 4 formed the extension component of this project. The implementation of this objective changed with time during the project. The original research proposal indicated that farm plans would be the main delivery vehicle. The next approach was to roll the catchment plan into the Federal Property Management Planning process, and finally local action plans were used as the chosen delivery method. The action plans provide a series of incentive payments for prescribed management practices by farmers based on the level of private and social benefits from the management practice.

The extension of results from the research was achieved by workshops during the property management planning phase and involved, in particular, the Tintinara and Willalooka Landcare Groups. The new appointees to the catchment management project, in particular the salt-land agronomists, have had full access to the knowledge produced by the research. This has been in the form of publications, personal contact with the researchers and use of the model and information contained in the GIS system.

The research funding has acted as a training ground for future researchers. The project has provided topics for one PhD student and part of a project for another. Two honours and one overseas MSc student have been associated with the study.

Finally, papers have been presented at national conferences such as the National Conference on Land Management for Dryland Salinity Control and the Third National Workshop on Productive Use of Saline Land. Several journal articles have been prepared and accepted in national and international journals. Articles have also been included in CSIRO publications, NATCOM and WATERLINK.

Economic Evaluation of Research Outcomes

This research project had a lower impact than envisaged at the signing of the research contract. The initial review of the research proposal by McGregor et al. (1994) provided a wide range of possible economic outcomes for the research. The research costs of the project were $1.21 M and the research was estimated to provide positive NPVs, at a real interest rate of 7%, for all scenarios presented. The NPV(at a 7% discount rate) generated by the research was estimated to range from a mean value of $0.5 M when wetland values are excluded to a high of $88.2 M when wetland values are included.

The second evaluation of this research project (Harrison and Tisdell, 1997) concluded that the performance levels fell in the lower part (with an NPV (@7%) of $3.1 M) of the wide range of performance levels presented in the first report, despite a reduction in project expenditure from $1.2 to $0.94 M[1].

The main reason cited for the lower NPV was that the ex ante evaluation based benefits to a significant extent on accelerating the rate of adoption of farm plans. In practice, the adoption was slower than initially anticipated. Farm planning was a relatively small component of the overall project in terms of budget allocation (only approximately $75,000) and research time. The second evaluation placed greater emphasis on the use of the groundwater model to generate information of relevance to overall regional management and also widened benefit classes to include protection of recreation values.

In both the preceding reports it was clearly stated that it was difficult to:

- identify clearly what benefits can be attributed to the research project, as distinct from related research and prior knowledge (McGregor et al., 1994, p 70); and
- isolate the benefits from the research project from those of the catchment management plan, including engineering works for drainage (Harrison and Tisdell, 1997, p 77).

This difficulty has remained in this, the third assessment of this research project. It is still impossible to isolate the impact of the research over that of the environmental impact assessment.

[1] The reduced project expenditure resulted from an adjustment to more accurately reflect the infrastructure support costs of the CSIRO but included additional LWRRDC funding.

A major contributing factor is that the environmental impact statement, which was initiated at a similar time to this research project, moved to a conclusion at a rate faster than the research process. This meant that, although the EIS was informed by the research project, the EIS gained a momentum of its own which meant that decisions had to be made before the research was completed.

While it is ideal for implementation of a major development project to follow research and development it did not happen in this case. This means that the on-the-ground impacts of the research are practically impossible to separate from those of the EIS.

For this reason it is clear that, in the absence of this research project, it was likely that the drainage works and changes in land management would have taken place in the USER.

The research outputs targeting the use of lucerne, native vegetation and salt-land agronomy clearly indicated that any biological alternative to drainage would not be effective in reducing the salinisation process. The modelling work, in particular, led to the realisation that drainage was needed.

It is important to note that there is no doubt that the research outcomes were important in the implementation of the current engineering works but their impact appears to be limited to confirming what had already been decided. The drainage works, which have commenced, are likely to lead to a reduction in the rate of land salinisation in the region.

Furthermore, there was a general recognition of the need to establish deep-rooted plants, such as lucerne or native vegetation, in the discharge zones, as noted in Walsh et al. (1993). This has started to occur but is not clearly attributable to the outputs of the research project but rather to the introduction of a new land management technique — claying — to the region. This has meant that farmers are now more confident to sow lucerne crops which have the impact of reducing water flow from discharge to recharge zones.

There are a number of less obvious outputs of this project. The Principal Researcher has been able to take the results from this research project and use them as inputs into other research projects. An example is that the understanding of vegetation dynamics in shallow watertable areas has been used to develop guidelines for establishing plantation and agroforestry systems as well as developing criteria and guidelines for managing groundwater in fragile ecosystems.

Other points of note are that the Principal Researcher found the interface with his research and the environmental impact statement process and extension a difficult continuum to manage. This has meant that he and other researchers have had to devise new skills which require them to develop strategies to help manage these very important strategic alliances. This is an important outcome and one that should be noted in future projects which have significant community interface, such as catchment-based projects. The benefits of this realisation have been felt in other projects currently managed by the Principal Researchers and others in CSIRO.

There are a number of other lessons which have been useful in subsequent research projects managed by the Principal Researcher and CSIRO. These are:

- involve community more in the research process;
- manage interactions with the community in a professional way;
- appointing a credible person to interact with the community to ensure that the total message is received, eg. the biological approach could have taken a higher profile in relation to the profile given to drainage. In particular, the research team could have been more involved in the process of describing how the research outcomes relate to the drainage options; and
- recognise that outputs from one research project can be used by similar projects. This indicates a need for fora where such information can be shared.

Economic performance estimates

The second report on this research project (Harrison and Tisdell, 1997) carried out a detailed economic assessment of the impacts of the research outcomes up to that report. There has been no change in the range of impacts that have resulted from the project.

As has been highlighted above it has at all stages, during the two initial assessments, been difficult to segregate the impact of this research project from those of the catchment management plan. This difficulty has remained in this the third analysis. It is still impossible to isolate the impact of the research from that of the catchment management plan. This could only be determined after a detailed survey of the participants in the catchment management plan — farmers, researchers, extension agents and engineers.

There has been a slight increase in expenditure between the evaluations. This has involved an increase in costs for the CSIRO of $10,000 and $5,000 for third parties. This is attributable to new publications reporting the outcomes of the research. The total expenditure pattern for the project is shown in Table CS4-1.

The economic analysis reported in Harrison and Tisdell (1997) has been reassessed on the basis of the new cost structure shown in Table CS4-1. The impact of the additional costs has been minor reduction in the NPV (@7%) from $3.133 M to $3.121 M and the IRR from 25.2 to 25.1%.

Harrison and Tisdell's 1997 economic assessment has been updated to provide more sensitivity information at the lower end of the benefit scale they adopted. The results shown in Tables CS4-2 and CS4-3 present a range of outcomes dependent on the level of benefit attributable to the research project. Two parameters have been varied, viz. the proportion of benefits flowing to agriculture, wetlands and natural vegetation, and the level of reduction in on-farm costs. The results reveal that, if the level of benefits to agriculture, wetlands and natural vegetation were reduced to zero, then the level of reduction in on-farm costs would need to be 10% before the investment would show an positive NPV (@7%). This was the level assessed as most likely in the previous economic assessment of this project.

If the level of on-farm cost reduction is decreased to zero then the level of benefits to agriculture, wetlands and natural vegetation would need to drop to approximately 5% before a negative NPV (@7%) would be achieved.

It is clear from this analysis that the research project would have to contribute only a small amount to the outputs of the catchment management project for it to produce a positive NPV (@7%). Given that the research has provided significant peace of mind to the team implementing the catchment plan, it would be appropriate to suggest that this research project has contributed a positive return on investment for the contributing organisations at a real discount rate of 7%. However, the return on research investment may be lower than that suggested in the previous update, with perhaps 5% reduction in farm costs and 10% benefits to agriculture, wetlands and natural vegetation, or an NPV of around 1.7 M.

Limitations of the economic analysis

The analysis does not consider the benefits from a combination of both engineering works and salt-land agronomy. The extent to which use will be made of the groundwater model by researchers in the future is difficult to predict.

Table CS4-1 Project expenditure for CWW18 ($1000)

Year	LWRRDC funds	CSIRO funds	Third parties[a]	Total
1992–93	138.3	116.9	60.0	315.2
1993–94	141.8	123.3	60.0	325.1
1994–95	112.3	131.7		244.0
1995–96	40.0	12.0		52.0
1996–97		10.0	5.0	15.0
Total	432.4	393.9	125.0	951.3

[a] SA Department of Mines and Energy and Primary Industries

Table CS4-2 NPV in relation to project benefit categories for project, at a 7% discount rate, CWW18 ($'000)

Reduction in on-farm costs (%)	Benefits to agriculture, wetlands and natural vegetation (%)					
	0	2.5	5.0	10.0	15.0	20.0
0.0	–748	–384	–20	708	1437	2165
2.5	–509	–144	220	948	1676	2405
5.0	–269	95	459	1187	1916	2644
10.0	210	574	938	1666	2395	3121a

[a] NPV $_{(@7\%)}$ reported in Harrison and Tisdell (1997).

Table CS4-3 IRR in relation to project benefit categories for project CWW18 (%)

Reduction in on-farm costs (%)	Benefits to agriculture, wetlands and natural vegetation (%)					
	0	2.5	5.0	10.0	15.0	20.0
0.0	< 0	1.8	6.8	12.6	16.4	19.3
2.5	< 0	5.1	9.3	14.5	18.1	20.8
5.0	1.9	8.2	11.8	16.4	19.7	22.3
10.0	10.3	13.9	16.5	20.1	22.9	25.1[a]

[a] IRR reported in Harrison and Tisdell (1997).

Monitoring and Information Requirements

There is no evidence of formal monitoring of the impacts of this research project's outcomes. This has made assessment of the impact of these outputs extremely difficult. The information that was available had been collected, most appropriately, by other local agencies. To obtain a detailed picture of the specific impacts of this research it would be necessary to isolate the impact of the research from the implementation of the catchment plan. This would involve intensive surveying of participants. This was beyond the scope of this particular assessment.

Conclusions and Recommendations

This complex project was concerned with a range of issues in wetland modelling and management, using a diverse range of methodologies. The research project has been carried out at the same time as a major assessment and decision-making process for a catchment management scheme for the area. This complexity in methodology and the associated evolving policy with respect the engineering works and land management of the Upper South East Region has meant that it has been impossible to isolate the full impacts of this research project.

The complexity of the project, in particular the ability to isolate out benefits, has persisted to this, the third life-of-project assessment. While the project has contributed to the decision-making associated with the implementation of the catchment management plan it is impossible to segregate this impact without a detailed survey of participants in the decision-making process including farmers, researchers, extension agents, engineers, wildlife officers and politicians. This was beyond the scope of this analysis.

The results presented show that only low levels of benefits from agriculture, wetlands and natural vegetation, as well as reduced on-farm costs, would be needed to obtain a positive NPV. Given the peace of mind given to those implementing the catchment management plan, at least these levels of impact are assessed to have occurred. It is likely that the overall NPV would fall somewhere between the minimum required to achieve a positive net present value at a real discount rate of 7% and the values reported in the second life-of-project evaluation.

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7 Case Study 5: Nutrient Limitations of Algal Growth: Physiological Assays and Chemical Analyses (MDR8)

Research Organisations:
The Murray–Darling Freshwater Research Centre (of the Cooperative Research Centre for Freshwater Ecology), Albury, NSW

Principal Researcher:
Dr R.L. Oliver

Executive Summary

This project has applied chemostatic culture techniques for algae to develop a nutrient induced fluorescence transient (NIFT) method of determining nutrient limitation. The NIFT assay is based on the occurrence of transient fluctuations in chlorophyll-a fluorescence caused by addition of the limiting nutrient to a sample containing either nitrogen or phosphorus limited phytoplankton.

The alternative test is through algal growth bioassays that are considered too labour intensive and expensive for repetitive use. The NIFT method has been demonstrated to compare favourably against standard growth assay techniques, with potential for considerable cost and time saving in determining nutrient status in water sources. Benefits will arise from reduced monitoring costs by water management agencies, and availability of better information on which to base algal management strategies. The benefits from this project are not yet clear. Further validation and technology transfer of the NIFT method will be required before widespread adoption. This updated economic analysis of the study suggests a benefit–cost ratio of 2.4, NPV (at a 7% discount rate) of $601,000 and an IRR of 15.1.

Background

The extensive use of Australia's river systems for agricultural and domestic purposes has led to deterioration in water quality and flow regime of many rivers. The consequences of these changes include increased salinity levels, reduced oxygen content and high levels of suspended solids in rivers. In recent times, the visual evidence of these changes has been increased frequency and magnitude of algal blooms. These blooms have significant social and economic costs as they reduce the quality of water available for human and livestock use. Similarly, the cost to water authorities and water users of minimising algal blooms is high. Strategies to manage algal blooms include managing the river flow and managing the nutrient availability for algal growth.

Blue-green algae need nutrients to exist and large quantities of nutrients to develop into blooms. Algal growth in rivers and water storages requires compounds such as phosphorus and nitrogen. Sources of these nutrients include:

- sewage treatment plants;
- urban stormwater drains;
- irrigation drains;
- intensive agricultural industries;
- run-off from agricultural land; and
- ecological processes.

An outbreak of blue-green algae in the Murray–Darling in 1991–92, reported to be "the world's largest recorded riverine algal bloom" (BGATF, 1992, p. vii) led to the establishment of the Blue-green Algal Task Force in November 1991 by the New South Wales Government (BGATF, 1992). The task force was comprised of a range of government departments, members of the public, universities and industry who deal with natural resources, primary industry, environmental protection, health, and water supply. The task force report (BGATF, 1992) highlighted the factors which contributed to algal blooms as:

- high nutrient levels, particularly phosphorus;
- low N:P ratios (less than 29:1)
- high water temperature (above 20˚C);
- high pH (levels of 8–10) and low carbon dioxide concentration;
- abundant zooplankton (blue-greens are relatively inevitable);

- low flows, leading to long retention times and calm water conditions; and
- reduction in turbidity to moderate levels, leading to increased light intensity (BGATF, 1992, p. xii).

The costs associated with the algal bloom were categorised in terms of lost livestock, environmental losses of fish stocks and native fauna and flora, and the potential economic damage caused to the tourism industry as a result of the media coverage of the bloom, in particular, the media coverage overseas. In attempting to value these costs, the task force reported the following costs:

> "(i) the direct cost to the NSW and Commonwealth Governments to provide water supplies during the State of Emergency for the Darling–Barwon blooms is estimated to be $1,260,000.
>
> (ii) lost income from tourism and recreation in local regions is $9.4 million, ascribed to the occurrence of blooms, and to negative media coverage.
>
> (iii) up to 1600 sheep and 40 cattle deaths were suspected by being caused by Darling–Barwon algal blooms" (BGATF, 1992, p. xi).

Blue-green algal blooms also have potentially high human health costs. Toxins produced by blue-green algae may cause liver damage, nervous system and stomach disorders, skin rashes and eye irritations. Upgrading water treatments works to remove toxins and associated discoloration and taste from drinking water is likely to be expensive. Direct costs will vary according to the duration and extent of each algal bloom. Algal blooms also adversely affect recreation and tourism. Income to regional economies surrounding large water storages is likely to be significantly affected by algal outbreaks. These costs could continue well after the bloom has dissipated as visitors lose confidence in the quality of the water storage as a recreational site.

In addressing the issue of how to avoid further outbreaks of algal blooms and restore the riverine ecology and hence the food web, the task force examined measures which may be used to control diffuse and point-sources of pollutants entering the river system and alternative waterway management options. The waterway management options included environmental flow allocations and greater regulation of the timing of water flows (BGATF, 1992, p. xviii).

Long-term strategies at alleviate the problem of algal blooms require a knowledge of the causal factors. The Murray–Darling Basin Ministerial Council (MDBMC) has developed an algal management strategy for the Murray–Darling Basin. Controlling nutrient sources is seen as a critical component of the management strategy. Areas highlighted by the MDBMC for the development of guidelines to reduce nutrient input into water sources include:

- nutrient removal at sewage treatment plants;
- off-river re-use of sewage effluent;
- intensive rural industries;
- land uses which are diffuse sources of nutrients;
- detergent manufacturing;
- effluent releases from point sources;
- riverboat waste disposal;
- urban stormwater management;
- whole farm planning; and
- irrigation drainage.

Many of these sources of nutrients produce high levels of nitrogen (N) and phosphorus (P). The MDBMC argues that the key elements of nutrient reduction include:

- identifying and quantifying the sources of nutrients in the river system;
- determining the options available for reducing the input of nutrients from these sources;
- undertaking benefit–cost and environmental assessment of the various options; and
- determining how resources may be obtained to implement the chosen options. (MDBMC, 1994, p.9)

This project developed a technique for measuring nitrogen limits during algal blooms. An understanding of the conditions and nutrients that lead to algal blooms, and the way in which they may be manipulated to reduce incidence of blooms, is essential for cost-effective management. Gaining this understanding requires the development, validation and implementation of techniques, such as that developed in this project, to measure nutrient limitations, and their use in examining relationships between land and water management, weather and algal biomass growth.

The NIFT assays are conducted at the peak of a bloom and in isolation of other tests. The NIFT assay measures the limiting level of nitrogen during the bloom but cannot be used to predict an outbreak of algal growth or bloom per se. The iron strip technique developed in MDR8 indicates how much phosphorus is in the water body and available for algal growth. To know how much nitrogen or phosphorus is necessary to limit algal blooms requires measurements of the levels of phosphorus and nitrogen that were present before a previous outbreak. Then, using NIFT test results of previous studies, it is possible to estimate the likely limiting factor in advance and implement appropriate management strategies. The results of the iron strip tests and the NIFT tests are complementary for predicting algal blooms.

Aims of the Project and Performance

The specific objectives of MDR8 were to:

- develop a suite of physiological assays to ascertain the relative importance of nitrogen and phosphorus limitation to algal growth;
- as conditions warrant, extend this set of key physiological assays to include techniques for identifying cellular limitations of other crucial elements such as silica, iron and molybdenum;
- test the physiological assays on cultures of common bloom-forming algae isolated from rivers of the Murray–Darling Basin and grown under defined nutrient conditions;
- use the physiological assays to demonstrate nutrient limitation in naturally occurring algal blooms and identify the nutrients controlling biomass development;
- compare the results of physiological assays with standard growth bioassays and with chemical analyses of total and bioavailable concentrations of key elements;
- attempt to relate bioavailable quantities of the limiting nutrient to algal biomass production; and
- investigate the influence of nutrient limitation and nutrient ratios on species dominance in blooms.

The development of the NIFT technique needs to be rigorously tested and validated before water testing agencies will consider adoption. Validation of the NIFT technique to a level for commercial adoption required additional funding. Additional funding was applied for, but because of the amount of money involved, the extension became a separate research project. The specific objectives of the new project, MDR18 (titled “Validation of the NIFT Assay for Identifying N and P Limitations on Phytoplankton Growth”), are to:

- establish the validity of the NIFT assay by addressing major questions identified during MDR8;
- confirm the assay on a green alga, a diatom and a bacterium, representating the main phytoplankton groups;
- determine if the NIFT assay for N and P limitations is reliable when the organisms are grown under N-limiting conditions, using both nitrate and ammonia as their sole inorganic nitrogen source;
- demonstrate that prolonged dark incubations does not influence the outcome of the NIFT assay;
- examine the effect of a nitrogen-fixing bacterium—*Anotheanum* is a nitrogen fixer that is common in water systems in Australia; and
- determine the suitability of commonly used fluorimeters for the NIFT assay, and acquire such fluorimeters from manufacturers to test the suitability of the assay.

As MDR18 is essentially an extension of MDR8 they will be considered one project for the purposes of analysis. MDR8 is essentially finished. The follow-up work of MDR18 is well developed in the areas of acquiring and testing the validity of the NIFT tests on fluorimeters, and the impact of prolonged dark incubations on the outcome of the NIFT assay. Further work on technology transfer in terms of organising the workshop is currently under way.

Final outcomes of MDR8

As discussed in the previous update, the continuous algal culturing equipment under Objectives 1 and 3 was successfully developed. The NIFT physiological assay technique was developed to identify N and P limitations and tested on cultures grown under defined nutrient conditions and samples from the three field sites. Under Objective 4, it was found that there is evidence that phosphorus may often not be the limiting nutrient, which raises issues concerning control strategies aimed at reducing phosphorus input to rivers. Under Objective 5, it has been established that physiological assays compare favourably with traditional growth assays, with major time and cost savings.

Objectives 2 and 7 were never completed. With respect to Objective 3, assays for nutrient limitation assays were not extended to Anabaena and Melrosia genera. With respect to Objective 6, preliminary work suggested there appeared to be little value in pursuing assays for nutrient limitation other than nitrogen and phosphorus, except perhaps for silica limitation in diatoms. Objective 7 led to the development of MDR18.

The change in research direction of MDR8 following the development of the NIFT assay required further exploration and funding to validate the assay as a method for measuring nitrogen limits in algal blooms. While the project objectives did not change since the initial evaluation, there were some changes in research emphasis. More effort than originally envisaged was made on development of physiological assays using the NIFT technique. NIFT responses have reliably predicted nutrient limitation and warrant the focus in the project on this new methodology. Less effort than planned was made on chemical analysis of cellular constituents.

Progress with MDR18

In MDR18, objectives 1–3 have been adequately achieved. Objective 4 is necessary, as the samples may need to be transported long distances to laboratories for testing. During transportation it is likely that the samples will be in darkness for considerable periods. The results of experiments to date indicate that NIFT assays do not change as a result of prolonged darkness during transportation. Objective 5 deals with the response of the NIFT assay to a nitrogen fixer growing without a source of inorganic nitrogen. It has been shown that if nitrogen is removed or is in low concentration it simulates nitrogen-fixers in a system. The results of the NIFT tests showed no nitrogen limitation in algal blooms because the nitrogen was fixed.

Objective 6 was to identify instruments that could be used to apply the NIFT assay to nitrogen testing. A fluorimeter is needed to operate the NIFT assay. Validation of the NIFT technique requires testing on various commercial fluorimeters. A list of fluorimeters used in Australia was acquired but obtaining these instruments on loan proved difficult because of commercial demand for them. The manufactures were not prepared to loan fluorimeters to the researchers for validation testing. Finally, a Turner design fluorimeter, a commonly used field instrument, was borrowed from the New South Wales Environmental Protection Agency and tested for the NIFT assay. The preliminary results are that the tests are producing consistent and accurate measurements.

Technical Outputs of the Project: Processes, Improved Management Techniques, Other Information

The technical outputs for the original MDR8 project agreed to between the Principal Investigator and LWRRDC are:

- one or more practical physiological assays to ascertain the relative importance of N and P limitation to algal growth in the laboratory and under field conditions, and to identify the nutrient controlling biomass development;
- determination of the importance of other limiting nutrients;
- a comparative assessment of the physiological assays with standard growth bioassays and chemical analyses;
- the relationship between bioavailable limiting nutrients and algal biomass production;
- the effects of nutrient limitation on species succession and dominance in blooms;
- determination of the influence of the N:P ratio on algal blooms; and
- biologically relevant water quality criteria that will enable water managers to assess the effectiveness of controlling nutrient loads to aquatic systems.

As outlined in the previous update, the most important technical output of the project was development of a simple, rapid, nutrient-specific assay for nutrient limitations for cultured cells. Application of this assay on field samples from the Murray–Darling river system led to questions on the relevance of the strong relationship between phosphorus load and algal biomass reported for water storages overseas. Evidence suggests that often phosphorus is not the limiting nutrient here, though it could become limiting if large reductions were made in phosphorus input. Also, some blue-green algae, including Anabaena, have the ability to overcome nitrogen limitation by fixing atmospheric nitrogen. A strong relationship appears to exists between river flow and algal biomass.

The study found nitrogen limitation of greater importance than expected. One of the implications is that, provided other conditions can be made unsuitable for nitrogen fixers, then nitrogen limitation will control the outbreak of algae. It is important to note that, when targeting water strategies aimed at algae control measures, if nitrogen is limiting rather than phosphorus this suggests that the reduction in the concentration in phosphorus would have to be significant before it became effective. It may be possible to reduce nitrogen rather than phosphorus. Lowering nitrogen concentration is possible by such measures as reducing the level of effluent entering the water supply. Effluent releases from treatment plants are seen as significant contributors to nitrogen in river systems. Similarly, the use of nitrogen-based fertilisers on pasture and broadacre farms adjoining riparian land could be regulated to take account of the resulting damage to riverine environments. In dairy areas there may be a considerable level of nitrogen run-off from livestock effluent.

Implications for riverine and water storage management

The results of the NIFT tests and associated research suggest that simply reducing the level of nitrogen may not be adequate for controlling algal blooms. Outbreak of algal blooms also depends on other compounds being limiting to growth, water temperature, light level, and the turbulence and flow of the water.

The success of reducing the level of nitrogen in the water also depends on the presence of nitrogen fixers. A nitrogen fixer is an alga which can obtain nitrogen from the air and so does not require combined inorganic nitrogen, such as nitrate or ammonia, to grow. In other words, the nitrogen-fixing varieties of algae gain a comparative advantage over other water plants when nitrogen is limiting, because they are not dependent on inorganic nitrogen for growth.

In riverine stretches, the cyanobacteria *Anabaena circinalis* is the most common form of algae and can fix nitrogen. In lakes and larger standing waters, such as dams, *Microcystis aeruginosa* and *Anabaena circinalis* may occur, but the former is the more common form of algae in large storages.

Blue-green algae of all forms are handicapped when water is flowing and deep because they depend on their buoyancy and dominance of the surface water to grow. If the flow is kept at a level that inhibits algal growth, the levels of nitrogen and phosphorus would not be critical.

Development and Adoption of Research to a Form Suitable for End-Users

The technology transfer from the research has yet to be realised. As a result, it will be necessary to monitor the adoption of the research over the next 3–5 years. Interest in the project's publications (requests, citations, etc.) and use of its techniques by other research laboratories (including overseas) is encouraging. Technology transfer plans include a workshop to be conducted with 25 industry people from across Australia representing water testing agencies and government authorities. The workshop is aiming to provide information on nutrients in water sources, the relationship with algae, the need for measuring particular forms of nutrients, and to describe some of the new techniques, such as the NIFT tests, which have been developed and the outcomes which have occurred. An open workshop forum is planned to discuss the need for, benefits and limitations of the new techniques, difficulties of implementing new techniques.

The workshop was originally to be held in March 1999, but was postponed until June or July. Possible outcomes of the workshop would be the adoption of assays or at least trial of the assays by potential adopters. From such adoptions and trials a larger database is expected to be developed to show the benefits and limitations of adopting these methods. Oliver (pers. comm. 1999) expected every State to be represented at the workshop. Delegates will be those responsible for overseeing and monitoring water-testing work carried out by the organisation. The organisations showing interest in attending the workshop include those listed as potential adopters.

Potential Users, Actual Users, Barriers to Adoption, Adoption Rates

Potential users

Potential adopters of the research include local and State government water testing agencies and research centres, as well as private water quality consulting firms. Organisations showing an interest in the research findings include (Oliver (pers. comm., 1999):

- Department of Natural Resources and Environment, Victoria;
- Department of Land and Water Conservation, New South Wales;
- Australian Water Technology;
- Department of Natural Resources, Queensland;
- Cooperative Research Centre for Water Quality and Treatment, South Australia;
- Department of Primary Industries, Tasmania;
- Water and Rivers, Western Australia;
- Goulburn–Murray Water;
- Melbourne Water; and
- The New South Wales Environmental Protection Agency.

Barriers to adoption

The limitations to adoption derive from the lack of knowledge by potential adopters of the NIFT assays, validation of the results of the NIFT assays, and the availability and cost of equipment to conduct the NIFT assay tests. Discussion with potential adopters during this evaluation was limited by the lack of knowledge concerning the NIFT assay and its validation. The workshop discussed previously should assist in overcoming this limitation to adoption.

The availability of fluorimeters for validation of the NIFT assay has also been a significant impediment to adoption. The researchers have been able to generate a list of fluorimeters that might be suitable and one has been tested. However, as discussed previously, the researchers have had limited success in acquiring equipment for testing and validation of the NIFT assay. Most of the water testing agencies contacted did not have fluorimeters readily available. Except for field fluorimeters, these instruments are not widely available because there have been very few reasons for the laboratories to have them. Fluorimeters are used for field testing for chlorophyll fluorescence, but because field testing can also be carried out on spectrophotometers there is no need for fluorimeters. The NIFT assay uses the chlorophyll fluorescence, but relies on the perturbation in the signal on the addition of a nutrient to estimate the concentration of algae in the water.

The cost of fluorimeters is also seen as a significant factor limiting adoption. They range in cost from $5,500 to $30,000 depending on the type on instrument. The cost of the instrument used during the study was approximately $25,000. Lower-priced instruments are available, such as the Turner Design N-AU-005 field instrument, but the researchers were unable to acquire one on loan for testing. A relatively cheap fluorimeter is being sought by the Principle Investigator of MDR18 to demonstrate the NIFT assays and entice water-testing agencies to adopt the NIFT assays.

Technical Outputs of the Project: Products, Processes, Improved Management Techniques, Other Information

This project has produced outputs in terms of the development of the NIFT assay, its validation and the production of published papers. The papers arising from the research include:

Oliver, R.L. (1998), "Nutrients and phytoplankton blooms: Measurements, models and management", In: Proceedings of the Coastal Nutrients Workshop, 30–31 October 1997, Sydney.

Oliver, R.L. (1997), "Identifying light and nutrient limitation of phytoplankton growth", NEMP Nutrient Workshop 1997.

Oliver, R. L. and Whittington, J. (1998), "Using measurements of variable chlorophyll-a fluorescence to investigate the influence of water movement on the photochemistry of phytoplankton". In: Physical processes in lakes and oceans, Imberger, J. (ed.), Coastal and Estuarine Studies 54:517–534, American Geophysical Union.

Wood, M.D. and Oliver, R.L. (1995), "Fluorescence transients in response to nutrient enrichment of nitrogen- and phosphorus-limited Microcystis aeruginosa cultures and natural phytoplankton populations: a measure of nutrient limitation", Australian Journal of Plant Physiology, 22: 331–40.

Research, Development and Extension Costs, Including Costs to LWRRDC and Host Organisation

Table CS5-1 presents the expenditure for the combined projects. The total expenditure on MDR8 and MDR18 was $508,771 and $36,181, respectively. Following the methodology adopted in the previous update, the research organisation contribution to MDR8 is based on a multiplier of 2.0 for research officer salaries and 0.2 of the Principal Investigator's time. The $48,700 to MDR8 was paid in compensation for LWRRDC's withdrawal from the CRC for Freshwater Ecology. LWWRRDC withdrew as a partner and injected additional funds removed from the Centre.

MDR8 officially ended on 31 January 1996. Between 1996 and 1998 there was no formal funding. The contribution by the research organisation to MDR18 is based on the pro-rata time of the principal investigator. The total funding for MDR18 from LWRRDC and associated funding bodies (NRMS and MDBC) was $27,273 over two years, consisting of two instalments of $13,636 each. MDR18 was essentially a one-year project operating from April 1998 to April 1999. The CRC contributed two instalments of $4,454 each. The total funding for the combined projects was $517,764.

Benefit–Cost Ratios

The NIFT project is part of a suite of projects aimed at gaining greater understanding of nutrient requirements of algae and their implications for algal growth. Valuation of projects such as MDR8 in isolation and divorcing it from the collective knowledge may underestimate the value of the research on the premise that the value of aggregate knowledge is worth more than the sum of its component parts.

MDR8 and MDR18 have limited adoption as yet and so the benefits arising from the research are still tentative estimates. Nevertheless, understanding the importance of nitrogen limits to algal growth and blooms is critical in the development of effective water and land management strategies.

Estimated Economic Performance and Sensitivity Analysis

Following the estimates developed in the previous two life-of-project evaluations on the damage saved each year and savings in water testing kits, Table CS5-2 presents the annual cash flow and performance criteria for the combined projects MDR8 and MDR18 on NIFT assays. It is assumed that adoption will commence after the completion of MDR18 at the rates used in the previous update.

Table CS5-3 presents a sensitivity analysis with respect to the social discount rate. Given a 7% discount rate the benefit–cost ratio is 2.4. At a discount rate of 10% the benefit-cost ratio is 1.7.

Table CS5-1 Expenditure for project MDR8 and MRD18 ('000)

Year	Planned LWRRDC funding	LWRRDC actual and outstanding	Research organisation (CRCFE)	Total funds
MDR8				
1992–93	104.7	16.6	48.7	65.3
1993–94	46.3	76.5	98.9	175.4
1994–95	60.4	47.7	92.2	139.9
1995–96	23.7	45.6	55.4	101.0
Total	235.1	186.4	295.2	481.6
MDR18				
1998–99	13.6	na	4.5	18.1
1999–00	13.6	na	4.5	18.1
Total	27.3	na	8.9	36.2
TOTAL	262.3	186.4	304.1	517.8

Table CS5-2 Annual cash flows and performance criteria, MDR18

Year	Damage saved each year (%)	Damage saved each year ('000)	Saving in water test costs ('000)	Project expenditure ('000)	Net cash flow ('000)
1992–93	0	0	0	65.3	−65.3
1993–94	0	0	0	175.4	−175.4
1994–95	0	0	0	139.9	−139.9
1995–96	0	0	0	101.0	−101.0
1996–97	0	0	0		0
1997–98	0	0	0		0
1998–99	0	0	0	18.1	−18.1
1999–00	0	0	0	18.1	−18.1
2000–01	0.125	31.1	36		67.1
2001–02	0.250	62.2	36		98.2
2002–03	0.375	93.4	72		165.4
2003–04	0.500	124.5	72		196.5
2004–05	0.625	155.6	72		227.6
2005–06	0.750	186.7	72		258.7
2006–07	0.875	217.9	72		289.9
2007–08	1.0	249.0	72		321.0
2008–09	1.0	249.0	72		321.0
2009–10	1.0	249.0	72		321.0
2010–11	1.0	249.0	72		321.0
2011–12	1.0	249.0	72		321.0
Net present value ($1000) =1121.7; Internal rate of return = 15.1; B/C = 3.4.					

Table CS5-3 Effect of social discount rate on NPV and benefit–cost ratio, MDR8

Discount rate (%)	NPV ($'000)	Benefit–cost ratio
4	1121.7	3.4
7	601.9	2.4
10	285.6	1.7

Potential project benefits

The potential benefits arising from the research have not changed significantly since the previous update. The development of MDR18 has significantly increased the likelihood of adoption, but actual adoption has yet to occur. The benefits of the research potentially include:

Cost-effective management strategies

Knowledge of the importance of nitrogen and of the situations in which lowering nitrogen levels may be effective in reducing the likelihood of algal blooms will result in more cost-effective management strategies to control outbreaks of algal blooms. Incorrect strategies to reduce nitrogen releases from sewage plants, for example, may be extremely expensive.

Reduced community costs from reduced incidence of algal blooms

The development of models based on iron strip and NIFT assay measures may provide more accurate predictive models. Strategies such as increased flow regimes may reduce the number and social cost of algal blooms.

Reduced costs of water testing

Water testing agencies exist in each State and Territory of Australia. The Principal Researcher believes that at least 60 agencies could be potentially large enough to justify expenditure on the necessary fluorimeter equipment. Depending on the cost and portability of the equipment, the number of adopters may vary. The regional offices adopting NIFT assay testing would depend on obtaining a lower-cost fluorimeter and laboratory facilities necessary to make the nutrient solutions.

In this analysis it is assumed that the 60 agencies conduct 40 tests per year and save $30 per year in testing by using NIFT assays, amounting to an annual saving of $72,000. It is assumed that for the first two years following the completion of MDR18, 30 agencies will have adopted the NIFT assays, and within three years the NIFT assays will have been accepted as the standard test for nutrient limits and 60 agencies will be regularly conducting tests.

Variations from initial evaluation

The additional project, MDR18, "Validation of the NIFT Essay for Identifying N and P Limitations on Phytoplankton Growth" is further validating the NIFT assays as a means of evaluating the nitrogen limits in algal blooms. This has increased the overall cost of the project. The adoption of the NIFT assays has been delayed as a result of commercial validation requirements and limitations on acquiring fluorimeters for testing. As a result the NVP has been reduced from $1.6 M to $601,900 and the benefit–cost ratio from 5.0 to 2.4. It appears that, while the adoption benefits predicted in the previous update have been delayed, it is likely that the value of the project may be realised in the next few years as the benefits of the workshops and testing of the NIFT assay evolves.

Future Monitoring Requirements

As previously discussed, the adoption of the NIFT assay has yet to occur. Future monitoring of interest by potential users in the assay following the workshop will be required. Similarly, as the NIFT assay validation is conducted potentially more adoption may occur and should be monitored.

Discussion and Conclusion

Algal blooms in rivers, lakes and water storages are posing a significant economic, social and environmental cost on Australia. Understanding the processes that contribute to such blooms is critical if these costs are to be managed. This project has applied chemostatic culture techniques for algae and developed the Nutrient Induced Fluorescence Transient (NIFT) method of determining nutrient limitation. The NIFT assay is based on the occurrence of transient fluctuations in chlorophyll-a fluorescence caused by the addition of the limiting nutrient to a sample containing either nitrogen or phosphorus limited phytoplankton. Water management agencies use standardised water testing methods and are reluctant to adopt new technology without significant testing and validation. The NIFT assay developed in this project is new technology and testing and validation is continuing. The final industry acceptance of the NIFT assay is yet to be realised.

Reference

BGATF (New South Wales Blue-Green Algae Task Force) (1992), Final Report of the New South Wales Blue-Green Algae Task Force, DWR, Sydney.

8 Case Study 6: On-Site Monitoring of Agro-Chemical Residues: a Valuable Tool for Irrigation Water Management (CPI4)

Research Organisations:
CSIRO Plant Industry, Canberra, ACT

Principal Researcher:
Dr J.H. Skerritt

Executive Summary

This project, together with research supported by other funding, has led to development of a number of enzyme immunoassays (EIA) for the detection of pesticide residues in water. The EIA tests are much less expensive and time consuming than traditional 'instrumental' tests, and are suited to applications under field conditions by personnel with limited training in their use. Prototype assays for compounds developed under this project have been used widely in other Australian research projects concerned with pesticide residues. As well, EIA kits have been manufactured and marketed by a commercial partner. These kits are suitable for use by researchers, State and local government resource managers, agricultural consultants and larger farms, with the potential for resource efficiency and environmental benefits.

This project has been highly successful in achieving research objectives. The commercialisation process has raised a number of issues relevant to future research projects. The project is estimated to yield a net present value (at a 7% discount rate) of $0.7 M, benefit–cost ratio of 2.0 and an internal rate of return of 25%.

Background, Objectives and Technical Outputs

Research into development of prototype kits for enzyme immunoassays (EIA or ELISA tests) has been motivated by the need for improved detection of pesticide residues in irrigation tailwater, natural waterbodies and water storages. Such tests can detect very low concentrations (of the order of one part per billion) of residue, and are much less expensive and time consuming and require less equipment than traditional (instrumental) tests. The possibility of further development and marketing of these tests in collaboration with a commercial partner was an outcome (but not a design objective) of the research program. The need for tests was particularly apparent in the cotton and horticulture industries where agro-chemicals are widely used.

The objective of this project has been to develop, trial and facilitate the use of EIA kits for detection in the field of pesticides in groundwater, irrigation surface run-off, and stock and domestic water supplies. More specifically, the research plan involved development and modification of laboratory and field tests kits for a range of compounds; field tests for reliability and sensitivity of the kits; use and validation of the kits with irrigation drainage water, and stock and domestic drinking water; and development of small immunoaffinity columns to allow concentration of pesticides from large volumes of water in the field for subsequent transport to the laboratory. Technical outputs have included prototype kits and advice on their use.

Progress and Achievements

Funding for the research was provided by LWRRDC, CSIRO Plant Industry, the Cotton R&D Corporation, Millipore Australia Pty Ltd/ImmunoSystems Inc., with a total expenditure of approximately $1 M, with LWRRDC having an 11% share in intellectual property (IP). The project proceeded without difficulties or budget changes. Some progress was made in development of enzyme immunoassays for nearly 20 compounds or groups of compounds. The level of progress varied between compounds, and for economic analysis in the first update, it was considered that four assays had been commercialised (viz. assays for diazinon, chlorpyrifos, endosulfan and molinate), and had a mean initial availability date of July 1995, while four others assays would be commercially available by July 1997 (for malathion, sulfonylureas, glyphosate and cholinesterase). Plans to develop small immunoaffinity columns and testing of domestic water supplies were not proceeded with.

Research supported by LWRRDC was conducted during 1992–95, and further development of EIA tests has continued (particularly for the grape industry) with other funding. Product commercialisation agreements were made between CRIRO and Millipore Australia. LWRRDC expressed concern that the arrangements may be in breach of the Project Agreement, and sought a number of amendments to the agreement between the Regents of the University of California and the CSIRO Plant Industry, to protect the interests of Australian farmers.

The major practical outcome of the project has been availability of prototype pesticide detection kits for use by other Australian researchers, and particularly Professor Ivan Kennedy (University of Sydney) and others in the Cooperative Research Centre for Sustainable Cotton Production. The various advantages ofboth prototype and commercialised kits, in terms of lower cost and time to apply, and disadvantages in terms of lower standing and unsuitability for multi-residue analysis, have been discussed in the previous update.

Following an air crash in which some key staff of Millipore were killed, the company reduced its range of activities, and ownership of the EIA tests was acquired by Ensys Environmental Products, which subsequently merged with Strategic Diagnostics Inc. (SDI).

For some pesticides, commercialisation of tests has not occurred where it was envisaged. For some other pesticides, commercialisation has occurred (the assays are advertised for sale by SDI) but no information has been provided to CSIRO to indicate whether the prototype kits developed by CSIRO were the ones commercialised. Table CS6-1 sets out current knowledge of the status of tests, excluding the four previously reported as commercialised.

CSIRO tests for malathion and glyphosate were regarded by both CSIRO and Millipore as insufficiently sensitive. An alternative Australian prototype was developed for detection of sulfonylureas. A test was in fact developed for chlorfluazuron (Helix™), but in a subsequent research project to CPI4. A test was developed for trichlopyr (Garlon™), the source of which is not clear, and no information or royalties for this test have been forthcoming from SDI.

It is notable that EIA kits are now being developed from prototypes produced by a number of research agencies, and not exclusively from CSIRO prototypes. EnviroLogix, whose Australian agent is ELISA Systems, has a commercial test for chlorpyrifos developed in the USA. Tests currently being used in the grape and wine industry for chlopyrifos and endosulfan were not developed by CSIRO.

Communications and Technology Transfer

As noted in the previous update, prototype kits have been provided to a number of natural resource management agencies, including

- CSIRO Water Resources;
- NSW Department of Water Resources;
- NSW EPA (Centre for Environmental Toxicology);

Table CS6-1 Progress in commercialisation of assays

Pesticide	Progress on commercialisation of assay
Pesticide	Progress on commercialisation of assay
Diuron	Millipore's more sensitive kit commercialised. CSIRO undertook extensive validation and developed protocols for their use in Australia.
Thiobencarb	Millipore's more sensitive kit commercialised. CSIRO undertook extensive validation and developed protocols for their use in Australia.
Malathion	Test not sensitive enough so not commercialised
Chlorfluazuron (Helix™)	Highly effective test developed in a separate project*
Cholinesterase	CSIRO were not involved in the test commercialised
Bromacil	Use dropped so not commercialised
Sulfonylureas	Millipore preferred test developed by Victorian Dept. of Agriculture
Glyphosate	Test not sensitive enough so not commercialised
Trichlopyr (Garlon™)	Kit marketed but CSIRO not advised of source or sales
Deltamethrin†	Commercialised by SDI
Dicofol	Not aware of commercialisation
DDT§	Commercialised and royalties paid. The Australian grape and wine industry uses a separate DDT assay.

* At the time of the first update, use of this chemical was suspended due to residues in beef.
† Incorrectly called pyrethroids in previous report.
§ Incorrectly called DDE in previous report.

- University of Sydney (Department of Agricultural Chemistry and Soil Science, Centre for Pesticide Application and Safety);
- Cooperative Research Centre for Sustainable Cotton Production (University of Sydney, NSW Department of Agriculture);
- Qld Department of Environment and Heritage;
- NSW Department of Land and Water Conservation; and
- water companies in south-western NSW.

While Dr Skerritt has continued to use EIA tests, and demonstrate their value, in the grape and wine industry, the main technology transfer has also been carried out by the CRC for Sustainable Cotton Production, in particular Professor Ivan Kennedy's group at the University of Sydney. No commercial kits have been used in these research projects. Prototype kits have been provided to other users.

A number of research projects have used EIA kits. One application has concerned endosulfan degradation on pasture. Another, led by postdoctoral fellow Dr Francisco Sanchez-Bayo, used endosulfan tests in research into avian exposure to pesticides in their diet. Tests have been conducted for endosulfan, DDT/DDE, chlorpyrifos, methyl parathion and diuron (made available through an American collaborator), but not diazinon or molinate, since these are not used in cotton.

Numbers of tests used are difficult to determine; a partial enumeration in work associated with the University of Sydney over the three years 1995–96 to 1997–98 is provided in Table CS6-2. As well, tests for DDT are being carried out by the NSW Environmental Protection Authority. Allowing for under-enumeration and users not recorded here, it would appear that approximately 5,000 tests a year are carried out with prototype kits. Also, it would appear that use of these tests or modifications of them will continue. On the other hand, future use of commercial kits in Australia under is likely to be low unless marketing arrangements are improved.

Professor Kennedy's group now has the capability to format ELISA kits for research.

- Nan-Ju Lee, PhD student and CRDC scholar supervised by Professor Kennedy and Dr Skerritt, developed ELISA kits for ensosulfan and pyrethroid, the former being used extensively in Professor Kennedy's program. These kits were developed at CSIRO.
- Shuo Wang, PhD supervised by Professor Kennedy and Dr Skerritt, developed new immunoassays to insect growth regulators (benzylphenylureas) such as chlorfluazuron and flufenoxuron. These kits were developed at the University of Sydney.

Approximately $35,000 in research funds has been transferred to CSIRO over several years to support extension activities by Ms Helen Beasley, including making prototype kits available to the University of Sydney.

At the request of the Queensland Department of Environment and Heritage (now Environmental Protection Agency), Professor Kennedy arranged a training workshop using commercial kits at the University of Southern Queensland, Toowoomba, attended by 12 registrants (for a fee of $650 each). A further workshop is planned.

An large project of the Australian Centre for International Agricultural Research (ACIAR) in Vietnam will use the existing EIA kits, new ones developed by Professor Kennedy's group, and commercial tests. The project will establish a pesticide monitoring network, along similar lines to another ACIAR project that Dr Skerritt has conducted in India (with the Central Food Technological Research Institute in Mysore)

Table CS6-2 Estimated numbers of EIA tests performed, 1995–96 to 1997–98

Activity	Approx. no. of tests
University undergraduate teaching — third year practical classes — for several years	200
Developmental work with PhD students	1000
A survey of DDT residues in the Macintyre, Gwydir and Namoi valleys (with a PhD student co-supervised by Dr Skerritt)	840
Analysis for drift samples with C-PAS at the University of Queensland Gatton College (with Dr Nicholas Woods)	3000
GRDC trial on endosulfan degradation in pastures	500
Research on exposure of birds to insecticides	500
Rainfall simulation and run-off research in Qld by Mark Silburn, DNR	500

Commercialisation and Intellectual Property Issues

The commercialisation arrangements for EIA kits between CSIRO and US partners have not worked as well as would have been desired. While Millipore Australia had an active presence in Australia, with 70 local employees, included marketing staff, Ensys had no Australian presence. For kits sold by SDI, the price has increased steeply and is now significantly higher in Australia than in the USA, and access to kits is less convenient. It is still possible to order Molinate kits, but the price is considered prohibitive – understood to be approximately $800 to $900, compared with approximately $A 400 in the USA — and this appears to caused some Australian agencies, including NSW Water Resources, to stop using SDI kits.

Since completion of CPI4, CSIRO has invited an expression of interest from SDI for commercial development rights for new tests, but SDI has not taken up this offer. This has allowed development of the kits by another firm, and has meant that the kits have become available to the grape and wine industry for a price of approximately $300, or about one third of that which would have been expected if marketed by SDI.

The CSIRO, like R&D corporations, aims to provide a service to Australian rural industries, and has now built safeguard clauses into commercialisation agreements. These clauses stipulate that the products must be made available in Australia at the same time as in the USA, an Australian agent is to be appointed, and the Australian price is to be no more than that in the USA after allowance for currency conversion and freight costs.

Possible modifications to future IP sharing

Mr P. Walsh, Commercial Manager in CSIRO Plant Industry, noted the difficulty when various agencies involved in research funding require formal intellectual property (IP) shares in research products. With multiple ownership of IP, patents often take several years to implement. Prolonged negotiations take place between CSIRO and research funding bodies, and each has high expenditure on legal representation. Obtaining a share of IP ownership is often a goal of funding bodies, but the high transaction costs may not be justified in a social cost–benefit context.

CSIRO Plant Industry makes little money out of commercialisation of research products, with the exception of new crop varieties. One example of the recognition of this fact is that CSIRO Plant Industry policy is now not to sell computer software, but rather to make it available free of charge to industry, on a no-liability basis.

The experience of high transaction costs and low royalty revenue raises the question of whether funding bodies such as R&D corporations and Cooperative Research Centres should insist on IP ownership. Arrangements appear to vary between funding bodies, with some insisting upon IP ownership, and others (including the Cotton R&D Corporation) foregoing ownership but insisting on royalty sharing. What is important is to protect the rights of Australian primary producers with respect to products developed as a result of research projects, and this may be achievable without sharing of IP ownership. As well, royalty sharing appears possible independent of IP ownership. These matters may require further investigation from a legal perspective.

Quantitative Economic Assessment

The 'with project' and 'without project' cases

It is assumed that, had the kits not been available, tests using laboratory instruments would have been necessary for pesticide residue detection. While EIA kits would eventually have been developed elsewhere had Dr Skerritt not undertaken research supported by LWRRDC, it is probable that the kits would not have been available for several years, and not in time for the research carried out by Professor Kennedy and other researchers who have used prototype kits. As a result, much of the research carried out by the CRC for Sustainable Cotton Production using these kits would not have been attempted.

Project expenditure

As indicated in Table CS6-3, project funds were obtained from a number of sources. LWRRDC funds were used mainly to meet the salary of a technician for 2.5 years to work on development of EIAs.

Kit sales and royalties

Royalty information has been obtained from CSIRO, as provided by SDI. It was pointed out that CSIRO cannot vouch for the reliability of the sales figures; no information is available on Australian customers, let alone overseas purchasers, and CSIRO does not wish to divert staff to monitor sales given the relatively small royalty income.

Table CS6-3 Expenditure for project CPI4 ($'000)

Year	LWRRDC funds	CSIRO funds, this project	Other funds[a]	Total
1992–93	33.8	89.9	181.0	304.6
1993–94	66.2	90.4	181.0	337.6
1994–95	70.2	90.8	181.0	342.0
Total	170.2	271.0	543.0	984.2
[a] Includes a component of earlier LWRRDC grant, funding from CRDC and Millipore Australia Pty Ltd/ImmunoSystems Inc., and CSIRO infrastructure support in relation to other external funding.				

Sales revenues and royalties received for molinate kits are as in Table CS6-4. Royalty applies at a rate of 6% of sales value, of which LWRRDC is entitled to 11%. The payment of royalties does not follow this implied pattern exactly, because of agreed minimum up-front payments and time lags in payment.

Table CS6–4 Revenue and royalties from molinate sales

Year	Sales value ($US)	CSIRO royalty ($A)	LWRRDC share ($A)
1996	4579	2434	268
1997	455	317	35
1998	8930	418	46
Source: CSIRO Plant Industry			

Sales of EIA kits for other pesticides, for which this project made a contribution in development, are indicated in Table CS6-5, where values are in US dollars. As indicated, the main sales have been of DDT and diazinon test kits, with the latter already appearing to tail off.

Table CS6-5 Revenue for sales of various commercial EIA kits

Test	1996 No. sold	Revenue	1997 No. sold	Revenue	1998 No. sold	Revenue
Kit chlorpyrifos plate	7	1,827	66	29,442	4	612
Diazinon plate	92	32,833	146	65,013	60	24,903
Kit DDT soil tubes	178	36,514	333	71,015	338	85,174
Kit endosulfan plate	0	0	3	1,341	4	841
Kit parathion plate	4	474	0	0	0	0
Source: CSIRO Plant Industry						

Again royalty applies at a rate of 6%, but payments do not follow this rate exactly owing to minimum up-front payments conditions and time lags; however, these timing complexities have not been allowed for in the analysis due to difficulty in establishing exact arrangements. Based on available information, total royalties for the period 1996 to 1998 are as summarised in Table CS6-6.

Table CS6-6 Total CSIRO royalties for commercialised EIA kits, 1996 to 199

Year	CSIRO royalty (excluding molinate) (A$)	CSIRO royalty for molinate (A$)	Total CSIRO royalty (A$)
1996	2,708.294	2,434	5,142
1997	1,5886.760	317	16,204
1998	1,0621.900	418	11,040

Given the LWRRDC share of IP of 11%, the amount of royalties received by LWRRDC would appear to be of the order of $1,000 per year, and would leave little after legal and other transactions costs, and hence royalties have not been considered further in the economic analysis.

Savings in research costs

As discussed above, it is estimated that approximately 5,000 prototype kits have been used per year, most by the CRC for Sustainable Cotton Production. When carrying out EIA tests, each 96-well plate, after allowing for standards and duplicates, can assay about 30 extracts or water samples. The cost per test is about $4 (including cost of preparing plates of $2.50, enzyme reagents, resynthesis and haptens, $1, and analytical equipment $0.50). The cost of instrumental analysis varies between pesticides, with endosulfan (about $60 per assay) and DDT (as low as $40 per assay) being among the least expensive. Prices have approximately halved during the past six years. For the economic analysis, it is assumed that 5,000 tests are carried out using prototype kits each year from 1995–96 to 1998–99, and that the cost of instrumental tests falls linearly from $120 per test to $60 per test over this period. Benefits from use of prototype kits are then assumed to fall off, on the grounds that kits would have become available from other sources. Specifically, it is assumed that for the next four years (to 2002–03) the number of assays falls by 1,000 per year, with the saving per assay held constant at $56.

Natural resource management benefits

Much of the research which has been undertaken using prototype kits would not have been feasible had prototype kits not been available. In fact, some analyses for pesticides are not possible by instrumental means, because the chemicals break down before they can be brought to the laboratory. Prototype kits have been used for a wide variety of applications, including research in the cotton, rice and horticulture industries. Benefits from research using the prototype kits would include protection to human health, improved management of irrigation water and of domestic water supplies, allaying fears of chemical residues, and avoidance of unnecessary environmental regulations with associated savings in regulatory and compliance costs.

Estimation of these benefits would involve a major research effort. While the research has presumably had a positive benefit-to-cost payoff, it is difficult to judge whether this payoff would have been greater than the research costs had resort to instrumental tests been necessary. Some indication of the payoff in cotton research is indicated by Case Study 1. For the economic analysis performed here, no allowance is made for resource management benefits additional to cost savings on pesticide residue testing. That is, the implicit assumption is made that the saving in test costs is matched by the resource management benefits. This is probably a conservative assumption.

Table CS6-7. Project revenues, costs and economic performance criteria, CPI4

Year	Number of tests using prototype kits	Savings to Australian researchers ($'000)	Project expenditure ($1000)	Net cash flow ('1000
1992–93			304.638	–304.6
1993–94			337.586	–337.6
1994–95			341.957	–342.0
1995–96	5000	580		580.0
1996–97	5000	480		480.0
1997–98	5000	380		380.0
1998–99	5000	280		280.0
1999–00	4000	224		224.0
2000–01	3000	168		168.0
2001–02	2000	112		112.0
2002–03	1000	56		56.0
Net present value ($'000) = 705.0 Internal rate of return (%) = 24.7 Benefit–cost ratio = 2.0 Assumptions				
Discount rate		7%		
Number of kits sold in 1995–96		5000		
Sale price instrumental test, 1995–96 ($)		120		
Sale price instrumental test, 1998–99 ($)		60		
Cost per EIA test ($)		4		

Benefits from training researchers

The prototype kits have been used extensively in undergraduate and postgraduate training at the University of Sydney. The saving in costs of these tests is included in the savings of research costs mentioned above. It is probably that this training would not have been affordable if only instrumental tests were available.

Estimated economic performance criteria and sensitivity analysis

Table CS6-7 summaries the economic analysis for this project. An NPV (at a 7% discount rate) of $700,000, internal rate of return of 25% and a B/C ratio of 2.0 are obtained.

Table CS6-8 provides a sensitivity analysis with respect to discount rate and number of assays performed using prototype kits. Numbers of assays in each year varied in proportion to that in 1995–96. As indicated in this table, if the number of assays performed with prototype kits is higher than assumed, the research payoff will be considerably increased. Varying the discount rate above or below 7% has only a moderate impact, because the project benefits are assumed to continue until 2002–03 only.

Table CS6-8 Sensitivity of NPV to discount rate and number of assays performed, CPI4

Number of EIA tests performed in 1995–96	Discount rate		
	4%	7%	10%
2500	–11	–107	–184
5000	924	705	526
7500	1858	1517	1236
10000	2793	2329	1946

Limitations of the analysis

The major limitation of the analysis is lack of information about the resource management benefits arising from use of the prototype kits in Australian research projects. The benefits of using the assays have been estimated in terms of savings relative to use of instrumental kits, but the research could have much higher payoff in terms of improved environmental management. Similarly, training benefits have been valued at savings relative to instrumental tests only, and may be underestimated.

There is potential for the royalty income for this project to increase, but because of to the uncertainty of this and small amounts received to date no allowance for royalties has been made in the economic analysis.

Changes in economic performance criteria relative to previous evaluation

The estimated payoff is slightly lower than in the previous evaluation. The use of prototype kits has far exceeded expectations, and has allowed broad ranging research to be carried out on pesticides residues. Resource management benefits, included as a separate category in the previous update. have been absorbed in this research cost saving.

In contrast, the anticipated royalty revenue, which was expected to be a major payoff item of the project (although this view was not advanced by the researchers) has not been forthcoming to date and probably will not eventuate.

Discussion and Conclusions

The rate and level of adoption of research outputs has been unexpectedly rapid, due to the need for sensitive and low-cost pesticides tests by other researchers. In the absence of project CPI4, it would have probably been some years before similar tests became available. The testing has tended to concentrate on a small number of pesticides, and in particular endosulfan and DDT.

Relative to the previous update, there have been striking changes in relative benefit levels for this project. Non-commercial use (by resource management agencies) has far exceeded commercial use by farmers and industry.

The commercialisation outcomes have been disappointing, with Australian farmers not gaining access to EIA tests at reasonable convenience and price. However, this has been a matter outside the control of CSIRO. The low royalty returns raises issues of transaction costs relative to social benefits from multiple ownership of intellectual property as distinct from royalty sharing.

Reference

Kennedy, I. (1999), University of Sydney, email correspondence.

9 Case Study 7: Compaction Control and Repair Practices for Cropping Lands in the Sub-Tropics (QPI14)

Research Organisations:
Department of Natural Resources, Rockhampton, Biloela and Emerald, Queensland

Principal Researcher:
Dr D.F. Yule and Mr B.J. Radford

Executive Summary

This is a large collaborative project with funding from LWRRDC and the Grains Research and Development Corporation (GRDC), and with linked projects funded by the Cooperative Research Centre for Sustainable Cotton Production, the National Landcare Program (NLP) and the Natural Heritage Trust (NHT); total expenditure is about $5 M. Soil compaction and repair trials have been carried out on research stations, and controlled traffic farming (CTF) trials conducted with a number of farmer cooperators.

Various complexities in making CTF functional have been addressed, and an integrated farming system has been developed, which differs radically from traditional tillage management. This project, and another at the University of Queensland Gatton College, have been the precursors to considerable adoption and research elsewhere in Australia. Uptake has been more rapid than predicted, and approximately 0.5 M ha are now managed under CTF in Australia.

Continued research has provided further evidence of cost savings, yield increases and environmental benefits of CTF. Mechanical soil compaction has been found to result in long-term yield depression. Cattle grazing on stubble when soil is wet has been found to reduced yield in subsequent grain crops. This project is predicted to have substantial economic benefits, with an NPV (at a 7% discount rate) of $41.2 M, benefit–cost ratio of 8.5 and IRR of 41%.

Background

Soil compaction has been recognised to substantially increase cropping costs and reduce yields on heavy clay soils such as those in central Queensland. A Queensland Department of Primary Industries project was developed to examine compaction control and repair practices. This was extended into a project concerned with controlled traffic systems, which involve:

> "… use of permanent wheel tracks throughout the cropping and fallow cycles. Ideally this should include all load carrying wheels, but header incompatibility usually means that only the tractor and spray boom traffic runs on the permanent wheel tracks" (DPI, 1998, p. 1).

Elimination or reduction of tillage associated with CTF only became a workable technology in the early 1970s when suitable herbicides became available for chemical rather than mechanical weed control, including Gramoxone™ then Roundup™[1]. The equivalent system of 'precision traffic' in the USA has not been widely adopted. The colder climate and shorter growing period (typically about 120 days) reduces the scope for opportunity cropping, and typically soils are not as prone to compaction.

Cultivation down the slope rather than on the contour goes against traditional soil conservation practice in dryland farming, hence uptake was initially cautious. CTF is not well suited for uneven land with irregular contours. Major advantages are: elimination of the need to till areas compacted by tractor and implement wheels; more timely access to fields after rain; and greater precision in machinery use (increasing field efficiency and allowing night spraying).

Commencement of a controlled traffic system generally means matching wheel widths for the planter and sprayer. For planters narrower than 12 m, the spray boom is often a multiple of two or three planter widths. It is notable that some farmers — particularly those who have been practising CTF for some years — are now using headers with compatible wheel widths.

Project QPI14 commenced with an emphasis on control and repair of soil compaction. Partly in response to a

1. Gramoxone and Roundup are trade names for the herbicides paraquat and glyphosate, respectively.

request by LWRRDC for an extension component, the project was broadened to examine CTF systems. Consequently, the project comprised a number of distinct but related components, including field experiments on soil compaction and repair — at the Biloela and Emerald DPI research stations — as well as research into CTF systems by cooperating farmers, research into impacts of soil compaction by grazing animals (at the Brigalow Research Station), and an extension program.

Nature of the Project

Agreed objectives

The stated objective of this project has been to improve soil management in the sub-tropical zone through development of compaction and run-off control techniques. Specific tasks were to:

1. measure the effect of compaction by farm machinery and grazing animals on soil properties and crop performance across soil types;
2. compare mechanical and biological ways to rejuvenate compacted soil;
3. develop soil management and machine use guidelines together with farm layouts to repair soil compaction and to control runoff on sloping lands;
4. integrate findings into farmer-acceptable whole system technologies and measure on-farm performance and crop and soil responses; and
5. extend soil management principles for the sub-tropical zone by contributing to packages such as SOILpak.

Progress and Achievements

Project delays and budget changes

An extension of six months to December 1998 was allowed, because of the late commencement of the project. Field trials were completed in July 1998, although residual effects of compaction are still being evaluated at the Biloela Research Station. Continued funding for extension has been obtained from non-LWRRDC sources.

Progress with respect to agreed objectives, milestones and technical outputs

Soil compaction experiments

Controlled experiments to determine the effect on soil properties and crop performance for a range of tillage treatments have continued at the Biloela and Emerald DPI research stations. Annual compaction with header tyres on wet soil generally reduced the amount of water stored in the soil at sowing compared with the control treatment, and this resulted in reduced grain yields (Radford and Yule, 1998). Annual compaction significantly reduced establishment, dry matter at anthesis and harvest, and grain yield in grain sorghum (DNR, 1997). It has been found that water run-off is reduced by about 30% in non-compacted soils.

Compaction repair by crop or pasture roots can only be effected with suitable machinery for planting in compacted soil. Although costly, this option appears preferable to deep ripping, which is also costly and delays cropping. Crops with fibrous root systems such as wheat have proved most effective in repairing compaction.

Modelling and simulation by Mr F. Chudleigh at Emerald, based on results of soil compaction trials at Biloela Research Station, have indicated that under zero tillage there is a risk that returns can be reduced due to lower wheat protein. This is a general problem in wheat growing, where "a substantial proportion of the cereal crop is now N deficient [due to removal with crops] resulting in failure to achieve its yield potential, lower grain protein and reduced profit. The amount of wheat delivered that is now downgraded [from prime hard] to hard, ASW or feed grade is increasing …" (Felton and Marcellos, 1999, p. 167). Increased nitrogen fertilizer is needed to avert this problem.

Refinement of controlled traffic farming systems

On-farm trials and supporting research have continued with a view to developing integrated controlled traffic systems, and this has provided further evidence of the applicability of this tillage approach:

Soil management and machine use guidelines have been refined. A requirement for adoption of CTF is a robust narrow-tyned high-clearance planter. Conversion of existing farm equipment is possible to avoid large outlays.

Major rainfall events have provided the opportunity to compare soil loss under CTF and traditional cultivation. In recent extreme rainfall events, CTF land on the Liverpool Plains (NSW) and at Chinchilla (Qld) was not severely eroded. Aerial observation and interviews with farmers in relation to a major erosion event in central Queensland in February 1997 revealed that CTF performed well. Run-off appears to be reduced by about 30% and soil loss consequently reduced. Cannon (1998, p. 4) describes the use of aerial surveys to provide a rapid assessment of erosion damage caused by over-design rainfall events on central Queensland farms. He concluded that "The installation of CTF across the affected areas would have reduced in-paddock soil movement by at least 90%". Mailler (1998, p. 183) noted that wheat harvesting "became quite difficult in the contoured country as I bounced from one wash to the next. At the time I was wondering how effective these contour banks were as there were a multitude of rills coming across the contour bay before spreading out in a silt fan in the bottom of the contour".

It is now possible to assert in extension literature that CTF increases crop yields and frequency of opportunity cropping, reduces operating costs, and reduces soil loss (as stated by Chapman and Powell, 1998).

CTF offers advantages in weed and insect control. In particular, spraying at night becomes more possible, with consequent reduction in evaporation and hence amount of chemical required. In some weather, spraying during the day is not possible because of drift and evaporation.

CTF requires increased management skills of farmers and farm workers, including improved tractor driving skills and improved ability to mix chemicals to control a variety of weeds.

Research on automated guidance systems (at the University of Southern Queensland) was discontinued, because of difficulties in implementation, and superiority of global positioning systems (GPS) over in-field markers. However, GPS remain too expensive for most farmers, and further development of guidance systems is needed. In the future, GPS could assist, or reduce the need for, controlled traffic systems.

The current focus on CTF concerns crop agronomy (improving yields) and reducing soil loss. Limited soil moisture has become less of a limit to cropping. Increased use of paddock records and soil testing is expected, together with environmental management systems (quality assurance, world best practice). More attention may be given to planning tillage systems at a whole farm level, with the philosophy of "Control the water, control the wheels!".

Large-scale farmers and their consultants are likely to carry our much of the research into CTF. If a "weed activated sprayer" can be developed, this could greatly reduce herbicide use and cost.

Trials on soil compaction due to livestock

Field trials revealed that "the management practice of grazing sorghum stubble when the surface soil is dry had no detrimental effect on the physical properties of this grey clay soil or on subsequent crop establishment and yield. The cattle reduced ground cover but provided a means of killing the sorghum regrowth" (DNR, 1997, p. 6). On the other hand stubble grazing under wet soil conditions led to reduced yield of the following crop (Radford, 1998). Hoof action can affect soil physical properties to a depth of 45 cm. These findings imply that stubble grazing under dry or drought conditions can save a spray application without yield reduction, but landholders would be advised to at least temporarily move stock out of stubble areas in the event of rain. As a result of this research, two graziers decided not to graze stubble.

Negative or inconclusive results

Although there have been many converts to CTF, change from contouring and working on the contours to working up and down the slope goes against many years of extension advice and accepted wisdom, and some scepticism remains. Some adopters have not appreciated the erosion control message from the central Queensland work. Some farmers want to plant their wheel tracks, having the perception these areas will erode. There is also concern over weed growth in wheel tracks, where weeds can be hardier and less likely to be killed by low-dose herbicides.

Rummery and Coleman (1999, p. 54) note a reduction in flexibility of expenditure timing with CTF:

> "the conventional farmer has to ability to choose when to update machinery infrastructure and often delays such decisions until a favourable season whereas the minimum tillage farmer must be able to finance this months chemical bill now".

Related research

Several related research projects have been initiated in Queensland and other States. Some of the Queensland projects include:

A project on "Minimizing Soil Erosion in Dryland Cotton" has been carried out at Emerald, funded by the CRC for Sustainable Cotton Production, and is due for completion during 1999. This project has demonstrated that soil loss on long downslope runs (600 m) is not high in extreme rainfall events.

A project on "Sustainable Farming Systems", being funded by GRDC to the extent of $3 M over 5 years, involves measuring soil loss on farm demonstration sites. The CTF researchers we will instrument for run-off, soil loss and pollutants at a contour bay scale. An economist (Mr Fred Chudleigh) is involved with this work.

Further work by the CFT team, being supported by Queensland Government (Special Treasury) funding, is concerned with 'cascading catchments' or measuring the downstream impacts of cropping through placing instruments in creeks and waterways.

Natural Heritage Trust funding has supported employment of extension officers, including W. Chapman, S. Cannon and F. Anderson.

A DNR special project is being carried out on "Large Scale Assessment of Soil Erosion", using aerial surveillance and ground truthing to monitor erosion after storms throughout Central Queensland.

A research group including Mr Tony Peterson (DNR Soil Conservation, Miles) and Dr David Freebairn (DNR, Toowoomba) are undertaking a GRDC funded project on “Speeding Adoption of CT on the Downs”.

Conservation Farmers (Confarm) is undertaking an NHT-supported controlled traffic adoption study.

Following a conference at the University of Queensland Gatton College (Tullberg and Yule, 1998), a national forum was formed, which is seeking a GRDC “national coordinating network grant” for CTF. A person is to be employed as information source and extension coordinator, and to encourage the machinery industry to make machinery available on a common rear-wheel track width.

Communications and Technology Transfer

Potential adopters

Soil compaction management and repair practices are relevant to a wide cross-section of dryland cropping, including major grain crops. CTF has particular appeal on heavy clay soils with high compaction potential. These are widespread in central Queensland. The target adopters are dryland farmers in central Queensland growing wheat, sorghum, cotton, sunflower, mung beans and chick peas. However, it has become recognised that the technology has wide application in Australia and overseas. The conditions under which CT is not suitable have been more clearly identified; in particular, uneven land with variable slope direction is less suited than long and uniform slopes. For sandy soils with little compaction problem, costs of conversion to controlled traffic may not be warranted. In colder climates where the growing season is too short for opportunity or double cropping, benefits will also be reduced.

Technology transfer strategies

The major technology transfer measures in this project have included:

- appointment of an extension officer, Mr Wayne Chapman, with NLP funding, based at Emerald. The extension team has been expanded to include Mr S. Cannon and Ms F. Anderson, and has been supported by NHT funding, and now has capacity to work with about 280 farmers. The team addresses farmer groups and produces extension literature. A one-week trip for Emerald farmers to Biloela, Gunnedah and Moree was conducted in February 1999. A newsletter series called CFT — Keeping on Track has been introduced (DNR, 1998–99). It provides technical information and notices of field days and tours, workshop reports, competitions, and other items of general interest;
- on-farm trials have continued, and this is considered more influential with other farmers than research-station trials;
- the principal investigators and extension officers have presented research findings at workshops and meetings of Landcare and other farmer groups;
- the planter modified for zero till for compaction trials at the Biloela Research Station has been hired out to farmers at a low charge. The planter has been found to work well when heavy trash remains in the field, and has allowed farmers to ascertain for themselves that planting is possible under these conditions if suitable machinery is available; and
- a video has been produced to demonstrate CTF and explain the advantages of this tillage system.

At the previous update, some caution was being exercised in promoting CTF systems because of lingering concerns that farmers may not be able to manage their complexity , and that adverse outcomes such as severe soil erosion events may lead to negative publicity. Over time, as adopters have expressed a high degree of satisfaction with the technology, extension activities have been stepped up. Most Central Queensland crop farmers should now be aware of controlled traffic farming.

Developments outside (but in some cases assisted by) the project have taken place which have also had a major effect on adoption:

- an ABC Lateline program, repeated in Best of Lateline, has been highly influential in raising awareness of CTF among the farming community;
- consultants to farmer groups have become interested in CTF, and have arranged for their clients to inspect farms which have adopted the technology. Of particular note have been three field tours by NSW farmer groups and their consultants from the Walgett area to Queensland, including two trips to central Queensland. Adoption of CTF has been favoured in western NSW by large tracts of relatively flat land, and the lack of soil conservation support, with government playing mainly a regulatory and custodial role;
- a private consultant (Mr Mailler) has established a field layout design service, charging about $1.40 per hectare. It is probable that, in the future, more of the services associated with CTF will be provided by contractors;
- machinery firms have begun to assist adoption by providing machinery items with a common wheel track or common multiples of distances, and machinery dealers have supported modification of machinery to a consistent rear-wheel track width and warranties for modified machinery;

- herbicides have become progressively less expensive relative to machinery purchase and operating costs, favouring substitution of chemical for mechanical weed control; and
- the proposal to GRDC for a "national coordinating network grant" to support a full-time extension coordinator if successful will further assist technology transfer.

Adoption progress

Farmers are in general highly supportive of CTF. This goes well beyond the initial six cooperators (Rod Birch, Lyall Swaffer, Ian Buss, Murray Jones, Charles McDonald and Bob Mathieson). The adoption rate has been considerably more rapid than predicted. This appears to have been an outcome of the technology transfer program, of reduced farmer tolerance of soil loss, and relative falls in herbicide costs.

In the past, about 10% of farmers interested in controlled traffic were testing systems by themselves; this has now risen to 40–50%. Also, some consultants are providing field design and other advisory services. Hence, it is no longer possible for the principal investigators or extension officers to closely monitor the rate of adoption.

Figure CS7-1 indicates number of farmers "seriously interested" in CTF and the area under this tillage system in central Queensland. About 220 growers have adopted, are in the process of adopting or have expressed strong interest in CTF, and DNR has had contact (usually on-farm visits) with about 70% of them. The area under CTF has increased rapidly, to a current level of about 36,000 ha. The principal investigators anticipated that, by 2000, there may be 200 adopters in central Queensland, with an average area of 1,200 ha under CTF, for a total area of 240,000 ha. There are about 800,000 ha of crop land in central Queensland, but only 500,000 is cropped each year.

CTF has been adopted by some farmers on the western Darling Downs, from Goondiwindi west to St George, north to Roma and around Chinchilla. Also, 200,000 ha is under CTF (growing wheat, sorghum, and other dryland crops) in the Liverpool Plains area of NSW, with adoption extending as far south as Dubbo. Controlled traffic has also become popular in Victoria and WA, where the designs are rather different, and involve "raised bed" systems, with wheel tracks also serving as drains. Australia-wide adoption has been estimated at about 0.5 M ha (Tullberg, 1999), although in many cases the CT systems are sub-optimal and will not be refined until normal machinery replacement ages. The goal nationally is 5 M ha in 5 years, or about a quarter of the national dryland cropping area.

Adoption elsewhere in Queensland and in other States is the result, in part, of research activities in QPI14 and technology transfer activities of the principal investigators and extension team. Although other work was being carried out on controlled traffic (notably the work of Dr Tullberg at UQ Gatton), had the central Queensland soil compaction and controlled traffic research not been carried out, the benefits of adoption elsewhere in Australia probably would not have eventuated, or at least would have been delayed for a number of years. However, it must be recognised that a number of other factors contributed to adoption. If, for example, one were evaluating the performance of the NSW consultants to farmer groups, some credit would be given to them for adoption by their clients. Also, it is notable that research programs have established in other districts and States, and these have played an important role in local adoption.

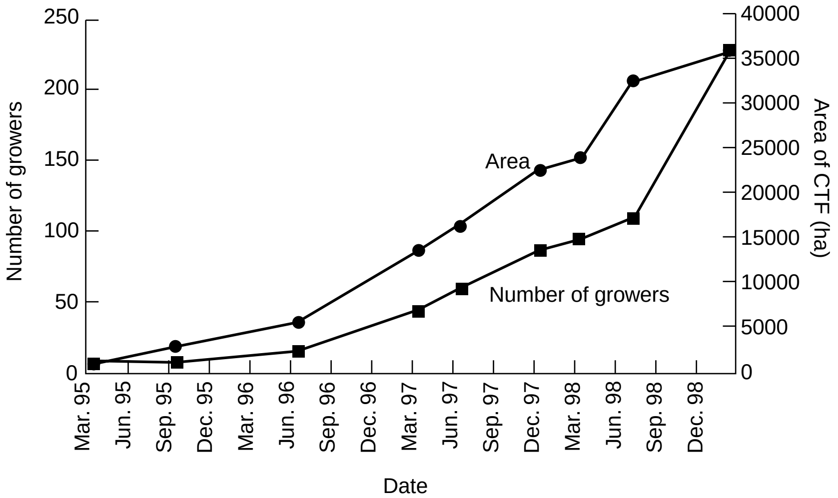

Figure CS7-1. Adoption progress of CTF. The lower line represents number of growers. Source: W. Chapman, Emerald.

Workshops, conferences and publications

Many conferences have been held recently, and research and extension papers written, on CTF. Most notable are the Second National Controlled Traffic Conference (Tullberg and Yule, 1998) and the Second National Conservation Farming and Minimum Tillage Conference (Burgis and Ridge, 1999). A conference of the Society of Engineering and Agriculture was held at UQ Gatton, where agreement was reached on CTF as a national focus for engineers.

The *CFT: Keeping on Track* newsletter produced by DNR Emerald, which originally appeared only occasionally, is now published more regularly. Various media articles have been produced.

Mr Chapman has presented various talks on controlled traffic, and provided an input to the Engineering in Agriculture Search workshop, where CTF was the only agreed-upon national initiative. A simple exposition of the nature and benefits of CTF has been prepared by Mr Chapman (in collaboration with Mr G. Powell) as one of the Crop Link Information Series brochures (DPI, 1998). Mr Radford gave a talk to the Theodore Landcare Group. A training workshop on CTF was held for 25 DNR and DPI staff. It is intended to produce a videotape on CTF, which could draw on an earlier short video by Dr Tullberg, the Lateline program, and aerial footage of run-off immediately following storms. No major CTF manual has been produced to date.

Quantitative Economic Assessment

The "without project" case

The "without CTF" case could be traditional tillage (TT) or zero tillage (ZT). Which of these applies has a major impact on costs, because the most expensive capital item for both ZT and CTF is a robust high-trash-clearance planter. An issue which arises in evaluation of this project is the extent to which the benefits of zero (or minimum) till would have eventuated if CTF had not been introduced. While zero till can be introduced without CTF, in practice adoption of ZT was relatively slow and partial, even with relatively lower prices of herbicides. When the project commenced, an area of approximately 10,000 ha in central Queensland was operated under ZT, and periodic mechanical weed control was carried out on most of this area. Introduction of CTF has been associated with a trebling of the area under ZT. Tullberg (1998, p. 3) notes that "the majority of farmers adopting controlled traffic have also taken the opportunity to reduce tillage". In this analysis, an attempt is made to separate out the economic impacts of ZT and controlled traffic.

Project expenditure

Project QPI14 was extended six months to December 1998. Even now the LWRRDC project is completed, considerable expenditure is continuing on technology transfer, including time and travel costs of the principal investigators and extension officers, and infrastructure support for them. Field trials on residual impacts of soil compaction at the Biloela Research Station are yet to be finalised. It is probable that extension expenditure will continue for several years. It would be inappropriate to include projected adoption of CTF without allowing for these continuing costs. A rough approximation to this expenditure would be 50% of six salaries plus on-costs, averaging about $65,000 per person (a total of about $200,000 per year), plus $50,000 in vehicle costs, other travel expenses and consumables per year. These costs are assumed to run from 1998–99 to 2001–02 (Table CS7-1).

Table CS7-1 Expenditure for project QPI14 ($1000)

Year	LWRRDC funds	GRDC funds	NLP funds[a]	Third party[b]	Research organisation (DNR)	Further extension support[c]	Total
1992–93	117.4	7.5		52.5	210.9		388.3
1993–94	163.1	42.5		115.0	421.7		742.4
1994–95	177.0	62.5	67.6	131.0	426.0		864.1
1995–96	183.6	55.0	64.6	137.0	430.1		870.3
1996–97	186.3	47.5	64.6	142.0	430.0		870.4
1997–98	89.0	20.0	25.3	73.5	215.0		422.8
1998–99					50.0	200.0	250.0
1999–00					50.0	200.0	250.0
2000–01					50.0	200.0	250.0
Total	916.4	235.0	222.1	651.0	2283.7	600.0	4908.2

[a] For extension program.
bCSIRO Soils, University of Southern Queensland, University of Central Queensland and National Landcare Program.
[c] Includes Natural Heritage Trust.

Adoption expenditure

A number changes in costs and revenues arise with introduction of CTF, as indicated in Table CS7-2. The major adoption costs are expenditure on field layouts and replacement or modification of machinery. Field layout work involves surveying and hire or purchase of a marking system for row placement (costing about $3,000–$10,000), and modification of contour banks where present to 'drive over' condition.

When switching from conventional tillage to ZT or CTF, some farmers spend a large amount on new tractors, planters and spray equipment. Similarly, farmers replacing machinery who continue with traditional tillage sometimes spend very large amounts on new machinery. A ZT planter can cost approximately $100,000. However, it is possible to introduce CTF with only a modest additional capital outlay, by delaying purchase of new machinery until normal replacement age of existing items, or by modifying existing machinery and equipment. At a minimum, the tractor, planter and spray rig need to be on the same wheel track width. A further step will be to convert grain headers to the same rear-wheel track width. Up to 12 central Queensland farmers are now considering adopting common wheel tracks for headers and other machinery.

The change in machinery outlays will depend on how rapidly CTF is introduced, and how 'handy' the grower is in terms of modifying machinery. Rather than outlay up to approximately $80,000 to $100,000 for a ZT planter, it is sometimes possible to modify an existing chisel plough or gyral seeder. DPI (1997) describe a conversion of a chisel plough to a ZT planter at a cost of $8,000, including $3,000 for a seed and fertilizer box.

Potentially, there can be a large saving in tractor costs when switching to CTF. Tullberg (1998) argues that 25% of tractor power "is dissipated in soil deformation under the tyres" and 30% in re-loosening wheeled soil, and that it is possible to reduce energy requirements for tillage operations by 50%. He notes that "farmers are sensibly cautious about reducing the margin of safety offered by a larger tractor, but many long-term controlled traffic farmers can demonstrate the economic benefits of reduced tractor size" (p. 2).

It is possible to make an approximately $60,000 reduction in cost of the tractor — from $150,000–$180,000 to $110,000–$130,000 — by replacing four-wheel drive by front-wheel-assist. Changeover appears to usually take place at about the time a farmer would normally replace his tractor. Some farmers say they can keep a tractor running with ZT, whereas they would have needed to make a change under

Table CS7-2 Economic impacts of controlled traffic farming

Cost and revenue category	Specific items	Nature of change
Capital outlays	Field layout	Increased cost
	Switch to compatible wheeltracks	Increased cost
	Power requirements	Reduced cost
	Reduced contour bank construction	Reduced cost
Operating costs	Increased field efficiency (less overlap)	Reduced cost
	Fuel and oil (less rolling resistance and drawbar pull)	Reduced cost
	Herbicides	Increased cost
	Insecticides	Reduced cost
	Fertilizer	Increased cost
	Transport costs	Increased cost
	Reduced machine operator labour	Reduced cost
	Higher labour skills required	Increased cost
	Reduced contour bank maintenance	Reduced cost
Crop revenue	Yield increase	Revenue increase
	Possible downgrading of wheat	Revenue reduction
Environmental benefits	Reduced soil erosion	Reduced economic cost
	Increased herbicide use but reduced insecticide use	Probably little impact on-farm
	Reduced fuel use	Reduced CO_2 emissions
	Reduced downstream transport of sediment and pesticides	Reduced off-site costs

conventional tillage. Hence, there can be a reduction in capital cost. As well as the reduction in capital cost, there can be a saving of 2 to 4 hours of tractor time per hectare, for which the cost is about $5/hour.

Rummery and Coleman (1999, p. 54) note “It is still early days but we believe the controlled traffic minimum tillage farmer will have less capital tied up in plant than his conventional tillage counterpart”. In other words, it appears probable that there will be some up-front cost in changeover to CTF but overall there will probably be a reduction in expenditure on machinery. For the purposes of this analysis, it is assumed that the change to CTF is cost neutral in capital outlays.

In the following analysis, it is assumed that the there will be field layout costs of $1.40/ha, and additional tractor expenditure of $24,000 and purchase of a marker system for $4000, for a cropping area of 1200 ha, or an additional overhead cost of about $25/ha.

Crop yields

Views differ as to crop yield impacts. Reduced soil compaction, improved soil structure and reduced soil erosion favour higher yields, as should greater flexibility in timing of planting, and ability to spray at night. Tullberg (1999) notes that improved trafficability allows operations to start one to two days earlier after rain, and this could allow more timely insect and weed control. Tullberg (1999) reports that “a wide ranging review of research on the impact of soil compaction on crop yield in Australia indicated a best overall estimate of 10–15% yield reduction”. Tullberg (1997, reported by George, 1998) reports an increase in yield response to controlled traffic of 22.8% for wheat, 5.0% for sorghum, 14.9% for maize, over a three-year period. He estimated a saving in tractor costs of $10 to $20 per ha, about half of which is for fuel, the rest presumably being overheads. He suggests that the additional water infiltration is worth $10–$20/ha in extra yield. Where “raised bed” systems of controlled traffic are adopted, these are likely to increase yield due to a reduction in waterlogging.

A number of farmers share the view that CTF will give rise to yield increases.

Grant (1998, p. 176) states that as a result of a combination of zero till and controlled traffic “our yields have improved 40%–50% in above average seasons and 30% in below average seasons and our cropping frequency has dramatically increased”.

Ball (1998, p. 138) similarly states “Above average year yield increases 40–50%; below average year yield increases 30%”.

Brownhill (1998, p. 174) endorsed CTF, noting a 33% reduction in spraying costs, mainly from reducing overlapping. He concludes “… why has there been such a massive adoption of controlled traffic. And the answer is simple. It’s common sense combined with a small outlay for a major financial gain”.

Krampl (1998, p. 177) notes yields increases of 10–15%.

Mailler (1998, p. 183) notes a gain in yield of “the part of the crop that would normally be double planted and suffering because of that”.

Increased opportunity for double-cropping (including ratoon cropping of grain sorghum) has been further confirmed as a major economic benefit of controlled traffic. As well, it has been argued that controlled traffic turns marginal cropping country into more economic cropping farming country, and there could be an increase in cropped area as a result, though this has not been included in the economic analysis.

Other farm and off-farm costs and benefits

The impact of introducing CTF on variable costs is complex to analyse. Relative to traditional tillage, reduced frequency of tilling, reduction in compaction and increased field efficiency should lead to a reduction in fuel costs, while spraying of weeds will increase herbicide costs. Ability to spray at night would tend to reduce pesticide costs. If the air temperature is greater than 27˚C, there is evaporative loss and reduced herbicide efficiency. In windy conditions, spray drift makes spraying impossible.

Tullberg et al. (1998) report that “each of the economic assessments of controlled traffic [has] demonstrated advantages in the range of $100–$150 ha/year”. Cash savings of between $18 and $40 per hectare have been reported (DPI, 1988).

An analysis of farm records in the Walgett area of NSW yielded the information shown in Table CS7-3. The minimum tillage here did not necessarily correspond to CTF, comprising a variety of transitional tillage states. This table indicates a slight increase in variable crop expenses per hectare (between about $3 and $36) and a large increase in crop income per hectare (between $70 and $150).

Further evidence of impacts on variable costs is provided by reports from adopters:

Birch (1999) notes an increase in field efficiency of 15% because of reduced overlap in crop operations, with a consequent saving of 15% in seed, spray and labour, which he equates to $27/ha.

Table CS7-3 Cost of production and gross margin for conventional and minimum till, averaged over 1995 to 1997

Tillage system	Item	Crop		
		Wheat	Sorghum	Chickpeas
Conventional	Expense ($/ha)	115.22	116.35	141.54
	Income ($/ha)	294.66	313.57	177.37
	Cost of production ($/t)	85.84	63.79	276.15
	Gross margin ($/t)	179.55	179.79	35.72
Minimum till	Expense ($/ha)	126.43	119.63	178.10
	Income ($/ha)	435.65	385.87	326.40
	Cost of production ($/t)	55.02	49.29	154.51
	Gross margin ($/t)	309.19	266.23	148.04

Mailler (1998) notes a reduction in trafficked area of 18% in changing from working as separate contour bays to working up and down the slope.

Krampl (1998, p. 177) notes that under CTF he has reduced the number of permanent staff from four to three, and the fuel bill has fallen by one third.

On the negative side, there is a risk of lower wheat grade when increased yield leads to depressed protein content, and this can reduce the wheat price by $50/tonne. This cost can be averted by increased fertilizer application. Another potential cost is that successful operation of CTF probably requires higher farming skills than conventional tillage, eg. for precise tractor driving and formulating chemicals to control multiple weed species, and some intractable weeds on the tracks. This could involve extra cost in training farm workers.

Economic flow-on effects of CTF

There have been identifiable changes in relative demands for farm inputs in recent years, at least in part associated with adoption of CTF. Sales of 'new iron' including chisel ploughs and of rubber tyres have decreased, and sales of herbicides and fertilizers have increased. These changes have affected incomes of farm supply firms. It would be difficult to isolate the extent to which these changes are the result of CT research, and they have not been taken into account in the economic analysis.

Environmental benefits

Soil erosion has been the greatest challenge in development of controlled traffic systems. It is a major problem in central Queensland, where in 1994, a small flood in the Fitzroy River carried six million tonnes of suspended sediment out to sea. Reduced use of fuel would reduce greenhouse gas emissions. Better targeting of insecticides should reduce insecticide use and transport off-site. Reduced soil erosion should lead to reduced off-site costs such as transport of agrochemicals to riverine environments, siltation of water storages and roadways, flood damage and water treatment costs. Ability to operate spray equipment sooner after rain could make groundrig spraying a more viable alternative to aerial spraying, with potential to reduce off-target spray drift.

The environmental benefits in terms of reduced soil loss appears to have been greater than previously realised. Also, the research has led to farmers being more conscious of soil loss and more vigilant to adopt farming systems which reduce soil loss. Tullberg (1999) argues that "controlled traffic will reduce soil erosion under most conditions". Birch (1999) also believes soil erosion is reduced:

> "By not working on the contour but working down the hill it has helped to reduce the amount of soil movement. No longer do we have water moving around the contour until it finds a depression, then tearing down the hill, deepening the depressions and moving lots of soil. We now have run off moving down individual rills in lesser quantities with much less soil movement" (Birch, 1999, p. 140).

Training benefits

This project has involved use of a number of postgraduate students. Through a substantial training component, it has provided an opportunity for them to gain research experience. Training has taken place in a multidisciplinary team environment.

Parameter values for economic analysis

Parameter values as in Table CS7-4 are adopted in the economic analysis. The yield increase is taken as 10%, and the increase in frequency of opportunity cropping as 16.7%. It is assumed that variable costs increase by $20/ha/year. This is a conservative estimate given that most observers appear to believe that variable costs fall. However, these observers may not have included all relevant costs, such as the need for increased fertilizer and more skilled machinery operators. Also, the estimates of cost reduction may have not used the same 'without project' case as here, including relatively lower prices of herbicides and partial adoption of ZT. In fact, many of the cost savings may have been attributed to ZT, but without the machinery expenditure for ZT being taken into account.

A project life of 20 years has been adopted for the analysis. The influence of discounting means that extending the planning horizon beyond 20 years would have little effect on the performance estimates.

Table CS7-4 Parameter values for economic analysis, QPI14

Variable		Expected value
Base CQ area to benefit (m ha)		0.50
Proportion of area	Crop	
0.44	Wheat (t/ha)	1.00
0.44	Sorghum (t/ha)	1.40
0.04	Sunflower (t/ha)	2.00
0.04	Cotton (bales/ha)	2.50
0.02	Chick peas (t/ha)	0.65
0.02	Mung beans (t/ha)	0.80
Crop price		
Wheat ($/t)		150.00
Sorghum ($/t)		100.00
Sunflower ($/t)		300.00
Cotton ($/bale)		400.00
Chick peas ($/t)		420.00
Mung beans ($/t)		420.00
Gross revenue per hectare ($)		203.78
Marginal increase in yield (%)		10.0
Area benefitting from opportunity cropping (%)		16.7
Increase in variable costs ($/ha)		20.00
Level of adoption (% of area to benefit)		
1996–97		2.00
1997–98		4.50
1998–99		8.00
1999–00		15.00
2000–01		25.00
2001–02		40.00
2002–03		50.00
2003–04		50.00
2004–05		50.00
2005–06		50.00
2006–07		50.00
Offsite erosion control benefits		
Extent of reduction (%)		20.00
Annual erosion cost ($/ha)		100.00

Net cash flows have been derived as in Table CS7-5 (where data for only the first 10 years are presented). The project generates an expected NPV (at a 7% discount rate) of $41.2 M, an internal rate of return of 41% and a benefit–cost ratio of 8.5. These performance criteria are sensitive to discount rate, although even for a discount rate of 10% the NPV is still large, at $28 M. These estimates are conservative in that no allowance is made for impact of this project on adoption of CTF elsewhere. For example, even if only $20/ha/yr of the benefits over the 200,000 ha adoption on the Liverpool Plains in NSW were taken into account, this would increase the net cash flow by $4 M a year. Taking this benefit as commencing 1998–99, another $35 M would be added to NPV.

Sensitivity analysis has been carried out on several cash flow variables. As indicated in Table CS7-5, the estimated NPV is highly sensitive to the discount rate, although the benefit–cost ratio remains high even at a 10% discount rate. Table CS7-6 indicates that NPV is quite sensitive to a number of parameters concerning cropping area, yield and cost effects, and offsite benefits, although the NPV remains positive over wide ranges of these parameters when adjusted individually. It is notable that if variable costs fall, the NPV could be substantially increased. In general, the economic performance of the project appears robust to downside risk in terms of lower yields, smaller gains in opportunity cropping, and reduced off-site benefits.

Limitations of the analysis

While greater confidence is being gained in changes in crop physical and economic performance under CTF, a high degree of uncertainty remains concerning impacts on machinery outlays and variable costs.

The analysis does not include benefits from greater understanding of soil compaction processes and prevention and repair practices outside the CTF context, or benefits from improved management of stubble grazing to avoid yield reduction in subsequent crops. Also, no allowance is made for benefits of adoption of CTF in other areas of Queensland and in other States.

The estimate of benefits from reduced soil loss is rather speculative. While the understanding of soil loss impacts of CTF is improving, there is limited information on the economic impact of soil loss to farmers and off-farm.

Variations from Earlier Evaluations

Economic performance estimates in this analysis are quite similar to those of the previous update. While the rate of adoption of CTF has been considerably greater than previously anticipated, the fall in revenues for the main crops (wheat and sorghum) and the downward revision in estimated dryland cropping area in central Queensland have been offsetting factors. As indicated above, the analysis has probably been conservative with regard to changes in variable costs, and lack of attribution of benefits of CTF adoption in other areas.

Table CS7-6 Sensitivity of NPV to parameter estimates, QPI14

Area under dryland cropping (M ha)				
	0.4	0.5	0.6	0.7
	32173	41211	50249	59287
Proportion of area with opportunity cropping (%)				
	0%	8.30%	16.70%	25%
	18161.7	29637.9	41252.3	52728.5
Change in yield (%)				
	0%	5%	10%	15%
	13976	27593	41211	54828
Change in variable costs ($/ha)				
	–20	0	20	40
	90557	65884	41211	16538
Reduction in soil loss (%)				
	0	10	20	30
	16538	28874	41211	53547
Outlay on machinery ($/ha)				
	0	12.5	25	37.5
	44208	42710	41211	39712

Table CS7-5. Annual cash flows to year 10 and economic performance criteria, QPI14

Item	Year commencing											
	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Research costs ($'000)	388.3	742.4	864.1	870.3	870.4	422.8	250.0	250.0	250.0	0.0	0.0	0.0
On-farm capital costs ($'000)					250.0	312.5	437.5	875.0	1250.0	1875.0	1250.0	0.0
Total costs ($'000)	388.3	742.4	864.1	870.3	1120.4	735.3	687.5	1125.0	1500.0	1875.0		
Production effects (normal cropping)												
Fraction of crop area adopting (%)					2.0	4.5	8.0	15.0	25.0	40.0	50.0	50.0
Area adopting ('000 ha)					10.0	22.5	40.0	75.0	125.0	200.0	250.0	250.0
Yield gain in each year (%)					10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Expected extra gross return ($/ha)					20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4
Increase in variable costs ($/ha)					20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Extra net revenue ($'000)					3.8	8.5	15.1	28.4	47.3	75.6	94.5	94.5
Production effects (opportunity cropping)												
Area adopting ('000 ha)					10.0	22.5	40.0	75.0	125.0	200.0	250.0	250.0
Opportunity cropping area ('000 ha)					1.7	3.8	6.7	12.5	20.8	33.3	41.7	41.7
Total revenue per hectare ($)					224.2	224.2	224.2	224.2	224.2	224.2	224.2	224.2
Net margin per hectare ($)					112.1	112.1	112.1	112.1	112.1	112.1	112.1	112.1
Total opportunity crop revenue ($'000)					186.8	420.4	747.3	1401.3	2335.4	3736.7	4670.9	4670.9
Off-site benefits ($'000)					200.0	450.0	800.0	1500.0	2500.0	4000.0	5000.0	5000.0
Total benefits ($'000)					390.6	878.9	1562.5	2929.6	4882.7	7812.3	9765.4	9765.4
Net cash flow ($'000)	−388.3	−742.4	−864.1	−870.3	−729.8	143.6	875.0	1804.6	3382.7	5937.3	9765.4	9765.4

Performance criteria	Discount rate (%)	NPV ($'000)	B/C ratio
	4%	61175	9.7
	7%	41211	8.5
	10%	28123	7.5
	IRR (%) = 40.9		

Monitoring and Information Requirements

Continued monitoring of the adoption of controlled traffic would be required to make future estimates of the payoff from this research program. In that some landholders are now introducing controlled traffic using consultants or their own skills, adoption area known to DNR officers would be expected to be an underestimate of the total area in central Queensland. More precise information on adoption levels would require observation and reporting by other DNR or DPI officers, or survey work.

The results of further economic studies are needed to clarify how expenditure on machinery purchases and modifications, and variable costs, change when CTF is introduced.

Discussion and Conclusions

This has been a highly successful research project. In particular, the attention to an integrated tillage system and on-farm trials has led to technology recognised as workable by landholders. The project has been large enough, and sufficient attention has been placed on complexities of an integrated farming system, that considerable extension effort has been warranted. After initial caution by landholders, the rate of adoption of this quite radically changed tillage system has been highly impressive.

While much of the benefits from CTF could be regarded as private benefits, there are considerable environmental benefits. Also, it is notable that additional farm income will results in additional taxation revenue, and when farm costs are reduced, much of the economic surplus arises in the form of consumer surplus. Hence, it would appear that public expenditure efforts on technology transfer have been warranted.

Technology transfer has been especially effective in this project, which provides a model for conveying new technology to farmers. The appointment of extension officers has played a key role in the technology transfer process. The influence of the ABC Landline program is notable.

Adoption has been much more rapid than expected. Research programs to validate, adapt and extend results of QPI14 (and of Dr Tullberg's ACIAR project at UQ Gatton) have been established throughout Queensland and interstate.

Involvement of consultants to graingrower groups on the Liverpool Plains provides an interesting case of the effectiveness of private sector agents in bringing about technology transfer.

In this project, the principal investigators have noted that economic evaluation in the LWRRDC life-of-project evaluations provide a useful source of source of economic information and reflection about the progress of the project.

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10 Variations in Project Performance between the Initial Life-of-Project Evaluation and Updates

This chapter reviews the evaluations that have been undertaken of seven research projects and one program over the three evaluations (1993,1996 and the current update). The first evaluation was conducted before a significant amount of the research had been conducted. As a result, the evaluation was based on a priori assumptions concerning the possible research outputs and practical outcomes. When the 1996 update was conducted, the research was further developed and potential adopters and benefits from the research were more clearly identifiable. As at April 1999, most of the research is completed and adoption patterns have become more apparent.

Variations in Economic Performance

Estimates of economic performance of the projects for the three evaluations are presented in Table 10-1. In the initial evaluation the knowledge base of potential adopters was poor and, as a result, benefit–cost ratios were not estimated for some projects. Some of the estimates of net present values of projects were considered merely indicative of the potential worth of the research. By the first update, the research direction of the projects, potential research outputs and adopters were more grounded. While this provided greater confidence in the estimated economic values, the research was not yet completed in most cases and the timing of adoption was speculative. The primary source of information for the initial evaluation and associated technology transfer was the principal investigators. In the first update, and more so in this update, the focus of the evaluation has moved towards adopters of the research and their perceptions of project benefits.

Table 10-1 reveals that significant slippage occurred between the initial and first update, with some indication of stabilisation of values in the current update as uncertainty as to the benefits of the research declines. In the current update, the valuations of four projects (UNE11, MDR8, CWW18 and UMO18) reveal further slippage in estimated economic performance. However, all projects appear to generate benefit–cost ratios greater than unity. Increases in estimated NPV and IRR have been obtained for DEP1, while estimated economic performance for CPI4 and QPI14 is relatively unchanged.

Table 10-1 Estimated net present value and benefit–cost ratio of each research project and program

Project code	Initial evaluation, 1993		First evaluation update, 1996		Second update, 1999	
	Estimated NPV ($m)	Benefit–cost ratio	Estimated NPV ($m)	Benefit–cost ratio	Estimated NPV ($m)	Benefit–cost ratio
UMO18	a	a	3.2	3.2	a	2.0
DEP1	a	a	2.3	6.2	a	6–20
UNE11	9.3	22.2	7.2	21.4	2.4	2.4
CWW18	0.5–88.3	a	3.1	4.8	1.7	2.5
MDR8	2.8	7.9	1.6	4.9	0.60	2.4
CPI4	a	a	1.5	2.5	0.71	2.0
QPI14	94.8	3.6	41	9.4	41.2	8.5

a Not derived during the life-of-project evaluations

Variation in the economic valuations conducted in this series of life-of-project evaluations stem from:

- earlier estimates of adoption being found, in retrospect, to be over-optimistic;
- an underestimate of the benefit flow from holistic research;
- an underestimate of the additive benefit stream from related research projects;
- changes in estimated values of social and collective goods; and
- improvements in valuation methods.

Over-optimistic estimates of adoption

Estimates of adoption overall have been shown to be over-optimist. The estimates in the earlier studies used higher adoption rates than have actually occurred. In one case studies, QPI14, the timing of adoption has been moved back 12 to 14 months. The timing of adoption in UNE11 and MDR8 has been moved back by 5 years and 3 years, respectively. In the case of UNE11, the research formally ended in 1994, yet the adoption of the technical outputs, while still likely, may not be realised for another three to five years. The delay in adoption reduced the discounted value of the research in present values. Such delays further reduced the value of the research between the evaluations, as funding of long-term technology transfer is limited and, without funding, the researchers have to move on to new projects. As a result, adoption may suffer from lack of a champion. The research centre where the research was conducted is continuing the technology transfer with the use of external funding and consultancies, but this problem is common to many research projects.

In cases where the research produces direct commercial products, such as in CPI4, the realisation of the benefits in terms of sales revenue and royalties has been less than expected and the value of the research has fallen. CPI4's final year of funding was 1994–95 and the benefit stream from sales peaked at only US$8,930 in 1998. This resulted in a fall of 0.5 in the benefit–cost ratio from 2.5 to 2.0 and a fall in the NPV from $1.5 M to $0.71 M. Commercial adoption can also be hampered by the need for rigorous testing which, in the case of MDR8, resulted in delays in adoption and further research funding. As a result, the NPV of MDR8 fell from $2.8 M in the initial evaluation to $0.6 M in the current update.

Benefit flow from holistic research

It is interesting to note that in the largest research project, QPI14, the benefit–cost ratio has held up between the previous update and this current update. The estimated benefit–cost ratio of QPI4 fell only marginally, from 9.4 to 8.5,— which is in contrast to the general slippage occurring in other research projects. A possible explanation for this increase is that larger projects gain more exposure and are more holistic in their problem solving.

Further, many of the research projects are based on previous or concurrent research and they contribute to the development of further research, which in total adds to greater than the sum of the individual components. Larger projects and programs are recognised in this regard, but where there is a series of smaller separate but related research projects, their value has been lost by separating out the individual contributions of such projects in the initial and first update. The current update has attempted to address that by including the benefit stream of research projects that have adopted the findings of such separate but related research projects.

Uncertainty surrounding the value of social and collective goods

When research projects involve social or collective goods, such as did DEP1, it is likely to be difficult to determine the value of the research with any accuracy. Such non-market benefits can often be a significant part of the benefits arising from a research project, but due to the nature of the projects are not valued or are valued with a high degree of uncertainty. Thus, a benefit–cost ratio for DEP1 has not been reported in the past, and in this update was seen as ranging between 6 and 20.

Improvements in valuation methods

Overall, methods of evaluation have not changed during the life-of-project evaluations, but in many cases the sources and certainty of information has changed. Between the initial evaluation and first update, improvements in valuation techniques were made in terms of data collection and consistency of analysis. The direction of projects was formalised and potential benefits and adopters became more certain in the following ways.

1. The value of UNE11 has declined from the previous evaluation as a result of over-optimistic estimate of the timing of adoption. UNE11 is part of a series of research projects investigating the potential benefits of adopting capacity sharing. Being part of this larger series, its value will not be realised until the series is completed and water authorities can evaluate the various facets of option, of which UNE11 addresses one.
2. Similarly, the research conducted in MDR8 is being expanded by MDR18, which aims at validating the NIFT assays as a means of evaluating the nitrogen limits in algal blooms. The value of MDR8 will not be realised until the assay validation is completed and tested in the market. The increased cost of this work

has been incorporated into the evaluation of the original project.

3. For projects with direct commercial value, knowledge on the level of sales and associated royalties has increased since the previous update and with it certainty in the economic valuation of the associated research. For example, the commercial value of the kits developed in CPI4 is being realised. The evaluation of CPI4 focuses on the royalties and sales of the commercialised kits between 1996 and 1998. As outlined in the case study, the use of prototype kits has far exceeded expectations, and has allowed broad-ranging research to be carried out on pesticides residues. Resource management benefits, included as a separate category in the previous update, have been absorbed in this research cost saving.

Finally, evaluation of QPI14 — a large collaborative project on soil compaction — has, like the other projects focused more on adoption. As a result, the analysis of technology transfer is greater in this report than in the previous two life-of-project evaluations. Adoption in other areas was recognised as having potentially higher value than that analysed in the analysis presented in this study. The result of more rapid adoption than expected in previous evaluations has led to higher net present value and benefit–cost ratios than estimated in previous studies.

Interpretation of the Results of a Quantitative Economic Analysis

Interpretation of the benefit–cost ratios or net present values should be made as part of an overall evaluation. It is important to recall that that a project has a lower than unity benefit–cost benefit ratio does not it itself indicate that the project is of little worth. If, for example, a project shows that current methods of dealing with a land or water problem are correct then there would appear to have been no tangible adoption and so the project would have a low benefit–cost ratio. But the findings of such a project are just as valuable for decision-support as if they had suggested significant and measurable changes to current practices. Similarly, projects that at face value appear to have failed to demonstrate that a new technique or technology is useful are valuable in that they suggest subsequent research to follow different paths or approach the problem from a different direction that may prove fruitful. Ideally, these values would be included in the project benefits.

Future Monitoring Requirements

As discussed in other chapters, the need for further monitoring is only justified in a number of research projects. In terms of certainty of evaluation, some of the projects have reached a position were they are unlikely to change or have benefit–cost ratios that are not high enough to warrant further monitoring. As noted in the previous update, uncertainties in the estimation of project expenditure, potential project benefit categories and the magnitude of benefits are of great importance in determining an accurate estimate of the value of research, especially in the first and early updates of an evaluation. As the research evolves and the adopters become more clearly defined, the adoption timing and level of adoption can be estimated with greater certainty, and random versus systematic changes can be separated.

The long-term returns of some of the adoption benefits may never be isolated for the purposes of valuation, as they become confounded in other projects or issues unrelated to the specific research questions at hand. Future monitoring will need to be able to resolve broader and more confounded applications of the research. This is not likely to be easy.

Conclusions

Despite the application of the best estimation techniques, slippage seems almost inevitable. The life-of-project evaluations have not been constant, but appear to be stabilising. Economists operate with uncertainty when dealing with the possible realised value of research that in a commercial sense may not be adopted for many years. The techniques adopted need to be sensitive to this uncertainty and adopt modest initial estimates of the value of research at its outset, as slippage is a major factor in reducing the value of research over time. Similarly, the additive nature of research needs to be realised.

In conclusion, the value of the research projects to date has tended to fall between the initial and first update as methods of estimation and knowledge of the potential benefits arising from the research projects and program improved. In this update it appears that, in the main, the economic values have stabilised.

11 Technology Transfer and Application of New Intellectual Knowledge: Processes and Impact of Land and Water Research Projects

The mission of LWRRDC requires it to support the development of intellectual knowledge in order to improve the management of land and water resources. In some cases, this intellectual knowledge is incorporated in new technologies and products, but in other cases it consists purely of managerial guidelines or sets of improved managerial procedures. Indeed, most of the intellectual knowledge generated by the 1993-group of research projects supported by LWRRDC and reviewed here gave rise to the latter type of end-products rather than to physical commodities embodying intellectual knowledge.

R&D by most large industrial companies today is largely conducted ‘in-house’ rather than farmed out and is a strategic consideration in the survival and development of such businesses. By contrast, LWRRDC-supported research is, as a rule, external to the bodies or businesses (such as farming enterprises) which may apply its results. In such cases, if this research is to have an impact, the results from it must be successfully transferred to those who might be expected to make use of it. Thus, in evaluating LWRRDC-supported projects it is vital to assess the adequacy of the transfer of technology or knowledge resulting from these research projects.

In order to assess the transfer of technology/knowledge, we must analyse the following:

- the process of transfer of intellectual knowledge;
- factors influencing the uptake of the knowledge; and
- the nature of the intellectual ‘property’ being transferred, eg. whether its application is to private goods or to social or collective commodities and whether private individuals or public institutions and voluntary organisations will apply it.

The above matters will now be examined, and their relevance to the 1993-group of LWRRDC-supported research projects reviewed.

The Process of Transferring of Intellectual Knowledge

In the theory of science and technology policy, less attention appears to be given to the process of transfer and extension of intellectual knowledge than to processes of R&D itself. While models of innovation and diffusion of new technologies do exist, they are often mechanistic, and do not give much attention to the processes involved in the transfer of knowledge. Nevertheless, even simple transfer models can help to highlight important issues and bring order to a situation which otherwise might appear to be disordered.

A very simple model of the process of transfer of technology/intellectual knowledge (which may have guided some of the thinking of LWRRDC on this matter) is illustrated in Figure 11-1. Researchers are seen as the transmitters who prepare information and transmit it to potential adopters (receivers), usually seen as resource-managers, who then process the information and decide whether or not to apply it to their management
.

This model, however, is inadequate for the following reasons:

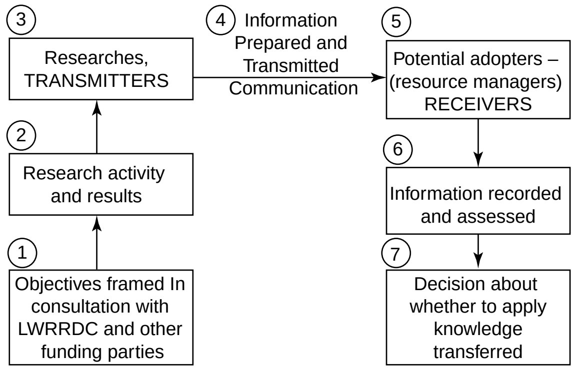

Figure 11-1. Simple unidirectional model of technology transfer, with resource-managers perceived as clients

- it gives the impression of being top-down because it is unidirectional. The only possibility for side-by-side direction seems to be in stage (1). That may occur, but if the 'client' body consulted has a top-down structure, it is possible that only those at the top have an influence on the research agenda;
- emphasis is on researchers adapting their research results and communicating these in a form likely to be easily assimilated by potential adopters. This seems to put all the burden of communication on the researchers. Ideally, potential adopters should also be on the lookout for new ideas and engage in search behaviour. The process should not be seen as one in which resource mangers are always passive. Two-way communication should exist;
- whether or not resource-managers will take account of information transmitted to them depends on their receptivity or set. This will be influenced in part by their goals and whether they see the information as relevant to the meeting of their goals; and
- taking into account their goals, resource-managers will decide whether or not to apply the information.

In relation to technology transfer, it is not only the motivation of potential adopters which matters, but also the motivation of researchers for communication. The motivation of researchers to communicate and transfer their results, their ability to do so and the resources available to them for that purpose, will have an impact on technology transfer. Furthermore, their costs of communication and the effectiveness of it may depend upon the extent to which they are able to use existing networks for communication or must create new networks. Serious difficulties arise when available networks are disrupted as happened, for example, in the case of UMO18.

To a considerable extent, the motivation of researchers to communicate their results to adopters depends on the personal or organisational benefit obtained by them. In business, such transfer can translate into extra profit for the firm where a saleable product is involved and possibly there are future promotion or other economic benefits for the staff members involved . But in academic organisations the benefits are less tangible. Publications in academic journals will be more highly weighted than technology transfer in this system. The gains to the researcher in this case may come via future grants from bodies which emphasise the transfer aspect, personal satisfaction and extended networks.

Thus, to the simple model in Figure 11-1, we should at least add an extra box or cell to the top row to indicate a number of the factors that influence researchers in their communication of research results so that it is like that shown in Figure 11-2.

The timing of the communication of research results also has to be considered. First, the results must be such that they are useful from a managerial point of view. Secondly, it is necessary to have confidence in their scientific validity. While early reporting of results has advantages, if there is a risk of communicating results that are insufficiently tested, then a degree of caution must be exercised.

Figures 11-1 and 11-2 suggest that communication should be focused on potential adopters. In this respect, it is therefore important that they be identified by the researchers. However, in cases where collective or social commodities are being supplied as a result of the research or a reduction in significant environmental spillovers can be expected from application of the research results, various pressures or interest groups (stakeholders) may have an interest in the research results. This may, for example, include environmental interest groups of various kinds, fishers, hunters and so on. In fact, application of some techniques may hinge on such groups exerting sufficient social demand to entice resource-managers to adopt these techniques. This is particularly so for methods or techniques having a substantial impact on collective commodities. Communication with special interest groups extends the number of parties requiring messages and adds to costs of communication. It also raises the question: Just how far scientists should be expected to promote communication to foster processes which can become highly political?

Patterns of Adoption

The economic benefits from a useful discovery depend on how long it takes to be adopted and how widely it is used. As explained in Harrison and Tisdell (1997, Ch. 14) the faster the rate of adoption of a new discovery and the more widely it is applied, the higher are its economic

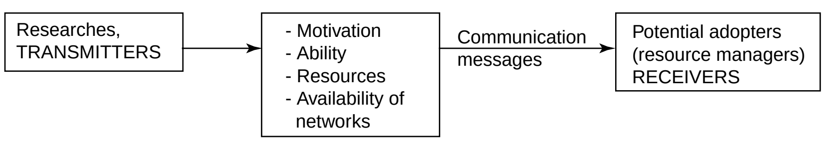

Figure 11-2. Factors influencing willingness of researchers to communicate and effectiveness of communication for technology transfer

returns, other things equal. Because there is usually a significant lag between the completion of research and the successful transfer of results from it, transfer and diffusion patterns for the new knowledge normally remain uncertain for some time after the completion of a research project. Different degrees of uncertainty exist about the adoption patterns of results from the projects reviewed here, even though all these research projects are being reviewed ex post.

In order to make progress in analysing this matter, it is useful to consider some standard patterns of adoption and diffusion of discoveries outlined in the literature (Cf. Tisdell, 1981, Ch. 3). It is often supposed in the relevant literature (cf. Griliches, 1957; Mansfield, 1968) that the pattern of adoption of a new useful idea or discovery is likely to take the form shown in Figure 11-3. There is usually a considerable lag between the discovery and its initial adoption, ie. innovation. Enos (1963) found that lags of 14 or so years are common in industry between an invention and corresponding innovation, but the length of lags varies widely. If initial trials of a new technique show it to be a success, it is likely then to be adopted at an increasing rate and then at a declining rate as the pool of remaining potential adopters becomes increasingly reduced. The initial adopters may be the more innovative of the potential adopters and/or those who feel they are likely to gain most by adopting the new practice. The length of the lag to first adoption is likely to be longer, the greater is the uncertainty surrounding the new technique, the higher penalty which applies if it turns out not to be a success in practice and the less effective is communication.

The adoption pattern shown in Figure 11-3, in which there is a lag before the first adoption of an invention, is of a logistic form or sigmoidal, the latter being the cumulative summation of the normal relative frequency distribution. In some management texts, it is assumed that the distribution of potential adopters is of a normal form with those on the lower tail of the normal distribution being described as innovators or thrusters and those on the upper tail being described as laggards. Sometimes contagion models are used to explain diffusion of processes, as is done by Ozga (1960).

Often, new ideas, products and techniques follow a cycle. They frequently become obsolete after a time and are replaced by superior ideas, products and techniques. Therefore, the adoption curve is liable in some cases to turn down after a point, eg. point C in Figure 11-3, when new techniques evolve. For this reason, as well as because of the impacts of discounting and the accelerating degree of uncertainty as one predicts further into the future, the projects reviewed here are assessed, as a general rule, only for a 20-year interval starting from the date of commencement of the research projects.

Given obsolescence of techniques, the adoption pattern for a technique may take the form illustrated by Figure 11-4. In this case, the life of the research project is OP and technology transfer begins before completion of the research project. In some cases, however, transfer may not commence until the research project ceases, as in the case of UMO18. In any case transfer is likely to occur quite late for most research projects.

A number of limitations of this model should be noted. Often a discovery does not occur at a particular point, but continually evolves and develops. This would be true, for example, of the list of sensitivities of organisms to salinity developed as a part of project UMO18. No allowance is made for the possibility that some adopters may only partially adopt a new technique and extend its use later if it proves to be successful according to their experience.

While the type of adoption function shown in Figure 11-3 may be common, other patterns may occur eg. the adoption relationship could have a number of plateaus, each representing encounters with groups with different degrees to resistance to adopting the new idea. Furthermore, for computational or operational purposes, it may be necessary to approximate the adoption function by a stepped function.

Multiple-stepped functions are assumed for several of the projects reviewed here, eg. the soil compaction project. However, sometimes a single-stepped function is

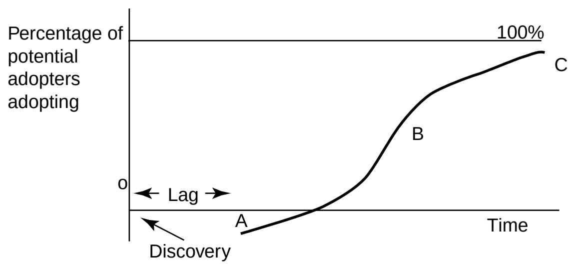

Figure 11-3. A logistic pattern of adoption of a new discovery following a lag before its first adoption

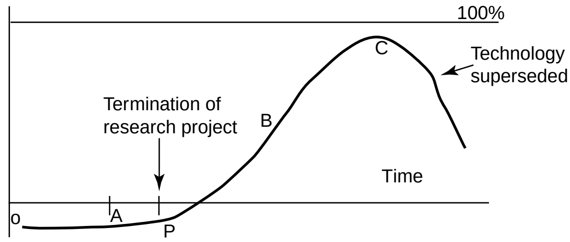

Figure 11-4. Possible adoption pattern when techniques or management methods may become superseded

assumed as for UMO18 and DEP1. In the case of UMO18, this simplifying assumption has been made because the likely pattern of adoption remains uncertain. In the case of DEP1, one of the techniques is 'lumpy', namely river flow variation — it is either instituted on the lower Murray River or it is not. However, there are other components of DEP1 which allow for more gradualism, as discussed. Thus, different research outputs of a LWRRDC-supported project may be adopted at differential rates, a factor not allowed for in simplified models.

Factors Influencing Adoption Rates and Barriers to Adoption

The emphasis in this section is on the factors other than on communication by researchers that may influence adopters to take up a new technique rather.

In relation to industrial techniques, it has been found that new techniques are likely to be more quickly adopted:

- the greater is the expected return from their adoption;
- the smaller is the investment or cost involved in implementation; and
- the smaller is the perceived risk associated with the adoption (cf. Mansfield, 1968).

Risk will be lower if incremental adoption is possible and if reversibility of the decision is easy. Incrementalism allows for learning-by-doing and exposes the adopter only to low risks initially. Greater reversibility means greater flexibility and less likelihood of sunk costs being incurred if the adoption does not turn out as expected. Where a new technique requires the use of very specific techniques, and may cause irreversible ecological or other damages, this would deter its adoption in land and water management.

In a very simplified case, the relationship between the likelihood of an adopter taking up a new technique in a given interval of time might be as shown in Figure 11-4. The curves marked P_1 P_1, P_2P_2, P_3P_3 represent contours of equal probability. For example, any combination such as that at A or B on P_1 P_1 has an equal probability of adoption but that corresponding to C would have a greater probability of adoption.

The above discussion relates mostly to private adopters of technology. While some of the new techniques developed as a result of LWRRDC-supported research will be adopted by private businesses, eg. improved management of soil compaction, most appear to depend on adoption by institutions and water regulators, eg. salinity management in wetlands and riverine areas (UMO18), ecological processes for the management of wetlands and floodplains (DEP1), capacity sharing (UNE11), and so on. In such cases, the process of adoption is liable to be much more complicated than when private businesses are the main adopters. Private businesses are likely to be motivated by private gains.

Institutions, because they are often involved in the control of resources with collective or social uses, must take account of political considerations in their decision-making. Very often some of the ecological services provided by the management of these institutions are not marketed or are only partially marketed. For example, their control of water flows can affect the conservation of biodiversity and the ecological health of wetlands and riverine areas and these ecological services are not marketed. Demand for them, as a rule, can be expressed only via political mechanisms and social movements, the latter being a part of the so-called civil society. The discovery of methods that make it possible to provide ecological services demanded by the public at reduced cost will increase the net social or collective demand for these — they increase the net benefit of providing the services. Furthermore, research which also provides greater awareness of the cost of losing ecological services may increase public demand for maintaining such services.

The demand for social or collective commodities, such as ecological services provided by water, can be complex because social conflict may arise. The application of new technology may favour one social group at the expense of another, although there can be occasions when no such conflict exists. When social conflict exists, it may delay the application of new techniques or managerial methods. For example, proposals to introduce increased fluctuations in river levels to improve the ecological health of wetlands and floodplains may be delayed by such factors, as might any new management method which requires greater allocation of freshwater for ecological purposes. While those wishing to improve the ecological health of wetlands may support such measures some farmers, eg. irrigators, may oppose these measures.

Public choice or political economy factors influence the adoption of techniques which have an impact on the

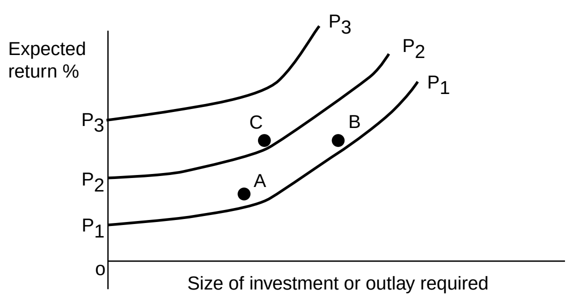

Figure 11-5. Adoption of new techniques in relation to rate of return and size of outlay

supply of collective or social commodities. Some of the factors which may influence the rate of adoption of such techniques are set out in Table 14.1. Adoption is likely to be slowed by group conflict, institutional inertia)eg. because of political caution and slow decision-making processes), institutional rent-seeking, absence of pressure groups to politically foster the adoption of the techniques, and low political capacity of groups favouring application of the technique. Very often commercial groups have greater political capacity than environmental groups in relation to political decisions about the supply of collective or social commodities. Partly this is because commercial interests are relatively well defined and industries mostly have well-developed networks and associations to support them. On the other hand, environmentalists/conservationists may not be very pro-active due to free-riding, particularly where many benefit from a conservation activity but each gain is a small amount. In this case, the type of problems arising in the case of supply of public goods, as discussed in the literature, are liable to arise. In fact, accelerating the adoption of techniques for social application may require a degree of institution building, such as that being undertaken by Wetland Care Australia. Nevertheless, the extent to which LWRRDC-supported researchers should engage in institution building for the purpose of increasing the rate of adoption of techniques is problematic because it goes well beyond the process of scientific inquiry

Observations about LWRRDC-Supported Projects and Adoption of Techniques in the Light of the Above

All of the 1993-group of LWRRDC projects reviewed here have a social dimension. This is true even of those with results which require adoption by private businesses, such as improved soil compaction management. Adoption of improved management techniques in these cases is expected to have favourable environmental spillovers, apart from private benefits. Let us consider some of the salient features of the eight case studies completed.

Case Study 1, effects of increased salinity on riverine and wetland biota (UMO18), was mostly concerned with proposing management practices to improve the ecological health of riverine and wetland areas. Thus, it was concerned essentially with the provision of social or collective ecological services. The researchers were required to engage in relatively fundamental research and to develop and transfer the results to resource-managers, providing them with management guidelines. The time frame for the project in retrospect was too short and effective transfer and interaction with resource-managers was impossible because of rapid changes in government institutions in Victoria.

Table 11-1 Factors likely to influence the adoption of techniques the application of which affects the supply of social or collective commodities

1	Group conflict — if some individuals lose and some gain, this may slow adoption, eg. changes in river flows may result in such conflict.
2	Institutional inertia and self-interest — Existing management or regulatory bodies may have an interest in maintaining the status quo and can be quite cautious in making changes. This may, for example, mean that capacity sharing arrangements are slow to be adopted. The exercise of institutional self-interest in maintaining the status quo is sometimes described as rent-seeking.
3	The existence of pressure groups with well developed networks. Depending on the composition of pressure groups, this may facilitate or hinder the adoption of new techniques. For example, if the group favouring adoption of a technique is poorly organised and its opponents are well organised, adoption is likely to be slowed.
4	The stronger the social demand for adoption of a technique the more likely it is to be adopted. Demand is liable to alter as a society develops and awareness will play a role in influencing this demand which in turn can influence resource-managers.
5	The relative political capacity of groups in conflict will help to determine outcomes concerning the adoption of technique having a social or collective impact.

Case Study 2, ecological processes for management of wetlands and floodplains — practical management systems (DEP1), contained only a small natural science research component and was principally intended to draw on other studies to encourage adoption of water management practices to improve the ecological performance of wetlands and floodplains. Although LWRRDC may have seen the main purpose of DEP1 as being to transfer results from three other associated research projects focused on natural science research, this transfer turned out to be impractical. While some transfer was possible from some of the associated projects, they were out of phase with DEP1. Therefore, it seemed wise not to restrict the development and transfer of practical management systems to the results from these three projects alone.

DEP1 (like UMO18) was concerned mainly with the supply of collective or social ecological services and had a variety of components. Some of the recommended management practices from the project can be applied only if adopted by major institutional managers. Many are non-incremental in nature, eg. alterations in fluctuations in river flows. Other components can be implemented by community groups and are more incremental in nature, eg. reintroduction of wetting and drying cycles to portions of wetland now permanently flooded. Technology transfer in this case is highly dependent on institutions and social bodies and movements. By using her contacts and networks, the Principal Investigator has been able to provide effective support for the adoption process, particularly because of her personal commitment to the goals of the project.

Case Study 3, the integration of wetland water supply and management in a market environment using capacity sharing (UNE11), is concerned with a shared commodity — water. The adoption of this proposed method of water allocation may bring economic advantages to irrigators and be acceptable to environmentalists. However, adoption of this method of water management transfers control of water resources from water authorities to water users, including environmentalists. It therefore is not favoured by some water authorities which want to retain institutional control. Some irrigators may also disapprove of it because it confers rights to the use of water for environmental purposes. Consequently, environmental groups may be able to manage some water for environmental purposes. Some irrigators may see this as the thin edge of the wedge; a precursor to greater water allocation for environmental purposes. While workshops for water resource-managers have informed them about the technique, these workshops do not ensure its adoption because resource-managers may believe that institutional goals will be compromised. Political pressure from water-users (irrigators and environmentalists) may be needed to ensure the necessary institutional change.

Case Study 4, management of a regional groundwater discharge zone in an area of dryland agriculture (CWW18), namely in the Upper South East Region of South Australia, was concerned with collective ecological services. As it transpired, results from CWW18 show that the biological possibilities which it was exploring for the control of dryland salinity in this region would on their own be ineffective in reducing the salinisation process. A drainage system would be needed to control watertables and engineering work to install this has been implemented. Whether or not use of lucerne, native vegetation and salt-land agronomy would have been economically worthwhile in conjunction with drainage was not explored. Little application could be made of the research results except to confirm that the biological solution was not feasible in this region as a means of controlling rising watertables. If it had been, the question would still have had to be addressed of how to implement the proposed biological strategy. Farmers of their own free will might not have been prepared individually to conform to the strategy unless each gained individually from its adoption. The dryland salinity problem is a collective or social problem and the free-rider problem (typified by the prisoners' dilemma problem or game theory) could have thwarted adoption of the collective strategy. In cases such as this, the natural science outcomes need to be married to social possibilities.

Case Study 5, nutrient limitations of algal growth: physiological assays and chemical analysis (MDR8), is mainly intended to assist water managers in controlling nutrient loads in aquatic systems. However, the transfer aspect was given little emphasis in the agreed objectives and expected technical outputs.

The main purpose of MRD8 was to develop the nutrient induced fluorescence test (NIFT) of determining nutrient limitations on the growth of blue-green algae. The NIFT method reduces the time and operating cost of such assays. The main adopters would be water authorities. However, the rate of adoption has been slow (no adoption to date) partly because only a few agencies have fluorimeters and their cost is relatively high, and many lack the laboratory facilities needed to complete the tests. Currently, water management authorities use standard methods of water testing and are reluctant to adopt new methods without significant testing and validation of these. A successor to project MRD8, MRD18, is designed to overcome the last-mentioned obstacles to adoption. While the list of objectives of MRD8 did not include technology transfer specifically nor did those of MRD18, the Principal Researcher is taking steps, eg. organising a workshop of representatives of water agencies, to facilitate technology transfer. Institutional caution, ingrained habits and lack of necessary complementary facilities appear to have slowed technology transfer in this case. The number of potential users of NIFT in

Australia is relatively small but the application of NIFT could have significant economic benefits.

Case Study 6, on-site monitoring of agro-chemical residues: a valuable tool for irrigation water management (CP14), is designed to provide relatively inexpensive field tests mostly for determining the presence of pesticide residues. The technologies for these tests are made available for specific pesticides in the form of a kit, which could be marketed and sold. An Australian commercial partner, Millipore Australia Pty Ltd, began to manufacture and market assay kits for four chemical compounds in 1997 and a number of assays for other compounds were expected to be commercialised in due course.

Millipore Australia Pty Ltd, a subsidiary of its American parent company belonging to the University of California, was proceeding satisfactorily to manufacture and sell kits in Australia until several key staff of its parent company were killed in an air crash. It then transferred its rights to manufacture, sell and distribute kits in which LWRRDC had a royalty interest to Ensys Environmental Products and the Australian operations of Millipore ceased. Production of kits in Australia also stopped. Subsequently, Ensys merged with Strategic Diagnostics Inc. (SDI), another US company. Neither had manufacturing or other operations in Australia and kits were manufactured in the US. There appeared to be little interest in the Australian market and little attempt was made to market kits in Australia. The landed price of kits in Australia (imported from the US) was now quite high. These recent developments have restricted Australian applications of these research results. Apart from earlier sales by Millapore Australia, CSIRO prototypes have been the main source of adoption in Australia. This case illustrates problems which can arise for Australian adopters when Australian developed techniques are embodied in commercial production overseas rather than in Australia. The distance factor in such cases also makes it more costly for Australian holders of intellectual property to monitor their stakes, as for example happened to CSIRO in this case.

Case Study 7, compaction control and repair practices for cropping lands in the sub-tropics (QP114), does not involve a saleable product per se. However, the management methods recommended as a result of it provide mainly, but not exclusively, private returns. In this case, adoption depends on convincing crop growers in the sub-tropics that the compaction control and repair practices recommended as a result of the project are profitable. The project has been very successful in its extension dimensions — considerable adoption of these practices has been achieved and adoption is continuing. An important favourable environmental externality from compaction control is reduced water run-off and soil erosion. Greater water retention and less soil erosion is likely to have benefits on as well as off-farm. The decision, however, to adopt these techniques is essentially an on-farm decision.

Thus, it can be seen that the adoption process is influenced by the characteristics of target groups, the nature of techniques developed and whether or not the use of techniques confers a private benefit or involves collective or social services, and whether or not the techniques are embodied in a saleable patentable product. When private incentives to adopt new techniques are absent or weak, considerable attention must be given to the social dimension of the adoption process. New techniques which confer significant net social benefits may fail to be applied because of social conflict or other social shortcomings eg. free-riding when collective commodities are involved. The adoption of techniques which alter the supply of social or collective commodities is significantly influenced by institutional arrangements and by any variation in these.

Concluding Comments

From the above overview, it can be seen that technology transfer and the transfer of intellectual knowledge, as well as the likelihood of adoption of new techniques and ideas, cannot be characterised by one simple model. In particular, the types of models applied to the technology adoption process in industry can rarely be applied to the type of technologies developed with LWRRDC-support. Such research is not usually in-house and rarely are the commodities produced as a result of the research patentable private goods or saleable products. Very often, but not always, adoption depends on institutions such as water control authorities and social non-market mechanisms, often of a political nature. In such cases, adoption is not assured by showing that use of the technique would confer a collective net economic or social benefit. Social conflict, institutional inertia, preservation of power and defects in social choice (such as free-riding), may conspire to thwart the adoption of a technique which appears to be worthwhile from a social point of view. Furthermore, institutional instability may diminish or eliminate interaction between researchers and potential users of new knowledge and delay development and adoption of new techniques. Some of these potential social problems for the transfer of techniques affecting the supply of collective or social commodities can be foreseen and allowed for, but not all.

Where private businesses are expected to adopt new practices, the incentive for them to do this is likely to be greatest when they obtain substantial private benefits from this action. If the benefits are mostly to the industry as a whole rather than to adopters individually, this is liable to reduce their economic incentive to adopt new practices. For example, soil compaction management techniques can substantially increase the private returns of adopters in target regions. Adoption of these techniques has therefore been relatively rapid.

In conclusion, note that most studies indicate that the process of product development (including marketing or extension costs) is very costly relative to invention costs. Studies in the United States (Mansfield et al., 1971; US Department of Commerce, 1967) indicate that, in industry, development costs may constitute over 80% of R&D costs, with invention costs accounting for less than 20%. While these findings are based on studies mainly of industrial innovation, they indicate that, if the product development and extension activities for LWRRDC-supported projects are to achieve success, a much larger proportion of funds must be earmarked for development and extension activities than seems to have been allowed for in the 1993-group of projects. Furthermore, the realistic time-frame for such activities must extend as a rule beyond the 4–5 years allowed for in most LWRRDC-supported research projects.

The question is also raised of whether researchers are the most effective individuals to provide extension services. Often they are lacking in the marketing, communication and political skills needed, and, because of reward systems, may have limited motivation to engage in technology transfer. The problem is especially complex in the case of LWRRDC-supported research because much of it involves the provision of goods or services of a collective or social nature which are not or only partially marketed.

The extension problem in Australia as far as improved management of natural resources such as land and water are concerned has become more pressing with the application of structural adjustment policies designed to foster a small government sector and to increasingly apply the user-pays principle. This resulted in the destruction of a number of pre-existing networks for resource-managers and, in many cases, for new decentralised systems new networks are only just evolving to replace the pre-existing ones. For example, Wetland Care Australia, a non-government organisation, has been provided with a small Commonwealth Government subsidy to develop such a network for water resource-managers. The existence of suitable networks and communication channels and changes in these, impacts on the scope for transferring LWRRDC-supported technological and managerial developments.

The role which LWRRDC itself should pay in the process of technology transfer may need to be reassessed. However, in the end, this can only be satisfactorily evaluated by considering all of the mechanisms which exist in Australia for transferring knowledge of techniques to Australia's resource-managers and to other interested stakeholders. To do this would go beyond the bounds of the present review.

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12 Monitoring Research, Technology Transfer and Adoption in Relation to Australia's Natural Resources

Under one of its terms of reference, this update has sought to review the information (being) collected during the course of the projects and define any changes needed in information collection for any subsequent life-of-project evaluations. Details of information requirements for further economic evaluations have been included in reports of the seven selected projects. General issues arising from experience of obtaining information and making monitoring recommendations in the three evaluations are now examined.

Issues Arising in Information Collection

Carrying out social cost–benefit analysis of research projects relating to the management of Australia's natural resources has substantial information requirements. Typically, this information is obtained from interviews with principal investigators (PIs) and current or potential adopters, and from review of project literature (proposals, reports, investigators' publications, conference proceedings). Scope exists for having researchers carry out routine collection of a greater amount of information which could be used in project evaluation. This. however. would impose additional costs on researchers. A number of questions relevant to how project performance monitoring may best be arranged and managed are listed in Table 12-1.

Information Requirements and Monitoring for Social CBA

To carry out social cost–benefit analysis of research projects, it is necessary to have information about project expenditure and benefits over a number of years. Project benefits include revenue generated and costs avoided, for government agencies and private landholders. These include non-market benefits such as reduced degradation of land, watercourses and wetlands. The estimates are made on an 'incremental cash flow' basis, ie. cash flows with the research project as against cash flows had the project not been undertaken.

Table 12-1 Some issues concerning project monitoring

What monitoring information is needed in the social-CBA framework?
What information is best collected by recording and what can be collected at greater convenience and adequate precision from subjective estimation and memory recall?
How frequently should information collection take place?
Should information collection be periodic or on an incident basis?
Who is the most appropriate person to collect the information?
How should the information collection be arranged?
Should the same information collection approach be applied for research, development, technology transfer and adoption?
To what extent can published materials be used in evaluation?
How may the monitoring information be validated?
What lessons do the life-of-project evaluations provide about project monitoring?
What are the economic trade-offs in information collection (in an MC=MR context)?

Some formal recording of physical and financial variables by researchers during their projects provides a systematic and reliable source of information for project evaluation. The need to rely on memory recall is reduced, and this may be important if evaluations are carried out only every three years or so.

An Economic Perspective on Collection of Monitoring Information

Monitoring is not automatically justified in its own right. The return from having the additional information should exceed the cost of that information. In practice, determining the value of information can be quite difficult (Ramsay et al., 1999), so a practical expedient is to collect data providing the task is not too onerous.

It was pointed out in one project (CPI4) that collection of one type of information suggested in the previous update (sales of EIA kits) could have very high costs in terms of the time of CSIRO staff.

Where project monitoring is likely to be expensive, it seems appropriate that the monitoring measures be negotiated with PIs before project commencement, eg. at the time when it is indicated that a project will be subjected to a continuing evaluation process.

Monitoring of All Projects vs Only Those Subject to Continuing Social Cost–Benefit Evaluation

The life-of-project evaluation series has provided information on what variables need to be monitored if a comprehensive socio-economic evaluation is to be performed. It is probable that, for projects not subject to such evaluation, current project reporting or some modest modification of it would be adequate and indeed optimal. However, current reporting such as in milestone reports is of limited value for socio-economic evaluation, for which considerably more information is required.

Collection of Expenditure Data

While the contribution of LWRRDC and other research organisations to a project is reliably documented, other funding inputs may be more difficult to estimate. In particular, estimation of the time inputs and costs of researchers, and the infrastructure support of host organisations or research and extension officers may present problems. Some organisations have their own formulae for estimation of these costs. However, in that the approaches vary, it may be preferable to use a standard approach, such as that suggested in the guidelines of the Australian Vice-Chancellors' Committee. The estimation will be most reliable if sound information about the time and other inputs of researchers and their organisations are available.

Another difficulty which arises concerning project expenditure is when associated research projects or extension activities are initiated, a decision must be made about whether to group these as part of the original project. If these are expenditures incurred in the generation and adoption of projected technology, then it would seem wise to include these as part of the project expenditure rather than as separate projects.

InformAtion Needs Concerning Project Benefits

While project expenditure is reasonably easy to identify, the estimation of benefits can be extremely difficult. Research projects dealing with natural systems generate project outputs which it is hoped to translate into practical outcomes, in the form new products, new technology or management systems, or new understanding of natural systems.

In the current evaluation and earlier rounds, a wide variety of project benefit categories has been identified, as in Table 12-2. For any benefit category, a number of information components or variables can be defined, so that a large number of variables have been identified as necessary to make estimates of project benefits.

Table 12-2 Categories of benefits from sample research projects

Increased crop yields
Reduced costs to farmers
Royalties from commercialised research projects
Cost savings from using research outputs in other research projects, e.g. prototype ELISA kits, fluoroassays
Improved knowledge on causes of algal blooms
Improved knowledge of salt sensitivity of macroflora
Appreciation of the role of drainage systems versus salt-land agronomy
Reduced soil erosion
Reduction in the rate of wetland degradation
Reduction in the rate of salinisation of crop land
Identification of best practice management methods
Estimation of the trade-off frontier between crop production and water for the environment
Who should collect information and when?

The logical candidates to carry out monitoring would be the PIs. However, it should be recognised that when the research has been completed, the researchers may have little incentive or willingness to engage in this activity. Also, sometimes the resource management agencies will have a better idea of the extent of adoption of new technology that the researchers who are the originators of this technology. This has been the case of project CPI4, when Professor Kennedy and researchers in the CRC for Sustainable Cotton Production had closer contact with use of prototype EIA kits than researchers who had developed the kits. Alternative systems could include PIs providing information directly to evaluators, or evaluators contacting PIs for information progressively between life-of-project evaluation updates.

The timing of monitoring information could be regular, eg. when research progress reports are made to funding bodies, or on an incident basis (when there are an events worthy of notification).

Variations in Monitoring Requirements between Projects and Over Time

The difficulty in obtaining information for socio-economic evaluation and monitoring varies considerably between projects.

During the research phase, the PIs are clearly the people to provide information about project performance. However, after research is completed but adoption is progressing, they may have limited knowledge of progress.

In the current study, particular emphasis has been placed on technology transfer and on adoption progress (types of adopters, rates of adoption, further development needed, obstacles to adoption).

Usefulness of Published Papers in Relation to Project Monitoring

To some extent, published material provides an easily accessed source of information from which to examine resource linkages or research and to obtain parameter estimates for economic analysis. Some forms of research output, particularly scientific papers, are not well suited in this regard and can involve considerable effort for the lay person to interpret. In this update, volumes of conference proceedings were particularly useful sources of information, for example the two recent volumes dealing with controlled traffic farming (Tullberg and Yule, 1998; Rummery and Coleman, 1999). These presented the views of researchers in readily comprehended form. Also highly useful were impressions of the new tillage technology and its cost and yield impacts from a number of farmers who had adopted minimum tillage or CTF. From an evaluation perspective, this provided readily available and relevant information, reducing the need to contact adopters, and could be regarded as an important component of the project monitoring.

Validation of Information for Project Evaluations

Often little information is available for estimation of economic impacts. Using a single estimate from a researcher or other source can involve a high risk of imprecision. Regardless of the source of information, it is desirable that some independent corroboration of the parameter values obtained. Often the estimates provided by researchers can be validated by resource managers.

Monitoring Experience in the Evaluations

While we have identified information which could be collected for monitoring purposes in the earlier evaluations, and copies or our reports have been made available to PIs, there has been no systematic monitoring of this information. Reasons for this include:

- there has been no formal request to collect the information;
- the projects had been completed or were nearing completion at the time of the first update, and all were completed at the time of the current update, hence researchers have not necessarily felt a continuing responsibility for information collection; and
- the lists compiled have been something of 'wish lists' rather than 'minimal data sets'.

It would appear that the PIs have become aware of the types of questions we have asked, and lists of questions have been provided to them before meetings, hence they have been reasonably well prepared to provide information on our visits. In some cases, the PIs have put considerable effort into preparation for meetings.

Much of the information required for evaluations concerns judgments about economic outcomes arising from research. This is not the kind of information which could be routinely collected, and subjective estimation by researchers and resource managers is probably the best approach to obtaining it.

Sometimes it was not possible to validate information obtained. In some cases, benefits have been adjusted downward after discussion with adopters, eg. for CPI4.

Compensation for Monitoring Time Inputs

Since monitoring imposes an additional task on researchers, it has a transaction cost. It would not be reasonable to impose this additional cost on researchers without some recompense.

If researchers or resource managers who are not LWRRDC funding recipients but who have a good understanding of adoption of technology generated in a LWRRDC project are asked to carry out monitoring on a regular basis, then it would be reasonable for some financial support to be provided to compensate for the time commitment to this activity.

Conclusions

While the monitoring information has only been used partially and informally in this series of life-of-project evaluations, a more formal approach to monitoring may be preferable in any new series commissioned. Monitoring can improve the quality of information available for life-of-project evaluations and hence the reliability of the economic estimates. However, this monitoring comes at a cost, and to be effective may require inputs from not only the principal investigators but also other researchers or resource managers, particularly with regard to monitoring of technology adoption. In some cases, monitoring will not be justified on economic grounds, and subjective recall will be adequate. Where monitoring is warranted, a formal request from LWRRDC and negotiation over variables to be recorded may be appropriate.

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13 Discussion and Conclusions

The three rounds of the life-of-project evaluation process for the selected projects have provided a number of important insights for research management. This report concerns a single group of projects (the 1993 group) for which the evaluations have now continued for six years, from the ex ante stage, through the period when projects were in progress, to the ex post stage in the sense that research has been completed.

The life-of-project evaluation process has important implications for LWRRDC, principal investigators and economists involved in evaluations, as discussed below.

Lessons for Economists Carrying Out Evaluations of Research Projects

The literature on cost–benefit analysis provides insights into differences in performance estimates between ex post versus ex ante evaluations, as indicated in the following examples.

Kostoff (1993, p. 46) observed in relation to federal research impact in the USA that

> "cost–benefit analyses appear to have limited accuracy and credibility when applied to basic research because of the quality of both the cost and benefit data due to large uncertainties characteristic of the research process …".

Haveman (1972, p. 111) noted that

> "ex post estimates of benefits often showed little relationship to their ex ante counterparts. On the basis of the few case studies and the a priori analysis presented here, one could conclude that there is a serious bias incorporated into agency evaluation procedures, resulting in persistent overstatement of expected benefits".

Palanisami and Easter (1984, p. 1785) found in relation to flood control investments that

> "[n]inety-two percent of ex ante benefits were supposed to come from water supply and 8% from flood control. Ex post estimates found zero water supply benefits and flood control 37 times higher than ex ante estimates... Still the ex post analysis shows that the ex ante estimates were based on inadequate information and did not include fishing and recreation benefits which accounted for 28% of the ex post benefits."

Similarly, Haveman (1972, p. 111) in the analysis of construction costs, noted "enormous variance was found among projects in the relationship between estimated and realised costs".

In other words, we might expect ex post estimates of performance criteria to be lower than ex ante estimates, with high variability between relative importance of benefit (and cost) categories. This pattern has been borne out in the life-of-project evaluation process.

It is reasonable to ask whether economists could do better in terms of their estimates, or whether their efforts are constrained by amount of information available at any point in time. In retrospect, it would appear that we may have relied too heavily on principal investigators' judgments in the ex ante evaluations, and were too optimistic about rate and level of adoption for some projects (though not for others). It is difficult to see how this prediction performance could have been improved. Perhaps greater experience or sharper judgment could lead to smarter predictions.

It is notable that the estimated economic performance was relatively stable between the first and current update. That is, once the research was well advanced, it became possible to make more reliable estimates of technical outputs and practical outcomes of the research.

An interesting issue which has arisen concerns what point in time can be regarded as 'ex post' in project evaluation. Even when all commissioned research has been completed, adoption may have barely commenced, so that retrospective evaluation of practical outcomes may not be possible for a decade or more after a project commences.

With regard to methods for estimating project benefits, the experience in research evaluation has demonstrated the need to rely on benefit transfer, because of time and cost considerations.

Lessons for Researchers

The evaluation process has indicated that at the ex ante stage researchers are in general over-optimistic about the economic payoff from their research. Also, it would appear that they sometimes agree to take on technology transfer activities for which they lack the skills, and for which the research outputs are too narrow. Development of integrated technology packages is usually a time — and resource — demanding task, and results of most project provide only components in a wider technology package. This is not to say that LWRRDC projects should not have a technology transfer component, but rather to sound a word of caution about the limitations on usefulness which can arise from excellent and well-targeted research.

Implications for Research Management by LWRRDC

LWRRDC has backed the life-of-project evaluation process, and commissioned three groups of sample projects for evaluation. This has resulted in considerable insights into the performance of the overall research portfolio.

As noted in the previous update, as evaluations progress through a number of rounds, the sample of projects is likely to become less representative, because of changes in funding priorities and mechanisms. In particular, the move to research programs rather than single projects has made the sample here less typical of the overall portfolio. However, it must be noted that programs are made up of component projects (with the added value of synergism between individual projects) so an evaluation of specific projects remains a worthwhile pursuit.

One of the clear findings is the need for flexibility in research management. Research into management of natural resources can be prone to delays (particularly research which is weather-dependent such as that relating to wetlands and floodplains), and need for supplementary funding. LWRRDC's clients have a high regard for the positive attitude of the agency in terms of research support.

One of the major issues which arises for research management is the extent to which an agency such as LWRRDC should fund or in other ways support technology transfer, and how it should do so. As noted above, there are limits to which research scientists can be expected to be effective extension operators and of the comprehensiveness of the technology package they can bring together.

It is notable that for a large project which involved employment of dedicated extension officers (QPI14), the rate of adoption of the new technology (controlled traffic farming) was well ahead of prior expectations. Consultants to farmer groups may become an increasingly important target for technology transfer activities.

Economic analysis is data-hungry, and monitoring is critical to the ability of economists to carry out project evaluations. While data access has been adequate for the series of evaluations, a more formal monitoring arrangement may be preferable should future life-of-project groups be initiated. However, this could impose considerable time costs on researchers, so a minimal required data set approach needs to be adopted, with monitoring activities negotiated with researchers.

The frequency of evaluations for this group of projects (about three years between each round) appears to have been appropriate. It is doubtful whether more frequent evaluations would be warranted on cost-effectiveness grounds.

Concerning the life-of-project evaluation process, the taking of periodic snapshots or project performance has proved to be a cost-effective means of research evaluation.

Cost–Benefit Considerations of the Life-of-Project Evaluation Process

The evaluation rounds in the life-of-project evaluation process represent an investment by LWRRDC, and it is appropriate to ask whether the payoff from this activity justifies the expenditure on it.

In this spirit, it is recommended that some but not all projects be subject to further evaluation with respect to appropriateness of technology transfer methods, adoption progress and economic performance.

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