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An Economic Analysis of GRDC Investment in the Managing Climate Variability Program (MCVP Phases II and III)

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An Economic Analysis of GRDC's Investment in the Managing Climate Variability Program (MCVP Phases II and III)

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Executive Summary

This economic evaluation refers to the investment in the Managing Climate Variability Program (MCVP) Phases II and III. MCVP II was managed initially by Land and Water Australia (LWA) before being transferred to management by the Grains Research and Development Corporation (GRDC) in 2009/10. MCVP Phase III was wholly managed by GRDC.

MCVP is a collaborative program between the Grains, Rural Industries and Sugar Research and Development Corporations; the Australian Government through the Department of Agriculture, Fisheries and Forestry; Dairy Australia; Meat & Livestock Australia (MLA); and the former LWA. MCVP Phases II and III build on the foundation laid by the Climate Variability in Agriculture Program (CVAP) and the MCVP Phase I. CVAP and MCVP Phase I were managed by LWA from 1992/93 to 2001/02 and from 2002/03 to 2006/7 respectively.

The aim of the program is to help primary industries and natural resource managers manage the risks and exploit the opportunities afforded by Australia's variable and changing climate by:

- improving forecasting accuracy, lead-time and ease of use,
- providing tools and services for managing climate risk, and
- increasing adoption of climate risk management.

Improved climate risk management through more effective use of forecasts is recognised as one of the key ongoing ways to adapt to a changing climate. The increasing frequency of extreme events is one example of a changing climate. The investment includes projects on a new area of research aiming at better forecasting of extremes on a multi-week timescale. In total, there are 26 projects from MCVP Phases II and III accounting for research, communication and management/administration investments, there are also two additional projects that are yet to be formally contracted, these are mentioned in this report for information purposes only.

There are three particularly notable outputs from the program:

- More rapid development of the Predictive Ocean Atmosphere Model for Australia (POAMA) to replace current statistical forecasts which are likely to be less useful as a result of climate change,
- Accelerating the use of POAMA to provide a new forecast at a multi-week timescale and a new forecast of the monsoon onset, and
- The launch of CliMate, a free mobile application with a web version forthcoming, that can be used to readily access and interrogate recent weather and likely climate probabilities for a location, and which has had 3,000 downloads in its first six weeks.

The benefits from this investment will largely accrue to Australian primary industries, as that is largely where the tools and products being developed are targeted. There are also some public benefits such as better natural resource management, enhanced scientific knowledge and some community spill-over benefits. A summary of the benefits from the current investment is shown in the following table.

Triple Bottom Line Summary of Principal Benefits from the Investment

Levy Paying Industries	**Spillovers**	
	Other Industries	**Public**
Economic Benefits		
Increased farm profits Reduced farm losses Enhanced awareness and adoption of climate risk information	Diverse non-farm benefits from improved seasonal and multi-week forecasts	Diverse benefits from improved seasonal and multi-week forecasts
Environmental Benefits		
Better natural resource management		Better natural resource management
Social Benefits		
Enhanced scientific knowledge More efficient industry research resource allocation	Enhanced awareness of climate risk information and capacity to adapt to climate change	Enhanced community preparedness and resilience Enhanced scientific knowledge More efficient public research resource allocation

Farmers benefiting from the MCVP investment can be categorised as follows for seasonal forecasts:

- Farmers already using the Seasonal Climate Outlooks (SCO) of the Bureau of Meteorology (BoM) transferring to POAMA when it becomes operational, and capturing mostly a marginal benefit,
- Farmers already using other seasonal forecasts transferring to POAMA and capturing mostly a marginal benefit, and
- Farmers not using either SCO or other seasonal forecasts and increasingly using POAMA with potentially a large benefit.

The proportion of farmers in the third category is unlikely to be large given the improved seasonal forecasting skill appears to be mainly marginal and concentrated in regions and seasons of existing skill from statistical forecasts or from various General Circulation Models (GCM) from international sources. However, the situation is likely to be different for multi-week forecasts from POAMA. These are essentially a new product with a large market depending on their accuracy and ease of use.

In summary, the benefit quantified is based on an estimate of the earlier and more rapid adoption of improved forecasts. The improvements will result from the diverse MCVP investments in the underlying science to improve forecast skill, from improved communication to users, and through applications and tools that develop the capacity of users to manage climate risks. Of the benefits identified, the principal benefit has been measured as a general increase in farm profits. The total investment of $15.45 million (present value terms) has been estimated to produce total gross benefits of $94.97 million (present value terms) providing a net present value of $79.52 million, a benefit-cost ration of 6.15 to 1 and an internal rate of return of 37.2%.

As there is only low confidence in key assumptions, the evaluation concludes that measures to improve information on uptake of products are warranted. Benefits would result from improved feedback to project and program design and also from increased investments from stakeholders. The latter would result from increased confidence in the high return demonstrated in this evaluation.

Glossary of Economic Terms

Benefit-cost ratio (B/C Ratio) - The ratio of the present value of investment benefits to the present value of investment costs.

Discounting - The process of relating the costs and benefits of an investment to a base year using a stated discount rate.

Internal Rate of Return (IRR) - The discount rate at which an investment has a net present value of zero, i.e. where present value of benefits = present value of costs.

Investment criteria - Measures of the economic worth of an investment such as Net Present Value, Benefit-Cost Ratio, and Internal Rate of Return.

Net Present Value (NPV) - The discounted value of the benefits of an investment less the discounted value of the investment costs, i.e. present value of benefits - present value of costs.

Present Value of Benefits (PVB) - The discounted value of benefits.

Present Value of Costs (PVC) - The discounted value of investment costs.

Abbreviations

ABARES	Australian Bureau of Agricultural & Resource Economics & Sciences
ACCESS	Australian Community Climate and Earth-System Simulator
AMOS	Australian Meteorological and Oceanographic Society
APSIM	Agricultural Production Systems Simulator
AWS	Automatic Weather Station
BoM	Bureau of Meteorology
CAWCR	Centre for Australian Weather and Climate Research
CCM	Community Climate Model
CCP	Climate Champion Program
CCRSPI	Climate Change Research Strategy for Primary Industries
COLA	Centre for Ocean-Land-Atmosphere studies
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CVAP	Climate Variability in Agriculture Program
DAFF	Department of Agriculture, Fisheries and Forestry
DAFF Qld	Department of Agriculture, Fisheries and Forestry, Queensland
DAFWA	Department of Agriculture and Food, Western Australia
DSS	Decision Support System
ENSO	El Niño/La Niña Southern Oscillation
GCM	General Circulation Model
GRDC	Grains Research & Development Corporation
GWRDC	Grape and Wine Research and Development Corporation
HAL	Horticulture Australia Limited
IOD	Indian Ocean Dipole
IOV	Inflation of Variance
MCVP	Managing Climate Variability Program
MJO	Madden-Julian Oscillation
MLA	Meat and Livestock Australia
NCC	National Climate Centre
POAMA	Predictive Ocean Atmosphere Model for Australia
QPIF	Queensland Primary Industries and Fisheries (now DAFF Qld)
SAM	Southern Annular Mode
SARDI	South Australian Research and Development Institute
SCO	Seasonal Climate Outlooks
SOI	Southern Oscillation Index
SST	Sea Surface Temperature
WATL	Water and the Land (BoM)
WMO	World Meteorological Organisation

Impact Assessment: An Economic Analysis of Investment in the Managing Climate Variability Program (MCVP Phases II and III)

1. Introduction

The Managing Climate Variability Program (MCVP) had its origins in the National Drought Policy of 1992 building on the opportunity for farmers to take more advantage of seasonal climate forecasts. MCVP is a collaborative program between the Grains, Rural Industries and Sugar Research and Development Corporations; the Australian Government through the Department of Agriculture, Fisheries and Forestry; Dairy Australia; Meat & Livestock Australia (MLA); and the former Land & Water Australia (LWA). The MCVP Phase I (2002/03 to 2006/07) was managed by Land and Water Australia. This economic analysis evaluates the impacts of the MCVP Phases II (2007/08 to 2009/10) and III (2010/11 to 2012/13). The Grains Research and Development Corporation (GRDC) managed the MCVP Phase II in its last year while MCVP Phase III was wholly managed by GRDC. The major change in the focus of the MCVP since 1992 has been the recent priority given to an expanded range of forecasts possible with the development of POAMA, a coupled ocean-atmosphere model. A new multi-week forecast is one potentially important investment.

The MCVP was created to increase Australia's capacity to capture opportunities and manage risks that emanate from climate variability. This is particularly important given that Australia is the world's driest inhabited continent and has the most variable climate. The aim of the program is to help primary industries and natural resource managers manage the risks and exploit the opportunities afforded by Australia's variable and changing climate by:

- improving forecasting accuracy, lead-time and ease of use,
- providing tools and services for managing climate risk, and
- increasing adoption of climate risk management.

Improved climate risk management through more effective use of forecasts is recognised as one of the key ways to adapt to a changing climate with an increased frequency of extreme events.

The MCVP strategy focuses on investments which increase forecasting accuracy, build the predictive capability of a wider range of key attributes such as temperature extremes, and develop tools which translate climate forecasts and resource attributes into decision support tools for primary industries and natural resource managers (Land and Water Australia, 2009).

Objective

The objective of this economic evaluation was to undertake an impact assessment of the Managing Climate Variability Program Phases II and III.

This objective was met through the following five steps:

1. Defining the projects being evaluated and measuring the inputs
2. Describing the outputs from the projects
3. Mapping outputs to outcomes and impacts
4. Estimating economic, social and environmental impacts and benefits.
5. Measuring some of the benefits

Past Investment

MCVP Phases II and III build on the foundation laid by the Climate Variability in Agriculture Program (CVAP) and the MCVP Phase I. CVAP and MCVP Phase I were managed by LWA from 1992/93 to 2001/02 and from 2002/03 to 2006/07 respectively. There were two notable changes made from CVAP beginning with MCVP Phase I. The first was the recognition of the potential contribution seasonal climate forecasts have in helping farmers adapt to climate change. The second was the need to strengthen the program in developing products more relevant to water and natural resource management issues.

In 2006 an economic analysis of the investment in CVAP was undertaken. CVAP ran from 1992/93 to 2001/02 after commencing as the National Climate Variability Program (NCVP). The total investment in CVAP was just over $33 million in total nominal dollars. The net present value of the LWA investment in CVAP was estimated at $4.8 million, providing a benefit-cost ratio of 5.7 to 1 and an internal rate of return of 48% (Land and Water Australia 2007). The increase in adoption was the key factor in the high ratio.

At the end of MCVP Phase I (2007) an impact analysis was undertaken to assess the program's impact for the 2002/03 to 2006/07 period. The total investment in MCVP Phase I was $7.0 million in total nominal dollars. The analysis estimated the net present value of the MCVP investment was about $5.6 million with a benefit-cost ratio of 1.7 to 1 and an internal rate of return of about 11% (Land and Water Australia 2007). The reduced rate of increase in adoption and concerns on the eventual loss of skill from statistical forecasts as result of climate change were contributors to the lower return.

2. The Investment

There are 26 projects from the Managing Climate Variability Program Phases II and III that are included in this analysis. Two additional projects (MCV000XY and MCV000XZ) were included for information purposes only as their contractual process began during MCV Phase III. Costs and benefits for these two projects are not included in the current analysis. However, the potential benefits of these two projects are described in the appendix. The following (Table 1) provides a code and title for each project included.

Table 1: Projects included in Managing Climate Variability Program (MCVP Phases II and III)

Project Code	**Project Title**
MCV00002	Improving seasonal forecasts for South-West Western Australia
HAL00003	Critical thresholds (tipping points) and climate change impacts/adaptation in horticulture
MCV00004	Climate change and variability: Assessing regional impacts of sugarcane production
MCV00005	Extremes, climate modes and reanalysis-based approaches to agricultural resilience
MCV00006	Assessing and managing heat stress in cereals
MCV00007	Teleconnections between climate drivers and regional climate, and model representation of links
MCV00008	Improving forecast accuracy, especially with improved Indian Ocean Initialisation
MCV00009	Improving multi-week predictions
MCV00010	Understanding frost risk in a variable and changing climate
MCV00011	Climate drivers and weather features for Australia
MCV00012	Multi-week climate outlook products for Australia (Phase I)
MCV00013	Temperature extremes and cropping in WA
MCV00014	Managing climate variability communication plan and budget July 2010-June 2013
MCV00015	MCVP Coordinator
MCV00017	Communication support and administration
MCV00018	Website
MCV00019	Communication products
MCV00022	Program Officer
MCV00023	Program management committee
MCV00024	Independent chair of management committee
MCV00027	Monitoring and evaluation-planned projects
MCV00028	Climate analyser DSS tools
MCV00029	Specifying Australia's climate variability in the context of a changing climate
MCV00030	Adding value to climate risk management decision support systems
MCV00031	Predictions of heat extremes on the multi-week timescale
MCV00032	Northern Australia/Monsoon prediction
MCV000XY[a]	A pilot study linking multi-week climate forecasts to N fertiliser decisions
MCV000XZ[b]	Multi-week climate outlook products for Australia (Phase II)

[a]This project had not yet secured funds or contracted by February 2013, it is included here for information purposes only and its costs are not included in the quantitative analysis.

[b]This project has a Project Agreement drawn up as at February 2013 but it is awaiting a formalisation by GRDC and the research organisation, similarly, it is included here for information purposes only and its costs are not included in the quantitative analysis.

Project Investment

The MCVP is funded by its collaborating partners. When LWA was wound up in 2009 a total of $3.06 million was transferred to the MCV program under GRDC management in the year ending June 2010. In 2008 DAFF had provided funding for the "Communicating Climate Change with Agricultural Industries" project which was led by LWA for delivery of climate knowledge to farmers through information sheets, *Farmer Forums* and *Master of Climate* training. MCVP partners, with the exception of GRDC, have committed funding for the program to June 2013 which is the targeted Phase III completion year. GRDC has committed to support the program for a further one year to June 2014. For the 2009/10 to 2012/13 period, GRDC has contributed the highest proportion (35.2%) of the total funds into the MCVP Phases II and III. Table 2 shows the proportions of partners' contributions to MCVP Phases II and III. The LWA funds that were transferred to MCVP under GRDC's management do not include DAFF's funding as the DAFF funded project was completed prior to MCVP migration to GRDC. Also, a small part of the funding for MCVP came from income from a number of projects; these contributions are accounted for under the 'miscellaneous projects' income in Table 2.

Table 2: MCVP Funding Sources and the Proportions of Funding by Source

Source of Funding	**Proportion of Total Funding (%)**
GRDC	35.2
LWA(a)	39.4
MLA	11.6
RIRDC	3.2
SRDC	2.7
Dairy Australia	1.5
Miscellaneous Projects Income	6.4
Total	100

[a] LWA funding proportion includes funds provided by all other MCVP partners except DAFF prior to June 2009

Source: MCVP Budget Data

The following tables show the annual investment by project for both MCVP funds (Table 3) and for researchers and other investors (Table 4). Table 5 provides the total investment by year from both sources.

Table 3: Investment by MCVP Partners by Project for Years Ending June 2009 to June 2014 (nominal $)

Project Code	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	Total
MCV00002	305,000	220,000	471,000	0	0	0	996,000
HAL00003	15,000	15,000	15,000	0	0	0	45,000
MCV00004	75,000	25,000	0	0	0	0	100,00
MCV00005	38,250	125,000	0	0	0	0	163,250
MCV00006	20,000	60,000	82,000	40,000	43,000	0	245,000
MCV00007	0	233,331	233,331	233,338	0	0	700,000
MCV00008	0	192,700	283,199	297,500	76,600	0	849,999
MCV00009	0	182,800	245,600	255,200	66,400	0	750,000
MCV00010	0	135,810	136,165	144,379	0	0	416,354
MCV00011	0	22,000	0	0	0	0	22,000
MCV00012	0	150,000	0	0	0	0	150,000
MCV00013	0	30,794	111,502	115,928	41,670	0	299,894
MCV00014	0	337,238	286,438	227,900	211,900	0	1,063,476
MCV00015	0	152,672	114,397	75,000	99,000	0	441,069
MCV00017	0	0	10,500	10,500	10,500	0	31,500
MCV00018	0	375	0	0	0	0	375
MCV00019	0	9,592	2,532	0	0	0	12,124
MCV00022	0	60,468	60,468	8,427	0	0	129,363
MCV00023	0	1,438	3,500	3,500	3,500	0	11,978
MCV00024	0	9,145	8,334	8,333	8,333	0	34,145
MCV00027	0	5,502	0	0	0	0	5,502
MCV00028	0	0	192,460	107,520	0	0	299,980
MCV00029	0	0	50,000	50,000	0	0	100,000
MCV00030	0	0	139,719	159,443	0	0	299,162
MCV00031	0	0	185,672	0	205,108	109,248	500,028
MCV00032	0	0	36,150	194,902	268,948	0	500,000
Total	453,250	1,968,865	2,667,967	1,931,870	1,034,959	109,248	8,166,159
MCV000XY[c]	*0*	*0*	*0*	*0*	*0*	*80,000*	*80,000*
MCV000XZ[c]	*0*	*0*	*0*	*0*	*0*	*190,000*	*190,000*

[c]Figures indicate assumed cost estimates and are not included in present value calculations as project contracts were not yet formalised as at February 2013

Source: MCVP Project reports and proposals

Table 4: Investment by Researchers and Others by Project for Years Ending June 2009 to June 2014 (nominal $)

Project Code	**2008/09**	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**Total**
MCV00002	454,009	376,475	282,961	0	0	0	1,113,445
HAL00003	15,000	15,000	15,000	0	0	0	45,000
MCV00004	138,417	0	0	0	0	0	138,417
MCV00005	34,875	157,500	0	0	0	0	192,375
MCV00006	62,000	62,000	62,000	0	0	0	186,000
MCV00007	0	233,333	233,333	233,334	0	0	700,000
MCV00008	0	207,300	283,400	290,600	74,500	0	855,800
MCV00009	0	181,700	252,000	252,500	65,600	0	751,800
MCV00010	0	80,743	108,787	114,965	0	0	304,495
MCV00011	0	20,000	0	0	0	0	20,000
MCV00012	0	72,000	0	0	0	0	72,000
MCV00013	0	54,700	177,000	156,200	104,000	0	491,900
MCV00014	0	0	0	0	0	0	0
MCV00015	0	0	0	0	0	0	0
MCV00017	0	0	0	0	0	0	0
MCV00018	0	0	0	0	0	0	0
MCV00019	0	0	0	0	0	0	0
MCV00022	0	0	0	0	0	0	0
MCV00023	0	0	0	0	0	0	0
MCV00024	0	0	0	0	0	0	0
MCV00027	0	0	0	0	0	0	0
MCV00028	0	0	0	0	0	0	0
MCV00029	0	0	115,225	115,325	0	0	230,550
MCV00030	0	0	48,800	81,600	0	0	130,400
MCV00031	0	0	196,118	203,962	106,060	0	506,140
MCV00032	0	0	105,295	203,543	211,685	0	520,523
Total	704,301	1,460,751	1,879,919	1,652,029	561,845	0	6,258,845
MCV000XY[d]	*0*	*0*	*0*	*0*	*0*	*0*	*0*
MCV000XZ[d]	*0*	*0*	*0*	*0*	*0*	*80,000*	*80,000*

[d]Figures indicate assumed funding estimate and are not included in present values calculations as project contracts were not yet formalised as at January 2013.

Source: MCVP Project reports and proposals

Table 5: Annual Investment in 26 MCVP Projects (nominal $)

Year ending June	MCVP Partners	Researchers and Others	Total
2009	453,250	704,301	1,157,551
2010	1,968,865	1,460,751	3,429,616
2011	2,667,967	1,879,919	4,547,886
2012	1,931,870	1,652,029	3,583,899
2013	1,034,959	561,845	1,596,804
2014	109,248	0	109,248
Total	8,166,159	6,258,845	14,425,004

3. Description of the Projects

The 28 projects identified in this analysis included research, communication and management/administration investments. The communication and management/ administration projects account for 12% of the total. BoM is the major research agency and is undertaking a number of projects aimed at more rapid development of a wider range of forecasts based on POAMA. The Climate Champions Program (CCP) within MCV00014 is a major communications focus for the overall investment. The CCP is managed by Econnect Communications which also has responsibilities for websites, newsletters and general communication activities.

The diverse projects in this analysis mainly fit into the applied research category. These projects sought to produce useful information mainly for the Australian primary industries and natural resource management sectors. Some projects such as forecasting the onset of the northern monsoon were targeted at regions and will be of value to key industries such as northern Australian beef. Others such as those targeting development of new multi-week forecasts will be more generic. MCV00013 "*Temperature extremes and cropping in Western Australia"* is an example of a beneficial project for agricultural industries that was aimed at assessing the impact of heat and frost variability for the south west region of Western Australia. Identifying likely trends resulting from climate change was also an objective. There were projects on DSS, for example developments for Yield Prophet which is based on APSIM and on mobile applications to facilitate access to climate and weather data. The APSIM was also used to investigate climate impacts on a sugar industry region. Many of the projects also had overlapping outcomes that were aimed at improving climate risk management by Australian farmers through developing and/or improving forecasting tools (e.g. multi-week rain and temperature forecasts). Other projects sought to understand the science behind Australian climate variability by reviewing past and current literature, studying historical datasets and hindcasting recorded and/or forecasting future climate.

The Appendix contains a detailed summary of each project included in this analysis. The summary covers the rationale, objectives, specific activities and outputs, outcomes and benefits for each of the projects.

4. Benefits

The actual and potential benefits derived from MCVP Phases II and III are primarily underpinned by the adoption by agricultural industries of profitable climate risk management strategies that have relied on improved forecasting methods produced by the projects. Adoption of MCVP products and use of climate risk information by primary industries also leads to some significant spill-over benefits in other areas such as natural resource management, insurance and all levels of government. Better natural resource management is a major public environmental benefit e.g. reduced negative impacts on sensitive waterways and marine ecosystems. Increases in community resilience will also result from more stable and profitable farming for different Australian farming communities. The new multi-week forecasts are likely to have major benefits to the community generally if they are shown to have sufficient skill and are promoted as an adjunct to short term weather forecasts.

Representatives of the organisations funding the MCVP were contacted for their views on the main benefits from their investment in MCVP. Important points from those who responded were:

- MCVP continues to be an outstanding example of the RDCs combining on a collaborative approach to a major national concern,
- The collaborative approach is of value in managing spillovers from generic national projects,
- Being part of the program is particularly valuable in giving timely access to new developments,
- Initiatives such as the investments in multi-week forecasts look likely to be a significant coup and confirmation of the advantages of a small independent research program able to exert leverage, and
- Concerns raised were the lack of investment support from some industries and the low levels of adoption in some regions.

MCVP has produced significant outputs for improving the accuracy of forecast models and their ease of use for on-farm decision making. However there has been limited information available on current levels of adoption and the likely uptake of program outputs by farmers. Information on the likely uptake is clearly limited because some key outputs are still experimental products being refined for release during 2013. Nonetheless, this program should result in wider and improved climate risk management as forecast skills improve and decision support tools become more accessible to farmers and easier to use. This will lead to reduced negative impacts of a changing and variable climate on farm incomes, the environment and society at large. Table 6 summarises the principal benefits types delivered by each of the projects.

Table 6: Type of Benefit Delivered by Projects

Project code	**Principal Benefit Types Identified** [(b)]					
	Increased farm profits and/or reduced losses	Better natural resource management	Enhanced awareness and capacity to adapt to climate change	More efficient public and industry research resource allocation	Enhanced community preparedness and resilience	Enhanced scientific knowledge
MCV00002	√	√			√	√
HAL00003	√				√	√
MCV00004	√	√				√
MCV00005	√			√	√	
MCV00006	√					√
MCV00007	√					√
MCV00008	√					√
MCV00009	√	√				√
MCV00010	√					√
MCV00011	√				√	√
MCV00012	√	√			√	
MCV00013	√				√	√
MCV00014			√	√		
MCV00015			√	√		
MCV00017			√	√		
MCV00018			√	√		
MCV00019			√	√		
MCV00022			√	√		
MCV00023			√	√		
MCV00024			√	√		
MCV00027				√		
MCV00028	√	√			√	√
MCV00029	√	√				√
MCV00030	√	√			√	√
MCV00031	√					√
MCV00032	√	√			√	√
MCV000XY	√	√				√
MCV000XZ	√	√			√	

[(b)]These do not explicitly identify spill-over benefits

Table 7 provides in a triple bottom line framework a summary of the principal types of benefits associated with the outcomes of the investment in MCVP Phases II and III. The table provides information with regard to the public versus private nature of the benefits.

Table 7: Triple Bottom Line Summary of Principal Benefits from the Investment

Levy Paying Industries	**Spillovers**	
	Other Industries	**Public**
Economic Benefits		
Increased farm profits Reduced farm losses Enhanced awareness and adoption of climate risk information	Diverse benefits from improved seasonal and multi-week forecasts	Diverse benefits from improved seasonal and multi-week forecasts
Environmental Benefits		
Better natural resource management		Better natural resource management
Social Benefits		
Enhanced scientific knowledge More efficient industry research resource allocation	Enhanced awareness of climate risk information and capacity to adapt to climate change	Enhanced community resilience Enhanced scientific knowledge More efficient public research resource allocation

Public versus Private Benefits

The MCVP was created to increase Australia's capacity to capture opportunities and manage risks that emanate from climate variability. Therefore the benefits identified are both private and public. The ultimate primary benefit of many of the projects in this analysis is in the form of increased/sustained farm profits in some years and/or reduced negative impacts on farm incomes in other years. In addition, there is improved capacity to adapt to climate change. Most of the projects analysed contributed to these private benefits; however there are other significant public benefits such as reductions in nutrient and sediment run-off into sensitive waterways and marine ecosystems and enhancing of community preparedness and resilience. The integrated management of the program has no doubt contributed to improved research resource allocation in the area of climate variability.

Many of the projects also contributed to enhancement of scientific knowledge and sharing of climate risk management strategies; the general public is likely to benefit from this information as well.

Distribution of Benefits Along the Supply Chain

The benefits from this investment will largely accrue to the Australian primary industries, as that is largely where the tools and products being developed are targeted. These industry benefits will be distributed between producers and along the supply chains including consumers.

Benefits to Other Industries/Sectors

Other industries apart from primary industries are likely to benefit from the research undertaken in this program through climate risk information availability for decision making e.g. weather index for insurance purposes.

Benefits Overseas

It is unlikely that there will be significant direct benefits to overseas industries; however some of the scientific knowledge and the processes developed from the MCVP are clearly of relevance to overseas interests. The advantages of the MCVP model have been previously recognised for its contribution to linking users of forecasts to the developers of improved forecasts. A funding model that recognised the public/private nature of the partnership was one key aspect (Cash and Buizer 2005). A case study on the CCP is currently being prepared with the National Farmers Federation for a publication involving the World Meteorological Organisation (WMO) and the World Farmers' Organisation (Beverley Henry, pers. comm., 2013).

Additionality and Marginality

Due to the principal sources of funding, the investment in MCVP was targeted primarily towards rural industries. These projects would have been regarded as medium to high priority by levy payers. In the event that the government matching contribution to the RDCs was restricted, it is likely that some (but perhaps not all) of these projects would have still been funded but at a reduced level of funding, assuming a levy system was still in place.

If no public funding at all had been available, it is likely that the investment would have been curtailed to about 50% of the actual MCVP budget. This would have been associated most likely with a somewhat reduced set of public benefits, depending on how the reductions in investment were spread across projects and the responses by non-RDC funders and researchers. Further detail is presented in Table 8.

Table 8: Potential Response to Reduced Public Funding to the RDCs

What priority were the projects in this cluster when funded?	Medium to High
Would MCVP partners have funded the program if only half of public funding to the RDCs had been available?	Yes, but with a reduced number of projects funded and/or reduced overall funding amount.
Would the cluster have been funded if no public funding for the RDCs had been available?	Yes, 50% of the actual funding

Match with National Priorities

The Australian Government's national and rural R&D priorities are reproduced in Table 9 as sourced from the Department of Industry, Innovation, Science, Research and Tertiary Education (DIISRTE, undated), and the Department of Agriculture, Fisheries and Forestry (DAFF, 2007).

Table 9: National and Rural R&D Research Priorities

National Research Priorities	**Rural Research Priorities**
1. An environmentally sustainable Australia 2. Promoting and maintaining good health 3. Frontier technologies for building and transforming Australian industries 4. Safeguarding Australia	1. Productivity and adding value 2. Supply chain and markets 3. Natural resource management 4.Climate variability and climate change 5. Biosecurity *Supporting the priorities:* Innovation skills Technology

The program contributes directly to National Research Priorities 1 and 3. Rural Research Priority 1, 3 and 4 are directly addressed by the program. Both supporting priorities are addressed by the MCVP projects.

5. Pathway to Adoption

Seasonal climate forecasts, the original focus of MCVP research, were first made widely available over two decades ago. The 1982/83 El Niño event created widespread awareness of the role that El Niño had in major Australian droughts and introduced the opportunity to predict a season ahead. Over two decades MCVP has funded numerous research projects and developed products to increase understanding and use of seasonal climate forecasts to manage climate-related risk. There is coverage to at least some extent of all major Australian regions and agricultural industries. There have also been some exploratory projects in water resources and natural resources management. In recent years there has been a rapid expansion in government programs promoting increased awareness of climate change impacts and of the benefits from adapting by increased understanding of climate variability. Over that period other agencies have increased their promotion of climate risk management through activities such as training programs and web-based products. Pathways continue to expand and range from direct provision of seasonal climate forecasts to decision support systems (DSS) such as Yield Prophet, and more recently to mobile applications.

The climate context

Climate variability has major impacts on Australian economic activity additional to agricultural impacts. For the vulnerability of the USA economy to climate variability, Lazo et al (2011) estimated a range of 3.4% of GDP based on the difference between the best and the worst climate impact years analysed. A conservative estimate for Australia assuming similar vulnerability indicates possible impacts on the Australian economy of the order of $50 billion. Recent climate variability has been shown to be an important factor influencing demand for climate information. (See discussion on adoption in the following section).

As shown in Figure 1 by the pattern of Australian wheat yields since 1990, yields over the last decade in particular have been highly variable. As stated for the major wheat producing state, Western Australia where there had been rapid yield increases during the 1990s "*It is notable that the low variability of yield during the period of rapid increase has been followed by a period since about 2000 of quite extreme variability of yield. It might be inferred that an unstable yield plateau has been reached, characterised by variable yield and associated with extreme variability of seasonal rainfall*" (DAFWA 2012).

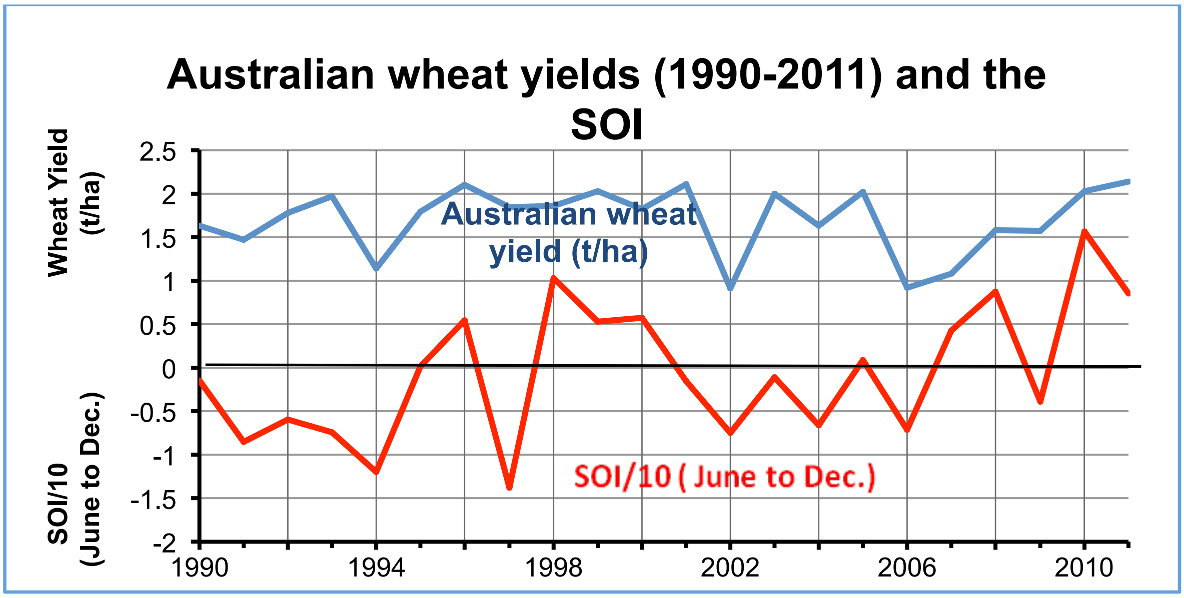

Figure 1: Australian wheat yields and the SOI over the period from 1990 to 2011

Source: Wheat yield data, ABARE (2012): SOI, Longpaddock (2013a)

The overall Australian pattern has been for major droughts, as evidenced by low wheat yields, to be related to widespread El Niño events indicated by generally low values of the SOI (one exception was 1997 with late rain, but which was an extreme El Niño and a year of record global temperature). The period since 1990 ended with an extreme La Niña event bringing extensive flooding to much of eastern Australia. The extended droughts, widespread flooding and increasing concerns on the current impacts of climate change particularly since the 2002 drought, were contributors to an increased awareness of climate risks and how to manage them. In the Murray Darling Basin for example, all years from 1996 to 2012 have had annual mean temperatures above average (WATL, 2012). The MCVP priorities have expanded to include forecasts of temperature extremes.

Sources of Information

Farmers now have access to what could be an overwhelming array of sources of climate and weather information from Australian and international sources. The Victorian DPI provides a recent example of the choices available in their expanded program of information on climate risk management. Included in the monthly newsletter, Fast Break (Vic DPI, 2012), are various outputs from five GCMs including POAMA experimental forecasts, three ensemble forecasts which combine individual forecasts, and three statistical forecasts.

A new MCVP product CliMate (project MCV000028), has recently been accepted as a mobile application (http://www.managingclimate.gov.au/news/new-free-climate-app-for-farmers/). The application for iPad and iPhone users gives easy access for queries on weather and climate information for a farmer's location. A web version will be made available in March, 2013. The application has had rapid early adoption despite limited publicity. Since it was first loaded on iTunes in mid-December 2012, CliMate has already been taken up by more than 3,000 by the end of January 2013 (David Freebairn, pers. comm., 2013).

The departments of agriculture in all states are providing expanded services related to climate risk management. Longpaddock (2012) was first established in the mid 1990s by the Queensland Department of Primary Industries. Current services provided by most states include web-based products, weekly newspaper articles and farm-or paddock-specific products. Products developed with support from MCVP and predecessor programs have had a crucial role in providing the products and the credibility to support the expansion. In Western Australia, the Department of Agriculture and Food produce a comprehensive monthly climate outlook. A new feature is a three month rainfall outlook from the Department's Statistical Seasonal Forecast system specifically for the Western Australian wheat belt (King, 2012). The forecasts are based on patterns of sea surface temperature (SST) and atmospheric pressure.

Other states, apart from Queensland with rapid early expansion during the drought years of the early 1990s and Victoria in the last decade, generally had their initial rapid expansion of training and information sources during the late 1990s. The proportion of Victorian farmers receiving climate information from the Victorian DPI increased from 17% in 2009 to 25% in 2011 (Anderson et al, 2012). It should be noted that although farmers use a wide range of sources of climate information, the sources often link back to BoM products or to products based on

BoM data. Farmers also use forecasts from different agencies. For example the Victorian survey showed that although an average over two surveys of 69% of farmers viewed the BoM seasonal climate outlook, 55% viewed other long range forecasts. Clearly some farmers check more than one source from the increasing range of Australian and international products. But as shown by Watkins and Jones (2012) there is often poor comprehension of seasonal forecasts based on probabilities. That finding is consistent with numerous earlier studies and studies in other fields, particularly psychology.

The probabilistic nature of seasonal forecasts remains as one of the on-going barriers to clear communication. It is likely that many farmers simply react to a headline warning of an El Niño as having a certain impact at their location. This perception ignores the probability basis as determined by the complexity of past seasonal and spatial patterns. A recency bias is also likely where the risk is determined from experience in only the last few years. Perceptions on whether forecast skill is reduced by climate change are likely to be a further constraint on adoption of statistical forecasts. As one provider stated "*Climate forecasts deal in probabilities and a probability-based forecast is not a definitive forecast. If you are not comfortable with probability based forecasts do not incorporate them into your management decisions*" (DAFF Qld 2012). Surveys of users of forecasts have been undertaken to help ensure more effective presentation of the new forecasts being developed based on POAMA (Econnect 2007, 2008).

The grains industry has been the focus of many climate risk management activities. Australia's first agriculture and climate blog and discussion site for advisers, growers and researchers (www.agriclimateculture.com.au) has been launched (GRDC 2010). The GRDC Farmer Survey (IPSOS 2010) reported on the diverse sources of general farming information used by farmers - "*The most common source of information for growers regarding farming practice change is their peers, other growers at 18%*". The Survey further stated "*Local contacts and support networks (agronomists, other growers, etc) are the most trusted sources of information and advice, and are highly influential in growers' farm management decisions*". Grower groups, field days, rural weeklies and leading growers in their district were all mentioned as influential. In recognition of these sources of information, MCVP including partners such as GRDC funded the Climate Champion Program (GRDC 2012a) whereby 34 famers were selected to take a role in improving communication on climate risk management with farmers in their industry and district. The participants in response to a survey question on the preferred sources of information on climate risk management for farmers in their area, ranked demonstrations including field days highest followed by information from their farm advisers and extension officers.

Econnect Communication manages the Climate Champion Program (CCP) as part of MCVP. Activities of the CCP and a wide range of sources of information on climate risk management are updated on an MCVP-managed website, Climate Kelpie (http://www.climatekelpie.com.au/). The site includes interviews with participants in CCP. In the six months to 30 June 2011, 5,384 visitors viewed 13,725 pages on Climate Kelpie (GRDC 2011). The website includes more than 20 DSS-type tools relevant to climate risk management.

The CCP provides an example of a major communication project in the current MCVP phase. The pathways to adoption developed by the Program result directly from the activities of the individual participants in CCP together with the range of communication and support activities undertaken by Econnect. For example, there were 186 media items over a 12-month period since March 2010 - an average of one item every two days. A highlight was the National Press Club event as part of a CCP national workshop. The CCP investment through its regional and industry coverage potentially has national scope. In addition much of the communications activity is delivered through national media and through industry-wide media such as "Ground Cover" for the grain industry. The participants in CCP clearly are an efficient way for regional and national media to source farmer content and case studies on a wide range of climate topics. The participants are also active contributors to MCVP research projects including a key role in product development.

Decision Support Systems (DSS)

Hochman and Carberry (2011) in a previous phase of MCVP surveyed stakeholders on DSS. They documented an emerging consensus on DSS characteristics which might turn around the generally poor direct adoption by farmers of DSS. Proposals for best practice included more rigorous finance and market planning of projects, and an emphasis on tools that encourage experimentation and support farmers intuition, as well as measures to strengthen existing networks. The survey did not directly address more indirect pathways that might arise for example through capacity building, consolidating feedback and knowledge, mobile applications and social networking, and stimulating integrative science.

There are many existing technologies such as no-till that help farmers adapt to climate variability and change. In Victoria the traditional pathways available through existing industry programs have been expanded to more effectively incorporate climate risk management as a mainstream activity. A previous phase of MCVP funded an expansion of extension services in climate risk management in Victoria. One outcome was the development of close links with BoM research and development. These links are used currently for consultation on forecast delivery for several of the current BoM projects funded by MCVP (Chris Sounness, pers. comm., 2012). The MCVP newsletter CliMag which was launched in 1999 was also acknowledged as an important pathway providing information on current MCVP activities.

The Pathway for Multi-Week Forecasts

The current MCVP phase includes an expanded focus which will eventually lead to an additional pathway. Research on improved seasonal climate forecasts has been augmented by research on multi-week forecasts. Increased skill, particularly if also demonstrated by current research for forecasts of extremes, has resulted from the MCVP focus on the time scale between weather forecasts a week ahead and seasonal climate forecasts. There is expected to be an exceptionally strong demand for multi-week forecasts and this can be met by changes to an existing pathway. The BoM website to which MCVP contributed, Water and the Land (WATL), is being redeveloped as a vehicle for seamless delivery during 2013 of POAMA forecasts at various timescales from weather to seasonal.

As indicated above, farmers currently access a wide range of sources of information on seasonal climate forecasts. Users of forecasts can be expected to make increased use of climate models at the expense of statistical forecasts based on historical relationships which may be less robust as the climate changes. With the changed emphasis of MCVP to include multi-week forecasts and on special purpose products from POAMA, there is likely to be a greater consolidation of pathways to adoption. POAMA has the capacity to readily produce forecasts for a wide range of meteorological variables such as wind and evaporation beyond current weather time scales.

6. Measurement of Benefits

As shown in Section 1, the current phase of MCVP builds on substantial investments of over $40 million (nominal) since the first investments two decades ago. With a continuing program, there are clearly attribution problems between benefits from past and current projects. The diversity of projects is another challenge. The benefits will result from MCVP investments in the underlying science to improve forecast skill, from improved communication to users, and through applications and tools that develop the capacity of users to manage climate risks. A simple aggregated approach is all that is justified given the diversity of projects and the limited data available on likely future adoption and benefits. One part of the MCVP, the CCP, has been evaluated (GRDC 2012b). That evaluation assumed that the benefits from the investment of about $1 million resulted from increased local adoption from the activities of the participants in the CCP. As for the MCVP generally, there was little data available on the likely additional adoption and benefits that could be attributed to the CCP investment. The estimated gross benefits were of the order of $3 million. Given the relatively small investment in CCP compared with the $14.4 million (Table 5, nominal dollars) investment in MCVP, the benefits from CCP are simply assumed to be a contributor to the total MCVP benefits and not accounted for separately.

The BoM is the lead agency for one third of the projects in this evaluation accounting for close to 40% of the MCVP investment. "*For the five years from 2009 to 2013, Managing Climate Variability is contributing in excess of $6 million, matched by the Bureau and CSIRO, to improving dynamical modelling-based climate forecasting*" (Binney 2011). The BoM funded projects all focus on improving POAMA forecasts and applications together with the presentation of products and most are concerned with prediction using various aspects of POAMA. Applications include impacts of extremes, which are being developed so they can use POAMA forecasts. POAMA seamless products will span time scales from weeks to seasons. Many of the other non-BoM projects funded depend to some extent on increased adoption of POAMA-based forecasts for example projects on frost risk and high temperature extremes.

Note the evaluation is not of the benefits resulting from all the various investments in POAMA. However, the benefits from POAMA in relation to the current BoM Seasonal Climate Outlooks (SCO) it will replace in 2013 will determine the adoption level POAMA will achieve. That adoption level will limit the benefits that can be achieved by the MCVP investment in this evaluation.

POAMA has been in development for over a decade and has evolved from a major CVAP project in 1999 which brought together resources in CSIRO and BoM to collaborate for the first time on a coupled ocean atmosphere model (CliMag 2002). Supercomputing capacity has been a major constraint on development to allow a more rapid transition from experimental to operational.

Benefits Measured

In accordance with previous evaluations, the main benefits to be measured are the increased profits to farmers that can be attributed to activities of the MCVP leading to improved climate risk management. Consistent with previous analyses and given very limited data availability on industry and regional adoption and benefits for various projects, an aggregate approach has been used. The increase has been assessed as simply an increase in net farm income.

In common with various approaches to extension and technology transfer, quantitative evaluation is exceptionally difficult for programs of this nature. Diffusion of information is via multiple pathways and it is usually not possible to attribute practice change to specific activities. Subjective estimates of low confidence will be made of the possible benefits as there are only two analyses of the benefits from using POAMA seasonal forecasts in farm management decisions (Asseng et al., 2012 a, b).

Previous evaluations were limited to benefits of seasonal climate forecasts. The current evaluation needs also to incorporate benefits from multi-week forecasts and forecasts of the onset of the northern wet season from improved POAMA modelling. These are effectively new products with potentially new markets. Previous analyses have taken estimates of benefits into account from a wide range of analyses simulating potential gains from using seasonal climate forecasts. These analyses could be easily undertaken using analogue years and comparing a strategy using skilful forecasts to one limited to climatology. A particular value of analogue years was the familiarity farmers have with their climatology as in their weather record, and with outcomes in specific years that are analogous to a current year. Probability forecasts from POAMA are generated using an ensemble approach generated from consecutive daily forecasts each with varying initial conditions. Procedures to facilitate the routine use of POAMA forecasts in simulation models remain in development. Demonstrations of POAMA value will have an important role in encouraging adoption. However unlike statistical forecasts which can be used to simulate outcomes for up to a century or more using the historical records of the SOI for example, hindcasts using POAMA are limited to the last few decades by the limited availability of data for many inputs, for example from satellite observations.

The latest version of POAMA (as summarised by Lim et al 2012):

- demonstrates internationally competitive skill in predicting ENSO (El Niño Southern Oscillation), and IOD with a scope for further improvements,
- is one of the best individual models in predicting Australian climate,
- demonstrates high skill in predicting seasonal mean of maximum temperatures and moderate skill (better than climatological forecasts) in predicting seasonal mean rainfall and minimum temperatures, and
- in regard to predicting Australian rainfall and temperatures, the accuracy and reliability of POAMA forecasts should be further improved by various efforts such as improving model physics, model resolution, ensemble generation strategy, etc.

The estimation of benefits will proceed by an outline of the skill of current seasonal climate forecasts as a basis for considering possible improvements to be had once POAMA is operational. For multi-week forecasts, the value of POAMA products will depend on their skill and demonstrations of additional value compared with other sources of information currently used or likely to be used in future. The examples of skill are from interim versions of POAMA. The operational versions will have skill measures based on more data and using more effective operational presentations of skill. In addition there are current MCVP projects which will contribute to improved skill, for example project MCV00008 is helping to improve the initialisation in the Indian Ocean, and project MCV00032 is on Northern Australia monsoon prediction.

Benefits Not Measured

The evaluation takes an aggregate approach based on judgements of the increase in POAMA benefits to the agricultural sector generally. Therefore benefits from the projects not specifically related to POAMA are recognised but not measured or valued. In addition to benefits to other sectors of the economy, improved climate risk management also contributes to environmental and social benefits, for example from reduced erosion and nutrient loss, and through improved drought management. The potential to reduce or at least have greater control over income variability is an important aspect that also has likely community benefits. More effective use of seasonal climate forecasts is acknowledged as one of the obvious ways that farmers can adapt to a changing climate with an increasing frequency of extreme events. This evaluation does not attempt to isolate that benefit.

The Counterfactual

Benefits will be estimated over a 30 year period against the base of a counterfactual scenario, that is, the likely pattern of benefits that would have eventuated if there had been no MCVP investment in Phases II and III. In the 2007 evaluation, the investment in MCVP Phase I was assumed to increase adoption to 55% of Australian farmers by 2016/17 compared with the 50% base assumed in 2006. But only 10% were assumed to achieve a substantial increase in profits from using seasonal climate forecasts. In MCVP Phase I, investments concentrated on increased adoption through new industry and regional applications rather than directly on improved skill as is the case with much of the current phase. Most projects were by funding to agencies to undertake joint projects. These projects were unlikely to eventuate without MCVP funding thus simplifying attribution. The current investment is also different in that respect. A high proportion of the funding was to BoM projects which would have continued to some extent but would have lacked the direct user focus and the links with rural industries that MCVP provided. This has implications for the increase in the rate of development and the rate of adoption attributable to the MCVP investment.

Adoption and Skill Levels of Current Forecasts

The level and pattern of skill of existing seasonal climate forecasts provides a baseline for considering the pattern of possible gains in terms of skill and whether there is some limit to the achievable adoption level. The demand for improved forecasts could be expected to vary regionally and seasonally as determined by the timing of risky decisions. As part of a previous evaluation, an analysis was done of the adoption of seasonal climate forecasts in relation to a simple measure of forecast skill. A revised presentation is shown in Figure 2 incorporating the data presented on an industry and major state basis.

The adoption measure used was the proportion of farmers taking seasonal forecasts into account (from Agriculture Advancing Australia surveys in 2000 and 2002 of a sample of 2,500 Australian farmers (CliMag 2005)). Representative rainfall stations, 23 in total, were selected for major industries weighted by industry size and location. Some stations were used more than once; Narrabri for example was used for grain and cotton. RAINMAN (Clewett et al 2003) was used to calculate shifts in the probability of a greater than median rainfall for La Niña and El Niño years (as defined simply for this purpose by an SOI of less or greater than 7 in the preceding three months).

As shown in Figure 2 and as might be expected, there is a pattern indicating a clear positive relationship between skill and adoption as defined. For example the low level in Western Australia reflects the reduced impact of ENSO and the limited number of months when there is a substantial shift in rainfall probabilities useful in decisions related to the seasonal cropping pattern. The demand for seasonal forecasts as in the rest of the grain belt around Australia is greatest in and before autumn to plan inputs and timing for winter crops. From that perspective, autumn forecasts are seen as most valuable. However for other decisions relating for example to winter crop marketing and nitrogen top dressing a winter spring forecast would be most valuable. In contrast to low skill in Western Australia , at Birchip the probability of above median rain is of the order of 20% in spring for an SOI<-7 in preceding months. The shift in probabilities for spring is therefore of the order of 30% from the median of 50%. Over all months with SOI<-7, the average is about 12%, similar to the average for Victoria in Figure 2. In northern Australia, spring and summer forecasts are more valuable for some industries, for example summer grain crops, sugar cane and cattle grazing. For other major industries such as horticulture, temperature forecasts at longer lead times are particularly valuable (Peter Deuter, pers. comm., 2013)

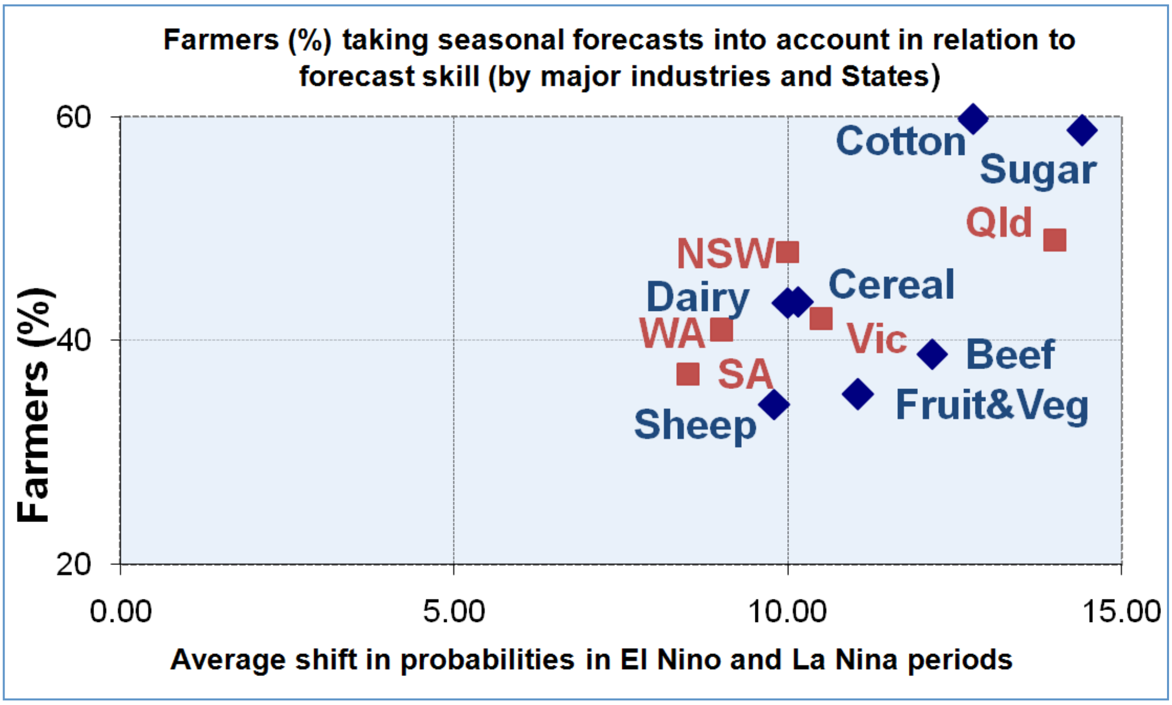

Figure 2: The proportion of Australian farmers taking seasonal climate forecasts into account in relation to a measure of forecast skill for their industry or State.

Source: Adapted from Land and Water Australia (2007) and based on surveys in 2000 and 2002

The data in Figure 2 provide an estimate (from more than a decade ago) of the proportion of Australian farmers taking seasonal climate forecasts into account. The proportion was 45% for Australian farmers overall compared with 43% for Victoria. A recent Victorian survey provides the best data to give some indication of the likely current Australian proportion. The Victoria average in relation to a more specific question on use of the BoM seasonal forecast for surveys in 2009 and 2011 was 69%. However, in comparison with most states, the extension effort to increase adoption of improved climate risk management increased in the last decade from a low base in Victoria during the 1990s. The baseline proportion for this evaluation is the proportion using any seasonal forecast as one category of potential adopters of POAMA seasonal forecasts. The Victorian survey showed 55% of farmers were using other seasonal forecasts. It can therefore be concluded conservatively that the proportion of Australian farmers using at least one seasonal forecast is likely to be at least in the vicinity of three out of four. It is possible that there remain a significant proportion of Australian farms that don't take seasonal forecasts into account. Explanations include the lack of skill of the forecasts at the time of key decisions or because of the nature of the enterprise, for example with irrigation from a secure supply. If that is the case current adoption levels may be close to a ceiling level unless there is a significant increase in regional and seasonal skill of forecasts.

The pattern of geographic and industry skill available to current users of the various seasonal climate forecasts could be expected to be broadly similar to that shown in Figure 2, at least for the purpose of showing opportunities for POAMA to lift skill for example if the ENSO and IOD signals are well represented. The BoM Outlook based on Pacific and Indian SST does incorporate explicitly an Indian Ocean component but an objective comparison of skill has not been located. The IOD signal is to some extent associated with the ENSO signal. In any case the SOI includes some Indian Ocean influence as it is based on Darwin and Tahiti pressure.

Potential Improvements in Forecast Skill

There are a number of aspects to increases in skill apart from the simple measure in Figure 2. For example important questions for some industries will include whether the period and the lead time when there is useful skill have been extended marginally or radically. One key question is whether POAMA will add skill generally (equivalent to a vertical shift in Figure 2) or increase skill in areas such as South Australia and Western Australia where skill and adoption were lower. The answer would depend to some extent on the limits to predictability and relevance to the timing of decisions, and whether there is in some sense an adoption ceiling being approached.

In relation to overall skill, it can be assumed that POAMA will not become operational until it is demonstrably superior to the current BoM Seasonal Outlook based on a statistical model of SST in the Indian and Pacific Oceans. Charles et al (2011) stated "*the poor reliability of seasonal forecasts based on dynamical coupled models is a barrier to their adoption as official outlooks by the Bureau of Meteorology*". However, as shown by Watkins and Jones (2012), POAMA outlooks have progressed to the point where they are generally more skilful (i.e., are 'correct' more often) than statistical schemes. In the simple performance measure using hit rates of above the median, an older version of POAMA averaged 56% compared with 53% for the current Bureau SCO. (Note that hit rates are higher for temperature forecasts so that rainfall values will be less than the combined average). In relation to reliability, there has also been a significant step forward. Recently several techniques have been shown to be successful in improving the reliability of the forecasts, to the point where climatologists believe POAMA may no longer be misjudging the true likelihood of events happening as it did in the past (Andrew Watkins, pers. comm., 2013).

Given that 50% is the no-skill hit rate, the hit rate examples do demonstrate that seasonal forecasts particularly of rainfall, typically have generally low to moderate skill on average. The key question is whether POAMA forecasts will result in a dramatic shift. Improvements have been gradual and marginal rather than dramatic breakthroughs. That has been the case looking back over a century of research. Quayle (1910) showed there were useful relationships for northern Victoria based on using atmospheric pressure to forecast a season ahead. But there are exceptions to generally low skill on average. The exceptions can be critical if they have skill for forecasting extreme events. During the recent and extreme La Niña event, the seasonal outlook for rainfall issued for November-January 2010–11 had a 'per cent correct' statistic of 90%. Typically a high proportion of statistical forecasts cluster around the median. The exceptions are mostly winter spring forecasts in eastern Australia when there is a strong ENSO signal adding credibility and skill. Similarly in northern Australia forecasts of the onset of the wet season are also more skilful when there is an ENSO signal. In addition POAMA forecasts will be potentially improved through incorporating the IOD.

On the second question on the location (regional and seasonal) of increased skill, the provisional answer appears to be that POAMA improvements will be concentrated in areas and seasons of existing skill or knowledge, particularly from ENSO and the IOD. The IOD skill is still being clarified. For example the current skill in the south in winter was lower than expected given various model developments. Factors involved (Oscar Alves, pers. comm., 2013) are the lower skill related to the modelled influence of IOD and model deficiencies in teleconnecting the IOD influence to southern Australia. Lower than expected skill in north-eastern Australia is thought to be related to the El Niño biases that coupled models suffer.

As shown in Figure 3, there is clearly a substantial improvement in accuracy in autumn for POAMA 2 compared with the previous version. Note that the skill for the eventual operational version, POAMA-2m, will be based on a larger hind-cast set. Skill could be expected to further increase and be more stable with maps smoothed rather than gridded. The comparison is for the forecast of autumn rainfall, a key decision time in southern Australia. The POAMA 2 pattern is actually similar to the one for the same period based on a negative SOI in January and February. The negative SOI forecast at that time is actually for increased probability of above median rainfall presumed to reflect a swing to a La Niña event in some years; see Longpaddock (2013b).

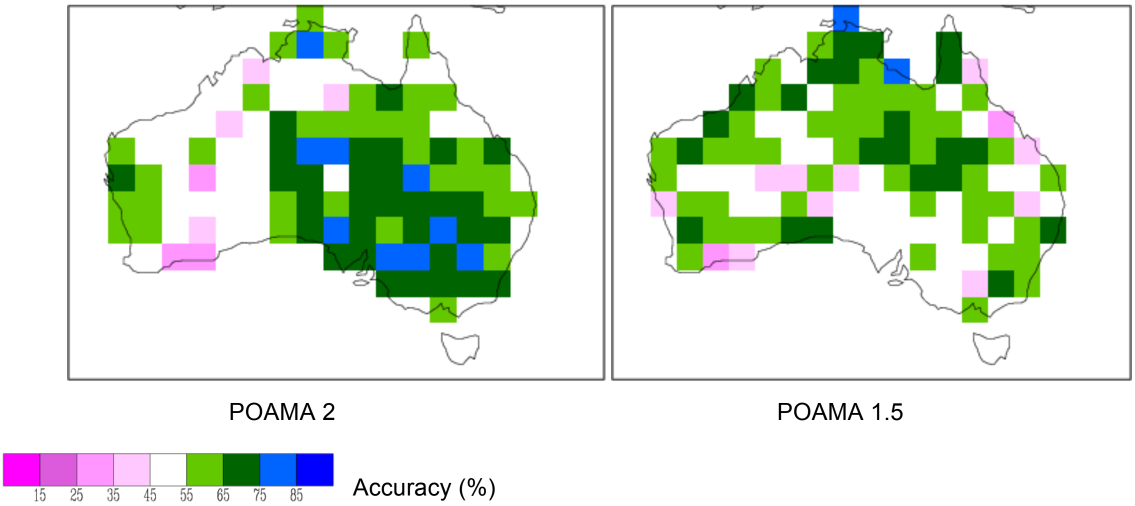

Figure 3: Accuracy score (%) for above median autumn (MAM) rainfall forecast for POAMA 2 and 1.5 for a lead time of one month for the 1980-2005 hindcast period.

Source: http://poama.BoM.gov.au/poama_skill/raintemp_poama15.shtml

Langford and Hendon (2011) evaluated POAMA P24 skill compared with forecasts from a range of international models. One difference was improvement in south-eastern Australia in autumn, a critical time for southern grain farmers and a gap time for ENSO forecasts. They also analysed comparisons of POAMA skill and reliability. POAMA version P24 was the most reliable individual model, and much more reliable than the earlier version P15b. Some particular models were superior in specific seasons. The analysis therefore concluded that for their purpose "*due to the clear need for improved reliability and more accurate seasonal rainfall forecasts for hydrological applications, we recommend further investigation of adopting an operational multi-model ensemble combining P24 with available European datasets*." Climate Kelpie lists an existing multi-model forecast from the International Research Institute for Climate and Society based on a weighted version of how several atmospheric models respond to expected SST patterns. This evaluation needs to take a long term view of the trend in likely benefits from POAMA compared to alternatives such as multi-model forecasts from international models and the resources available for POAMA to remain competitive. One possible development is the eventual inclusion of POAMA in a multi-model forecast which would increase forecast skill and may require some dilution of benefits.

Multi-Week Forecasts

Multi-week prediction is a developing research focus. The World Meteorological Organisation has recognised the potential and implemented a project on multi-week prediction. BoM is represented and Australian achievements in multi-week can be attributed to the MCVP project (Debra Hudson, pers. comm., 2013). For POAMA2 forecasting two weeks in advance, the most skilful periods are winter and spring for rainfall and spring for maximum temperature. The skill is much stronger in eastern Australia. Forecast skill is found to be increased during extremes of ENSO, the Indian Ocean Dipole and the Southern Annular Mode (SAM). There is higher skill in predicting the Madden Julian Oscillation. As shown in Figure 4 skill is currently highest when there is either a strong ENSO or an IOD with neutral ENSO.

The first multi-week project funded by MCVP established the strong case for including multi-week forecasts as a new BoM product. A current exploratory project will evaluate multi-week forecasts for forecasting extremes. These are considered to be potentially more valuable. A further investment would then be required to advance forecasts of extremes to operational status. The multi-week projects have also made important spillover contributions to POAMA generally. For example, enhancements to the ensemble generation strategy and initialisation of the forecasts were reported to have improved the reliability of the forecasts on the seasonal timescale.

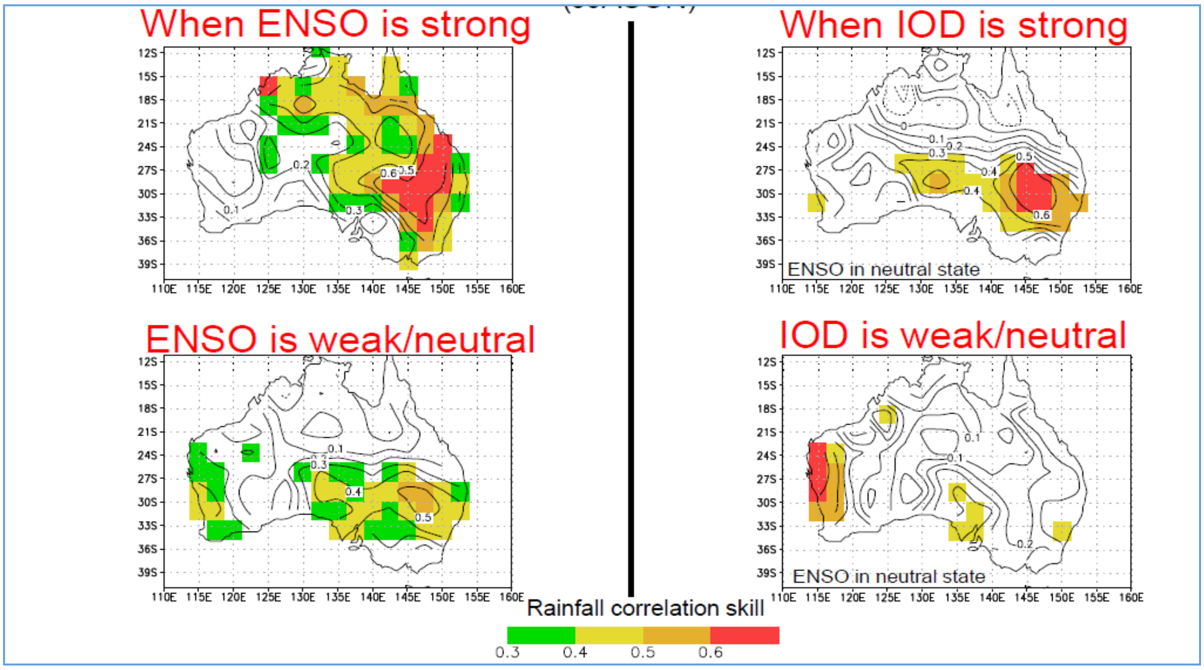

Figure 4: Multi-week forecasts: Windows of opportunity as determined by ENSO and IOD status based on rainfall skill for a forecast of fortnight two ahead (days 15-28) for the period from June to November (Hudson et al 2012).

Adoption from Increased Skill of POAMA Products

For this analysis, it can be assumed that most potential users of POAMA products are already at least aware of or making use of seasonal forecasts to an extent warranted by their skill and value in their regional or seasonal situation. There will be few exceptions assuming that the forecast would normally provide a clear signal only when there is a significant widely publicised ENSO event for example. Over the last decade farmers are more aware of opportunities to respond more flexibly to changing seasonal outlooks. In the GRDC grower survey in response to the question on “adopting new or different management practices to actively manage climate variability” the proportion responding positively increased to a peak of 64% in 2008, up from 53% in 2006 (GRDC 2012a). The extreme droughts over the last decade were likely to be a factor because wetter years since have seen the proportion fall again to 52% in 2012. The GRDC survey (IPSOS 2010) reported that “*Nationally, growers were significantly more likely to mention the drought as a motivator of farming practice change over the past 2 years, when compared to 2008 results (56% vs. 40%)”*. A similar pattern was apparent for the Victorian survey (Anderson et al 2012).

The examples in Figure 4 demonstrate that, as was likely to be the case for seasonal climate forecasts, a substantial part of the skill of POAMA multi-week forecasts is likely to arise when there is a strong ENSO or IOD influence. The capacity of seasonal forecasts to provide more accurate forecasts of extremes is a key aspect of their overall value. As shown in Figure 1, the years of major droughts for the wheat industry were typically El Niño events. The multi-week skill is likely to be consistent with seasonal skill for the same influences. For example at a one month time scale the “Will it Rain” publication (Partridge, 1991) showed over two decades ago changes in extremes related to ENSO as indicated by the SOI. The expectation was for double the number of frosts at Dalby in July for a concurrent negative SOI class compared with a positive one. Similarly December maximum temperatures were shown to be likely to be higher when SOI was positive. Therefore the benefit from the POAMA multi-week forecasts will be reduced to the extent that some potential users are already factoring in an ENSO influence. The estimate of the benefit would also need to take into account a multi-week forecast promoted on Climate Kelpie, that is the COLA (2012) 8-15 day with climate outlooks for temperature, precipitation, and soil moisture. Therefore for an existing user of COLA products, the potential for them to adopt POAMA multi-week forecasts will depend in part on improved skill. But overall in comparison to seasonal forecasts, multi-week forecasts from POAMA are effectively a new product in a market yet to be developed. The presentation as part of a seamless forecast system placed between existing widely used weather and seasonal forecasts should ensure widespread awareness.

For forecasts of the monsoon onset, some of the skill that will be available from POAMA forecasts has been routinely available for over two decades (Stone and Auliciems 1992). For example when the SOI is in a “Consistently Positive Phase” at the end of August there is a much increased chance of exceeding median rainfall from September to November over much of northern Australia (Longpaddock, 2013a). However POAMA is likely to have even more improved lead time giving a marginal benefit in situations where that is of value.

In summary, adoption of the new POAMA products therefore needs to take into account the likely levels of adoption in the absence of MCVP investment as determined by the alternative forecasts available.

Benefits from Increased Skill of POAMA Products

The Asseng et al (2012a) analysis concluded that *"The POAMA seasonal rainfall forecast has significant skill in forecasting rainfall season types in some regions of the Western Australian wheat-belt. When combined with other systems knowledge using APSIM, the POAMA seasonal rainfall forecast can translate into about $50/ha of additional gross margins when used in N management decisions in wheat cropping"*. Asseng et al (2012b) also estimated the benefits for a wheat sheep farm with additional land made available for cropping from pasture in ''above-median'' rainfall seasons. The additional gross margin increased to $66/ha. The analyses used a six month forecast using POAMA 1.5. Accuracy (on hits on an above and below median basis) was 70% over the 26 years in the analysis. However this was for only one grid and atypical levels can be random. As illustrated in Figure 3, the more recent version of POAMA generally has less skill in Western Australia for a three month forecast from March. But for the six month forecasts used at specific locations, the newer version of POAMA may be more valuable by other skill measures even though the 70% measure is unchanged (Peter McIntosh, pers. comm., 2012). Also noted in relation to overall improvements from the newest version of POAMA was that; *"The increase is small but useful. Some regions have got a little worse. This is typical of modelling advances. The skill in the grain regions has probably improved the most".*

There are clearly small improvements in skill and these could be expected to translate to improvements in value provided the improvements can be readily communicated. But the generality of the Western Australia results would need further analyses in southwest Western Australia and in eastern Australia given the different crop model parameters, the resolution of the version used and the short period of years in the analysis (Oscar Alves, pers. comm., 2013). But it can be concluded for the forthcoming operational version of POAMA with equivalent skill of 70% or more particularly in some regions of eastern Australia that skill should be sufficient to allow promotion, encourage adoption and increase benefits. The conclusion is dependent on existing users of other seasonal forecasts valuing and accessing POAMA.

The potential to use POAMA forecasts for grain crop management has yet to be developed through extension programs in Western Australia or other regions. In Western Australia the current general strategy is summed up as *"Playing the season rather than trying to predict the season, is the best strategy"* (Bill Bowden, pers. comm., 2012).

In relation to multi-week forecasts, there are examples quoted of applications where they are likely to be valuable, for example scheduling spraying, harvesting, irrigating where there is flexibility to do so. The potential number is of course large as is the case for weather forecasts a few days ahead. For seasonal forecasts, over 90 examples of actual applications have been documented (Hassall and Associates, 2002). There are also potential applications in livestock industries. One example of the current use on an experimental basis was for animal health: *"Multi week forecasts can give us a heads up for animal health issues such as flystrike for example when hot and wet weather is coming"* (Susan Carn, pers. comm., 2012).

In the absence of definitive data on benefits, the approach adopted will need to build logically on previous evaluations taking into account developments over the last decade. Previous evaluations of investment in climate variability R&D over the last decade have been based on increases in the number of Australian farmers taking seasonal climate forecasts into account. However there are relatively few occasions when there is a major change in probabilities leading to an expectation of profitable decision making. Only 10% of farmers taking forecasts into account were assumed to be benefiting to a significant extent, i.e. a benefit of 10% of Net Value of farm Production (NVP). That percentage of benefit was based on a wide range of simulation studies comparing strategies that used seasonal climate forecasts of rainfall with a traditional strategy (one based on climatology) which does not take account of a seasonal forecast (the studies were reviewed in Land and Water Australia (2007)). For this analysis, the benefit is being assessed in terms of the added value from the MCVP investment for farmers using various POAMA forecasts.

Any assessment of likely adoption and benefits achieved from the MCVP investment will need to be based on broad judgement of the importance of a range of factors that can only be considered in a qualitative way. Table 10 presents a summary which is followed by the derivation of the estimates that define benefits. Table 11 then summarises the basis for the assumptions.

Table 10: Summary of possible Contributors to Adoption by farmers of POAMA Products influenced by MCVP investments compared with Current Sources of Information

Aspect	Influence on the Adoption Rate and Benefits	
	Negative	**Positive**
Regions and seasons of most skilful forecasts	Perception of limited advantage over current ENSO-based statistical forecasts and increasing knowledge of the separate impacts of other drivers such as IOD.	Improved marketing of advantages over competitors, for example at longer lead times and using a model with seamless forecasts from weather to multi-week to seasonal to integrate knowledge.
Seamless forecasts (weather/multi-week/seasonal)	Lack of awareness of reduced skill beyond period of weather forecasts.	Easier and more diverse access to a range of forecasts including from innovative products such as CliMate.
Demonstrations of value	Limited examples of increased value compared with analogue forecasts.	Effective communication of improved skill as an alternative to showing value.
Climate change/ decadal variability	Assumption that climate change and decadal variability are not current issues and therefore not reducing skill of statistical forecasts.	Recognition of increasing impacts of climate change and decadal variability on skill of statistical forecasts.
Comprehension of terminology	Misunderstandings of probability forecasts and failure to use skill information.	Emphasis on User Centred Design principles and responsiveness to feedback and testing of comprehension.
Funding	Reduced servicing of users post MCVP projects with reduced feedback.	Targeted new projects to maintain end to end linkages and demonstrate value.

Farmers benefiting from the MCVP investment can be categorised by their use of the new POAMA multi-week forecasts, the monsoon onset or the POAMA seasonal forecasts. In each case the benefit is in relation to the currently used forecast that POAMA will displace. As multi-week forecasts and the monsoon onset are in many respects essentially a new product there will be an increasingly large proportion of farmers becoming aware of the various products and benefiting to some extent. Farmers will also be in one of three categories of seasonal forecast users. These are:

- Farmers already using the BoM SCO transferring to POAMA with mostly a marginal benefit
- Farmers already using other seasonal forecasts transferring to POAMA with mostly a marginal benefit, and
- Farmers not using any seasonal forecast and increasingly using POAMA with potentially a larger benefit per farmer.

The proportion of farmers in the third category is unlikely to be large given the improved skill is mainly marginal and in regions and seasons of existing skill. Given no survey data is available on benefits for each of the POAMA forecasts, an aggregate approach is preferable to limit the number of judgements required.

<u>Initial year of benefits</u> - POAMA is scheduled to become operational during 2013. Therefore the first year of benefits attributable to MCVP is assumed to be 2015. In the without MCVP scenario, development is assumed to be delayed one year (2016). BoM research leaders indicated a larger lead was probable. However, the conservative one year lead was used in our calculations and a sensitivity analysis with lower and higher lead values was undertaken (Table 16).

<u>Maximum increase in adoption with a benefit attributable to POAMA</u> - taking into account a potentially large adoption for multi-week forecasts and more limited additional adoption of POAMA seasonal forecasts, an increase of an additional 25% above current levels is assumed. The increase is assumed to be the same with the MCVP investment as for the scenario without the MCVP investment.

<u>Years to reach the maximum adoption</u> - 5 years has been assumed, given rapid adoption could be expected for multi-week forecasts if useful increases in skill are demonstrated. In the without MCVP scenario, 7.5 years is assumed.

<u>Benefits</u> - a fixed level of 2% of NVP is assumed (equivalent to about $1,600 per farm). The benefit is much lower than the value of 10% assumed in previous evaluations on the basis that this is either more a marginal increase for existing users or a smaller benefit for multi-week forecasts compared with seasonal forecasts.

The key benefit valued in the evaluation therefore is based on two parameters: benefits commencing in 2015 rather than 2016 and a more rapid rate of adoption to reach the maximum adoption level assumed. The maximum adoption level and the increase in profit gained are assumed the same for both with MCVP investment and without MCVP investment.

Summary of Assumptions

A summary of the key assumptions made to value the benefits is shown in Table 11.

Table 11: Summary of Assumptions

Item	Value	Source
Net Value of Farm Production (NVP) (from year of first benefit)	$11.3 billion	ABARES (2012) for 2010-11, 2011-12
Number of Farm Establishments	135,000	ABARES (2012) for 2010-11
NVP/Farm Establishments	$84,000	Average
WITH MCVP INVESTMENT		
Adoption of POAMA Products First year of benefit	2015	BoM plan to launch in 2013
Years to reach maximum	5	Authors' assumption (see text for basis for limit)
Maximum increase in adoption attributable to POAMA products (% of Farm Establishments)	25 %	Authors' assumption (see text for basis for limit)
Increased additional profit attributable to POAMA (% of Net Value of Farm Production)	2 %	Authors' assumption including reduced marginal benefit for farmers already adopting seasonal climate forecasts
WITHOUT MCVP INVESTMENT		
Adoption of POAMA Products First year of benefit	2016	Authors' (assumes one year lag compared to the WITH MCVP)
Years to reach maximum	7.5	Authors (assumes half as long again compared to WITH MCVP)
Maximum increase in adoption attributable to POAMA products (% of Farm Establishments)	25 %	Authors' (assumes same limit as for WITH MCVP)
Increased additional profit attributable to POAMA (% of Net Value of Farm Production)	2 %	Authors' (assumes same as for WITH MCVP)

Results

All past costs are expressed in 2011/12 dollar terms using the CPI. All benefits and costs after 2011/12 were expressed in 2011/12 dollar terms. All costs and benefits were discounted to 2011/12 using a discount rate of 5%. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2013/14).

Investment criteria were estimated for both total investment and for the MCVP partners' investment alone. Each set of investment criteria was estimated for different periods of benefits. The investment criteria were all positive as reported in Tables 12 and 13.

Table 12: Investment Criteria for Total Investment and Total Benefits for Each Benefit Period (discount rate 5%)

Investment Criteria	**Number of years from last year of investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	72.52	94.97	94.97	94.97	94.97	94.97
Present value of costs ($m)	15.45	15.45	15.45	15.45	15.45	15.45	15.45
Net present value ($m)	-15.45	57.07	79.52	79.52	79.52	79.52	79.52
Benefit-cost ratio	0.00	4.69	6.15	6.15	6.15	6.15	6.15
Internal rate of return (%)	neg	34.6	37.2	37.2	37.2	37.2	37.2

Table 13: Investment Criteria for GRDC Investment and Benefits to GRDC for Each Benefit Period (discount rate 5%)

Investment Criteria	Number of years from last year of investment						
	0	5	10	15	20	25	30
Present value of benefits ($m)	0.00	40.98	53.67	53.67	53.67	53.67	53.67
Present value of costs ($m)	8.69	8.69	8.69	8.69	8.69	8.69	8.69
Net present value ($m)	-8.69	32.29	44.98	44.98	44.98	44.98	44.98
Benefit-cost ratio	0.00	4.71	6.17	6.17	6.17	6.17	6.17
Internal rate of return (%)	neg	35.2	37.2	37.2	37.2	37.2	37.8

The quantified benefits are allocated to the Rural Research Priorities as expressed in Table 14.

Table 14: Allocation of Quantified Benefits to Rural Research Priorities

Rural Research Priority	Allocation
Productivity and adding value	100%

It could be argued that the *Climate Change and Climate Variability* priority (RRP 4) was also addressed quantitatively-in essence this MCVP investment addressed RRP 4 via a change in the productivity and adding value priority.

The annual net benefit cash flows for both total investment and MCVP partners' investment for the investment period plus the 30 year period from year of last investment are shown in Figure 5.

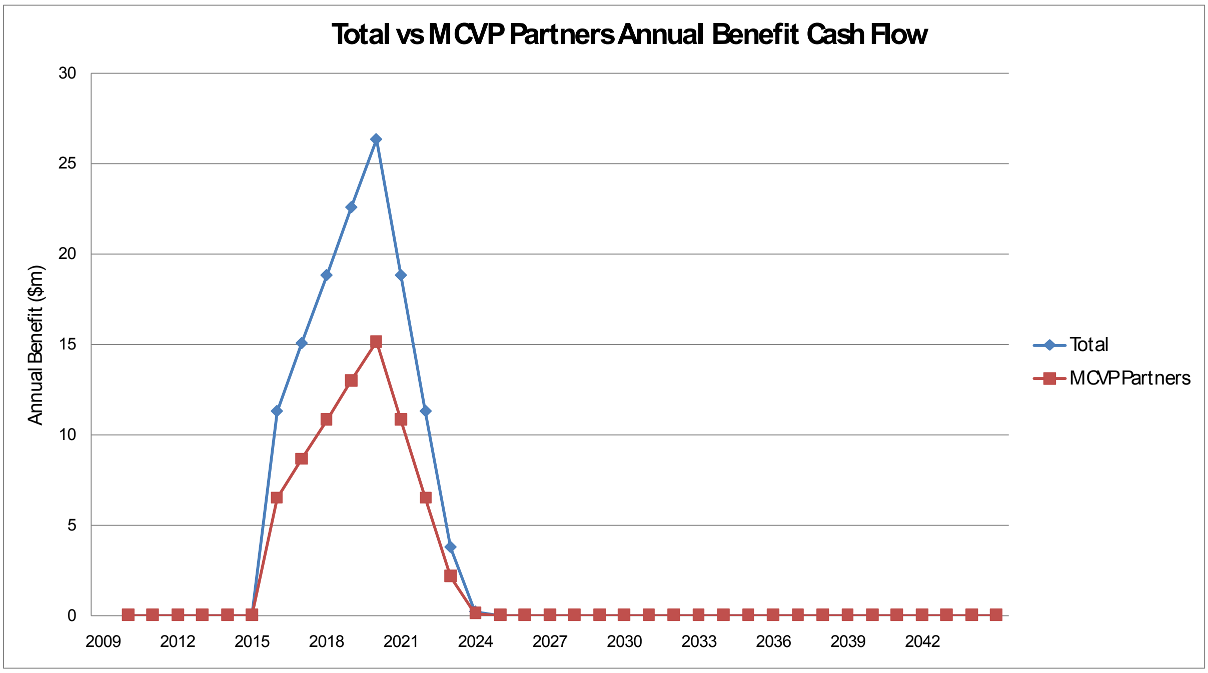

Figure 5: Annual Benefit Cash Flow

The total annual benefit cash flows with and without the total investment in MCVP Phase II and III for the investment period plus the 30 year period from year of last investment are shown in Figure 6.

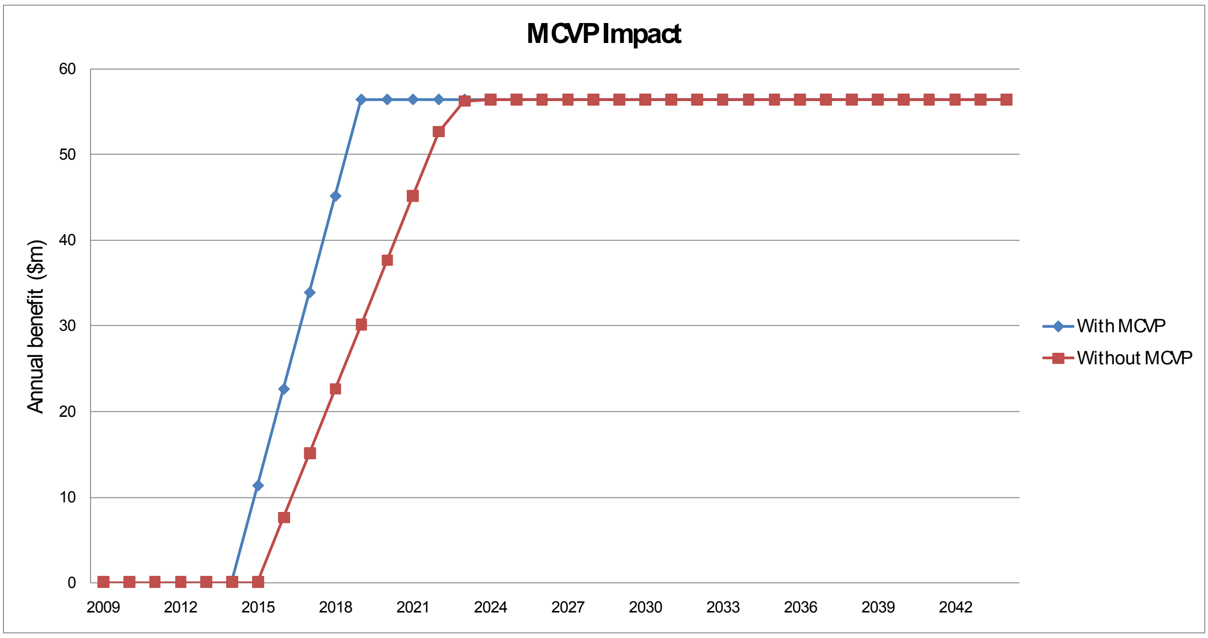

Figure 6: Annual Benefit Cash Flow With and Without MCVP Phase II and III

Sensitivity Analyses

Table 15 presents a sensitivity analysis carried out on the discount rate for the total investment. The sensitivity analysis was performed with benefits taken over the life of the total investment plus 30 years from the last year of investment. All other parameters were held at their base values. The results show that the criteria are not particularly sensitive to the discount rate.

Table 15: Sensitivity to Discount Rate (Total investment, 30 years).

Investment criteria	**Discount Rate**		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	128.26	94.97	71.86
Present value of costs ($m)	14.74	15.45	16.20
Net present value ($m)	113.52	79.52	55.66
Benefit-cost ratio	8.70	6.15	4.44

Table 16 presents a sensitivity analysis carried out on the assumed difference in lead time to benefits for the "*With MCVP*" and "*Without MCVP*" scenarios. All other parameters are held constant at their base values.

Table 16: Sensitivity to Assumed Lead Time for the With and Without MCVP Scenarios (Total investment, 30 years).

Investment criteria	**Assumed Lead Time (years)**		
	0	**1 (base)**	**2**
Present value of benefits ($m)	53.01	94.97	134.72
Present value of costs ($m)	15.45	15.45	15.45
Net present value ($m)	37.56	79.52	119.27
Benefit-cost ratio	3.43	6.15	8.72
Internal rate of return (%)	25.3	37.2	43.3

For zero lead time it is assumed that the "*Without MCVP*" benefits start in same year as for "*With MCVP*" in year 2015. The benefits for this scenario are from the more rapid adoption pattern of "*With MCVP*". For the two year lead time it was assumed that the "*Without MCVP*" benefits are delayed and commence in 2017 while the "*With MCVP*" benefits are held at their base year (2015). The results show that assuming a 2 year lead time increases the net present value by about 50% of base, the benefit cost ratio increases from 6.15 to 1 to 8.72 to 1 and the internal rate of return will improve from 37% to 43%.

7. Confidence Rating

The results produced are highly dependent on the assumptions made, many of which are uncertain. There are two factors that warrant recognition. The first factor is the coverage of benefits. Where there are multiple types of benefits it is often not possible to quantify all the benefits that may be linked to the investment. The second factor involves uncertainty regarding the assumptions made, including the linkage between the research and the assumed outcomes.

A confidence rating based on these two factors has been given to the results of the investment analysis (Table 17). The rating categories used are High, Medium and Low, where:

- High: denotes a good coverage of benefits or reasonable confidence in the assumptions made
- Medium: denotes only a reasonable coverage of benefits or some significant uncertainties in assumptions made
- Low: denotes a poor coverage of benefits or many uncertainties in assumptions made

Table 17: Confidence in Analysis of MCVP

Coverage of Benefits	Confidence in Assumptions
Medium	Low

The levels of confidence clearly warrant recommendations for improvement. These are outlined in the next section.

8. Conclusions and Lessons Learnt

This analysis included 26 MCVP projects undertaken between years 2009 and 2014. The total investment in MCVP has been $14.4 million in total nominal dollars. MCVP partners accounted for 56.5% of the total investment in these projects.

MCVP has produced significant outputs in improving accuracy of forecast models and enhancing ease of use of the models for on-farm decision making. The evaluation has concentrated on the benefits from new POAMA forecasts given these were a major component of the total MCVP investment. Farmers benefiting from the MCVP investment are those already using the BoM SCO and other seasonal forecasts and who will transfer to POAMA. These will mostly gain a marginal benefit from replacing current statistical forecasts based on historical relationships with dynamical forecasts built on atmospheric and ocean conditions. Other beneficiaries will be farmers that are not using seasonal forecasts but will start using POAMA to gain in some cases a potentially larger benefit than the others; however, these are unlikely to be a large proportion of the farmers assumed benefiting. A larger increase in adoption and benefits is possible for multi-week forecasts dependent on the accuracy they achieve and how that is communicated.

The benefits from this investment will largely accrue to the Australian primary industries, as that is largely where the tools and products being developed are targeted. There are also some public benefits such as better natural resource management, enhanced scientific knowledge and some other community spill-over benefits.

The principal benefit valued from the investment in MCVP Phases II and III has been an increase in farm profits. Based on assumptions for this profit gain, the total MCVP investment of $15.45 million (present value terms) has been estimated to produce total gross benefits of $94.97 million (present value terms) providing a net present value of $79.52 million, a benefit-cost ration of 6.15 to 1 and an internal rate of return of 37.2%.

These results show that the returns to MCVP Phases II and III are positive, and better than those achieved by MCVP Phase I. As mentioned in Section 1, the lower returns for MCVP Phase 1 were due to a reduced rate of increase in adoption and concerns on the eventual loss of skill from statistical forecasts. However, the benefit-cost ratio and the internal rate of return of the results for MCVP Phases II and III are not too different from the CVAP (1992-2002) which had a benefit cost ratio of 5.7 to 1 and an internal rate of return of 48%. CVAP's net present value was $4.8 million. The increase in adoption of what was essentially a new product was the key factor to the high returns for this initial program of climate variability investment. The high returns from MCVP Phases II and III are attributed to a higher proportion of farmers benefiting but a lower benefit per farm. In addition more rapid adoption of new weather and seasonal forecast information for on-farm decision making was assumed because of greater awareness of the benefits from improved climate risk management given the extremes of the last decade

The conclusion of an attractive return is not highly sensitive to key assumptions. This robust result reflects the size of the market and the more rapid adoption attributed to the MCVP investment. However, the low confidence in the results from this evaluation warrants a concerted response. There is a clear opportunity to confirm the results and boost returns to the current investment in the short and long term. Improved information on how farmers are currently using seasonal forecasts and monitoring of how new products add value are the key requirements. The impacts of improved performance information would be three-fold:

1. Rapid feedback to shape product design and delivery,
2. Realignment of project research priorities with potential benefits, and
3. Input to evaluations likely to warrant increased investment by a wider range of stakeholders.

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Appendix: Description of Each of the 28 Projects

Project MCV00002: Improving seasonal forecasts for South-West Western Australia	
Project details	Organisation: CSIRO Period: September 2008 to April 2011 Principal investigator: Senthold Asseng
Rationale	Farm income from dry-land cropping can vary substantially from year to year due to climate variability. There are a number of farm management options that can be adjusted to cope with different season types if some information about the season is known in advance. This project explored ways of using existing seasonal climate forecasts from the Predictive Ocean Atmosphere Model for Australia (POAMA) to increase farm income from cropping enterprises in south-west Western Australia (WA). The project also aimed to contribute substantially to the long-term improvement of model forecasts by analysing model strengths and weaknesses to inform model development.
Objectives	To improve prediction of early, mid and late growing season rainfall in distinct climate regions in south-west Western Australia relevant to the wheat industry using a global circulation model. To establish estimates of forecast uncertainty based on the range of model forecasts, the range of on-farm outcome, and benchmarking against existing forecast schemes. To improve predictability of soil moisture, yield and pasture growth through linking seasonal forecasts to farm practice, soil type and existing information such as stored soil moisture. To improve articulation of cereal farm practice options, with potential spin-offs to the grazing industry, based on forecast skill and reliability. To establish foundations for ongoing strategic investment in improvement of global circulation models.
Activities and Outputs	Farmers in the WA northern region preferred short-term (several weeks to several months) forecasts for tactical decisions such as dry sowing, early and late season nitrogen (N) application, cultivar choice and fungicide application. Farmers in the WA southern region were more interested in seasonal forecast of rainfall and frost risk, but would also benefit from shorter term forecasts for dry sowing and tactical N application. POAMA-1.5 was benchmarked against other forecast systems in the wheat belt of WA. POAMA-1.5 was found to do very well in the southern wheat belt but had little useful skill in the northern region. The reason for POAMA-1.5's low skill in the north was due to the difficulty in simulating the cut-off low for this region. In the southern region POAMA-1.5 could predict above or below median rainfall in 19 of 27 years and this level of skill is of considerable benefit to agriculture. During this project a new version (i.e. POAMA-2.4) of the model was developed, with many improvements to the overall climate simulation but there was no improvement in the forecast skill for May-Oct in south west WA. However rainfall forecast skill for later in the year was improved considerably as was the skill of longer lead time forecasts. The new POAMA-2.4 model has a much more complex method for generating ensemble members and this has improved the statistical reliability of the ensemble spread, but this new model version was not explored further for benefits to agricultural prediction and value. The study used a more realistic and conservative strategy where the expected return from adding $1 of N is typically $2. Using a POAMA-1.5 model in this case was found to achieve long-term returns of more than $50/ha in the WA southern wheat belt. Similar returns were also demonstrated for mixed wheat-sheep farming. The payoff time for using such a forecast was shown to be 7 years at 95% confidence, or 3 years at 80% confidence. The value of short-term (10 day) forecasts was assessed in wheat cropping and the results show that benefits can range from $10-100/ha for early sowing, and $10-160/h for late N and fungicide application depending on the in-season rainfall. The results indicated frost forecast had little or no value compared to simply managing for average conditions. The yield penalty for delaying sowing outweighed the potential yield loss due to frost when frost damage is assumed to be average as compared to severe. At least 12 papers were published or submitted for publication in journals, conference proceedings and the Bureau of Meteorology's Monthly Weather Review. At least 16 presentations were made in Australia, New Zealand, Japan and Argentina. There were also a number of media releases undertaken e.g. Econnect press release on benefit from better climate forecasts, and an ABC interview, among others.

Outcomes	The project has highlighted the potential value of POAMA forecasts to the wheat industry in WA if operational seasonal forecasts are shown to have appropriate skill. The project has also identified a number of areas that need improvement e.g. improvements in short-term forecasts for tactical agricultural management. The project has shown that there is additional potential value of a seasonal rainfall forecast in mixed crop-livestock farming systems. Potentially, increased farm economic benefits from both short-term and seasonal management decisions made using POAMA forecasts. Potential optimised use of N and fungicides resulting in less off-farm chemical run-off and input cost savings.
Benefits	Potentially, reduced losses and/or optimised incomes in wheat and mixed wheat-livestock farming in the south-west WA region. Potentially, reduced nutrient/chemical run-off from farms. Potentially, contributions to the south west WA communities' resilience. Demonstration of a methodology to show similar potential benefits in eastern Australia provided there are no constraints in terms of forecast skill and crop model parameters.
HAL00003: Critical thresholds (tipping points) and climate change impacts/adaptation in horticulture	
Project details	Organisation: Queensland Primary Industries and Fisheries (QPIF) Period: January 2009 to March 2011 Principal investigator: Peter Deuter
Rationale	Horticulture in Australia comprises a large number of commodities contributing approximately $7 billion annually to the Australian economy. Horticultural crops are grown in a wide range of production regions due to the diversity of micro-climates. All horticultural crops are temperature sensitive and most have specific temperature requirements for optimum yield and quality. Climate indices and critical temperature thresholds of significance were poorly understood so the impact of climate change on businesses and cropping systems in specific regions had not been well documented, and the resilience of the system could not be properly assessed. A review of the literature and industry consultation was required to document critical thresholds for major horticultural commodities, as well as to understand the broader risks associated with climate change and the resilience of growers and industries.
Objectives	To establish practical understanding of critical temperature thresholds of significance to specific horticultural crops and production regions of Australia To identify commodities and/or regions which, under climate change, are/or will be significantly impacted by increasing temperatures. To assess the impacts on production systems and/or regions, and identify adaptation strategies to address these impacts.
Activities and Outputs	Current understanding of critical temperature thresholds were identified and documented through a review of literature for selected major horticultural crops. Additional data on critical temperature thresholds was collected through consultation with growers, consultants and scientists. The fruits and vegetables covered were: lettuce, cauliflower, banana, apple, citrus, pineapple, tomato, macadamia, capsicum, sweet corn, avocado and pumpkin. The impact of projected temperature change in 2030 was determined for selected horticultural commodities in current production regions. Overall there are no expected significant impacts before 2030 for most horticultural commodities. However, some of the products are expected to be slightly negatively impacted by temperatures by 2030, these are: apples (e.g. those produced in Applethorpe and Tatura regions), winter lettuce in all regions, citrus grown in the Riverina region, winter tomatoes in QLD, and capsicum in north QLD. Potential adaptation strategies were documented; these include use of more adaptable cultivars, better agronomic practices and site selection to avoid unsuitable climate factors. Commodity case studies were undertaken and reported for lettuce, banana, apple, citrus, pineapple, tomato, macadamia, capsicum and avocado. Some of the major recommendations from this study include; An assessment of the vulnerability of major horticultural commodities and/or production regions in Australia. Identification of alternative locations where temperatures will be more favourable up to and after 2030. Providing more adaptable cultivars.
Outcomes	The key outcome of the project is the better understanding of temperature thresholds affecting a small number of horticultural crops, and the impact of further temperature rises on these commodities under a changing climate. Increased Australian farmers understanding of critical temperature thresholds of significance to

	their specific horticultural crops and production regions. Better adaptation strategies by farmers from increased knowledge of commodities/regions that are likely to be impacted by increasing temperatures under climate change. Contributions to and support for long lead times (1-6 months) and short season lengths (one month or less) that will help farmers make better decisions (Peter Deuter pers. comm., 2013).
Benefits	Increased scientific knowledge Enhanced industry understanding of current and future temperature threats to profitable production. Contribution to sustained production and supply of quality Australian horticultural products through more informed adaptation strategies. Contributions to the horticulture farming communities' resilience.
MCV00004: Climate change and variability: Assessing regional impacts of sugarcane production	
Project details	Organisation: Reef Catchments – Mackay Whitsunday Inc Period: January 2009 to July 2010 Principal investigator: Will Higham
Rationale	The sugar industry in the Mackay-Whitsunday Region is a major landuse industry within the coastal zone with some 20% of the landscape growing cane. In recent years there had been strong research on management practices to improve the sustainability of this industry, particularly through improvements in water through better soil, nutrient and herbicide management. With climate change issues strongly on the national agenda, there was a need to address potential issues, maintain industry profitability while ensuring sustainable management. Climate variability had always been an issue for the Queensland sugar industry, together with proximity to sensitive receiving waters in the Great Barrier Reef lagoon. Increased climatic extremes could compromise the current management practices and place further community pressure on industry performance. Further regulatory action was to be expected unless the industry met increasingly stringent performance criteria. Future changes in crop management practice needed to consider beneficial off-site impacts as well as immediate production considerations.
Objectives	To investigate the complex interactions between farm management (tillage, controlled traffic, and nitrogen inputs), soil types, regional rainfall patterns, sugarcane productivity and predicted climate change. To predict which sugarcane farm management practices in the Mackay□Whitsunday region need to be adopted to meet proposed water quality targets and maintain productivity under different degrees of potential climate change.
Activities and Outputs	APSIM was used to investigate complex interactions between farm management, soil type, regional rainfall patterns, sugarcane productivity and predicated climate change. The simulation analysis showed that crop management options can have a greater effect on median N loads lost from sugarcane cropping in the Mackay-Whitsunday region than potential climate change. The CO_2 fertilisation effect was simulated and this was found to result in higher yields than would otherwise have been predicted from other climate change effects such temperature increases and changed rainfall patterns. However the final report states that there is uncertainty about the exact impact of CO_2 fertilisation on sugarcane growth and further work in this area is required. Practices that reduce runoff are likely to lead to increased N losses via other pathways such as deep drainage. The role of groundwater in contributing N to creek and rivers in the region was identified as worthy of investigation to test the efficacy of some of the proposed management practices. However, there are some management options, such as reduced N application which could reduce N losses by all pathways and thus give the assumed water quality benefits. Based on available soil information, the predicted effect of soil and local weather patterns on N loads was found to be small compared to the effects of crop management. The study concluded that controlled traffic management, planting of soybean for fallow management, reduced N application and minimal tillage were required. The study also states that management practices may require even further improvements if N lost via deep drainage is found to have significant influence on N in waterways in the region. The variations in N loads for different soils and local climatic variations appeared to be small relative to impact of proposed management practices; however a more extensive representation of soils types may provide different insights.
Outcomes	Potential increased awareness of alternative sugarcane management practices and their benefits. Potential contribution to sugarcane farming systems that reduce N run off in the Mackay-Whitsunday region. Potentially, adoption of management practices that lead to reduced N fertiliser application.
Benefits	Potential contribution to input costs savings for the sugar industry through reduced N application.

	Potential contribution to avoided industry costs of more strict regulatory frameworks. Potential contribution to reduced nitrogen loads in waterways and the Great Barrier Reef lagoon and reduced impacts on biodiversity.
MCV00005: Extremes, climate modes and reanalysis based approaches to agricultural resilience	
Project details	Organisation: Cindual Pty Ltd Period: December 2008 to December 2011 Principal investigator: Peter Best
Rationale	Agribusiness in Australia is vulnerable to decreased cash flow caused by extreme weather events such as heat stress, large hail, sustained drought and major floods. Resilience to such events could be improved by better and earlier seasonal warnings of upcoming events and a range of more efficient weather and production risk insurances. The design and operation of these options could be aided by using the extensive historical weather information available from the 20th Century Reanalysis Project data. This current project was an attempt to apply such information to everyday agricultural decision making. It was designed to leverage off international experience in weather index insurance and seasonal forecasting but with more emphasis on the more extreme end of the spectrum (weather disasters) and on large-scale climate indices that facilitate interactions throughout the insurance chain from the insured to the reinsurer and capital markets.
Objectives	To investigate new weather reconstructions as a basis for estimating extreme weather conditions that affects many agricultural operations in Australia. To use long-term time series of climate mode indices to determine how much extreme statistics depend on regional characteristics and climate modes. To use these associations as a basis for index insurance, thereby providing an alternative to indemnity insurance for hail, cattle heat stress and low wheat yield. To utilise any lagged associations for seasonal forecasting of these extreme events. To summarise the benefits and problems associated with the use of the 20th Century Reanalysis Project (20CRP) information.
Activities and Outputs	The project has constructed prototype software/web tools to look at the sub-daily data under 5 components of: climate indices and extreme weather characterisation, the potential for hail, extremes of potential wheat yield, heatwaves and cattle stress, and insurance considerations. An extensive literature review revealed an emerging consensus on the important climate indicators for rainfall and some other key meteorological variables for Australia. Australia-wide trends of rising 100-year return values for temperature and convective activity were confirmed using reanalysis information for 130 years. The correlations of monthly maximum temperature and monthly average precipitation rates with key climate indices were found to vary with location, month and the position of the time period under consideration in longer-term climate oscillations. There was some degree of predictability found for the agriculturally important extremes at the 2 month horizon, especially for the four main indices (SOI, SAM, IOD and PDO), particularly when the influences of soil moisture are extracted from the signal. The reanalysis confirmed that the number of hail-days per year in much of Australia had increased in the past 50 years and this trend was expected to continue as global and regional warming intensifies. There were indications of moderate dependence of hail risk on the southern oscillation index (SOI). There was an observed considerable difference between the inland and near-coastal sites, with a doubling of hail days at the coast. In Australia, the main hail season was found to be November through to January with peak hail risk usually in December. The project identified soil moisture at the start of the season as a very useful predictor of potential wheat yield for many sites across Australia. Climate indices were found to be of varying importance in different regions; if soil moisture influences are removed, the dominant index is the SOI for many northern districts but other climate indices are as important in more southern or western wheat-growing regions. Climate indices were found to have the potential to give a reasonable guide to summer heatwave conditions for many agricultural regions of Australia. Initial results gave support to the core idea of bringing together reanalysis information as the underlying “loss” database, concentrating on very severe weather events and using climate indicators together with important regional conditions for the basis of a weather-index insurance scheme. A number of recommendations were given for the next steps to bring these ideas closer to practical uses such as an insurance alternative to “exceptional circumstances” measures that were being phased out as an inefficient measure to making farming enterprises resilient to a series of major disasters such as droughts and floods. The reanalysis information at the current 2° resolution was found to be sufficient for general analysis of regional extremes, especially for surface and near-surface parameters.

Outcomes	Potential basis for seasonal forecasting of heatwave risks and for index insurance for heat stress livestock losses. Potential contributions to the development of more efficient insurance schemes for cropping and livestock farming enterprises against extreme weather events. Potential enhanced insurance industry ability to develop multi-year weather insurance products that better reflect the region's extreme weather and climate risks. Potential improved engagement by insurers and reinsurers with the agribusiness market through better design and pricing of insurance innovations. Potential improved estimation of return periods for single and multivariate regional weather extremes.
Benefits	Potential enhanced farming enterprises' resilience. Potential reduced farming enterprises financial losses due to extreme weather events. Potential public funds savings from reduced or avoided "exceptional circumstances" government aid to farmers affected by extreme weather events.
MCV00006: Assessing and managing heat stress in cereals	
Project details	Organisation: South Australian Research and Development Institute (SARDI) Period: May 2009 to March 2013 Principal investigator: Peter Hayman
Rationale	High temperatures during spring were recognised by grain growers as a major weather risk. Heat events such as 12 October 2004 and mid November 2009 had raised questions that could only be partially answered due to incomplete understanding of the likelihood and consequences of spring heat events on wheat crops. Therefore there was an identified need to understand the high temperature impacts on cereal crops and the subsequent consequences for yield losses.
Objectives	To characterise the meteorology (synoptic conditions) and climatology of heat events at different periods of the winter growing season. To disentangle the impact of heat stress and water stress and improve our understanding of the damage caused by the timing of events using a series of controlled environment and field experiments. To develop a risk management package that assists the farmer to determine the risk and return of a late planting and sheds light on the future of cropping in a region.
Activities and Outputs	The project benefitted from the addition of a GRDC PhD scholarship of Hasim Talukde on "physiological studies of the response of wheat to short-term heat stress during reproductive development". Designed and tested chambers to heat wheat in the field so as to simulate a spring heat event and study the impact on wheat plants. Two refereed papers describing the construction of chambers and the testing and evaluation of wheat heat stress sensitivities were presented at the 2010 Australian Agronomy Conference. A presentation was given at the 2010 Hart Field day with demonstration of the heat chamber. Developed an excel spreadsheet to analyse the SILO data and show the chance of temperatures exceeding any threshold for any site. ENSO was shown to have a statistically significant impact on the number of spring heat events. Preliminary results found that a single day when the temperature was ramped up to a maximum of 35ºC just prior to flowering led to wheat yield loss of 20-30%. Analysis done during the project identified that the risk of hot air temperatures is greater in the mid to high rainfall sites like Roseworthy (flowering in October) than warm, low rainfall sites like Minnipa because of earlier flowering (mid September). Developed a draft risk management package that includes likelihood of temperature over a phenological period and allows the user to estimate the damage function. Inconclusive results from the field experiment have led to a delay in the development of the risk management package. Final report submission date extended (at no extra cost) by 9 months to 31 March 2013 to include another winter growing season of experimentation. Expected outputs include: statistically significant results between heated and controlled plots, a final risk management package, integration of data into APSIM, and synthesis report of controlled environment and field experiments.
Outcomes	Potentially, improved understanding and communication of the impact of spring heat events on wheat crops and the likelihood of events in the southern grains belt. Potentially, improved heat stress management to avoid crop losses.
Benefits	Potential contribution to reduced income losses from heat stress in the southern grains belt. Enhanced scientific knowledge.
MCV00007: Teleconnections between climate drivers and regional climate, and model representation of links	
Project details	Organisation: CSIRO Marine and Atmospheric Research Period: May 2010 to May 2013 Principal investigator: Peter McIntosh

Rationale	Growing season rainfall in southern Australian wheat growing regions varied from year to year due to remote influences from major climate drivers such as El Nino Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), Southern Annular Mode (SAM) and atmospheric blocking. Seasonal prediction skill could be improved by understanding the teleconnection processes that allow remote drivers to influence local weather systems, and then ensuring that climate models correctly represent these teleconnections. If these models are capable of accurately representing all the important physical phenomena that affect climate, then the predictions will likely have useful skill for farmers. It was therefore necessary to understand the important climate processes by analysing observations, and then assessing these same processes in models.
Objectives	To establish the key teleconnections between climate drivers (e.g. ENSO and IOD) and regional climate. To assess the accuracy with which climate models simulate these teleconnections.
Activities and Outputs	Reports documenting synoptic climatology of the major grain areas of Australia. Planned outputs include: Science reports describing the major drivers of rainfall variability in the grain regions and the manner in which they connect to rainfall. Science report evaluating model performance of remote drivers and teleconnections. Models of interest are Predictive Ocean Atmosphere Model for Australia (POAMA), The Australian Community Climate and Earth-System Simulator (ACCESS) and the Community Climate Model (CCM).
Outcomes	Planned outcomes include: Better understanding of the role played by rain-bearing weather systems (e.g. cut-off lows) in local climate, and how to better represent these processes in models. Improved understanding of seasonal climate variability related to tropical and high-latitude drivers (ENSO and IOD) and how to better represent these in models. Better understanding of the manner in which remote drivers of rainfall transmit their influence to synoptic systems and rainfall.
Benefits	Enhanced scientific knowledge. Potential contributions to improved farm decision making. Potential contributions to enhanced climate risk management by Australian farmers.
MCV00008: Improving forecast accuracy, especially with improved Indian ocean initialisation	
Project details	Organisation: Bureau of Meteorology Period: May 2010 to May 2013 Principal investigator: Oscar Alves
Rationale	Sea surface temperature variations of the tropical Indian Ocean are a prominent source of climate variability for Western Australia through to south-eastern Australia. Much of the climate anomalies in south-eastern Australia that develop during El Nino were a result of the co-variance of Sea Surface Temperature (SST) in the Indian Ocean. SST anomalies in the Indian Ocean also developed independently of El Nino, especially associated with the Indian Ocean Dipole, and were also a prominent source of climate variability in both south-western Western Australia and south-eastern Australia. The forecast skill of tropical Indian Ocean SST with POAMA-1.5 seasonal forecast system was much less than for that in the Pacific Ocean. This limited the predictive skill for regional climate. The difference in skill of predicting SST between the two oceans might stem from the model error and poor initial conditions in the Indian Ocean entered into the model as a result of a lack of sufficient observation, or it might have been a true reflection of fundamental differences in the predictability of the two oceans. This project aimed to address these issues and especially aimed at improving predictive skill of the Indian Ocean and, ultimately, the predictive skill of regional climate in south-west WA through to south-eastern Australia.
Objectives	To increase understanding of Indian Ocean predictability including links to the Pacific Ocean. To understand the lack of skill in the tropical Indian Ocean in comparison to the Pacific Ocean for existing POAMA-1.5 system. To develop improvements to the assimilation system and provide better initial conditions in the tropical Indian Ocean. To improve climate forecasts from improved initial conditions in the Indian Ocean incorporated within the dynamical model.
Activities and Outputs	Undertook a comparison of the skill of Indian Ocean SST predictions from POAMA-2 and POAMA-1.5 with international models. Results showed that during the second half of the year, when the Indian Ocean Dipole (IOD) develops, the forecast skill from the POAMA model is as good as the best international model and that model error is a common problem for limiting forecast skill of IOD. A comparison of POAMA-2 and POAMA-1.5 showed that the new ocean data assimilation system has led to an increase in SST forecast skill in the Pacific Ocean, however in Indian

	Ocean results, there was an increase in skill in the subsurface temperature but this did not translate into increased skill in the SST. The study found that the initialisation of ocean salinity played an important role in the improvements observed in POAMA-2. A paper titled “How predictable is the Indian Ocean Dipole” by Shi et al (2012) was published in the Monthly Weather Review journal. A paper titled “Impact of assimilating salinity on the simulated mean state and variability in a coupled seasonal forecast model” by Zhao et al (2012) was also published in the Monthly Weather Review journal. This project also contributed to an international study that compared heat content from all major international ocean re-analysis and a paper by Xue et al titled “A comparative analysis of upper ocean heat content variability from an ensemble of operational ocean re-analyses” was published.
Outcomes	Increased understanding of Indian Ocean predictability including links to the Pacific Ocean which will influence climate. Increased understanding of the lack of skill in the tropical Indian Ocean in comparison to the Pacific Ocean as a key input to improving POAMA. Development of improvements to the assimilation system to provide better initial conditions for the tropical Indian Ocean. Contributions to improvements of multi-week to seasonal climate forecasts as a result of improved initial conditions in the Indian Ocean informing the model.
Benefits	Potential contribution to increased predictive skill of regional climate. Potential contribution to more informed farming systems to optimise farm outputs and minimise losses.
MCV00009: Improving multi-week predictions	
Project details	Organisation: Bureau of Meteorology Period: October 2009 to September 2012 Principal investigator: Debra Hudson
Rationale	Seasonal prediction had traditionally provided forecasts of seasonal mean conditions (e.g. mean conditions for the upcoming 3 months) with lead times from 1 to 9 months. Users of climate forecast, such as in agriculture and water management, were increasingly demanding forecast guidance on time scales and lead times shorter than seasonal. This project sought to investigate climate variability and predictability on multi-week timescales, its simulation in POAMA and its predictive skill for regional rainfall and temperature. This would help guide the development of multi-week climate products. POAMA was not originally designed for multi-week forecasting and had deficiencies in this regard and there was a need to make it more suitable for multi-week forecasting.
Objectives	To explore and define the strengths and weaknesses of the POAMA prediction system for making multi-week predictions across Australia, especially with a view to providing forecast products for Australian agriculture. To improve understanding of the climate drivers (e.g. El Nino, Madden Julian Oscillation) that control climate variability on these multi-week timescales and that influence the skill of the forecasts. To conduct research to identify potentially skilful multi-week products, with quality suitable to be considered as operational Bureau products, so that these can be developed operationally via a companion investment in Water and the Land (WATL).
Activities and Outputs	This project investigated the potential use of POAMA as a multi-week prediction tool for Australia. A 27-year hindcast dataset was analysed, focusing on precipitation and minimum and maximum temperatures over Australia in the first month of the forecast. For the eastern Australia region and the winter and spring seasons the forecast of the second fortnight performed generally better than using a climatological forecast, persistence of observed, or persistence of the forecast for the first fortnight (average days 1-14). The model had generally poorer skill in predicting minimum temperatures. POAMA demonstrated useful skill in predicting both summer (27 Jan-8 Feb) and winter (14-31 Aug) heat waves of 2009 at lead times greater than a week; this was particularly true for the south-east for the winter heat wave. The role of key drivers of Australian climate variability for providing predictability on multi-week time-scales has also been investigated. During winter and spring, when POAMA’s skill for predicting precipitation is highest, forecast skill was found to be increased during extremes of the El Niño Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD) and the Southern Annular Mode (SAM). POAMA simulated well the evolution and pattern of rainfall variation over the tropical Indo-Pacific that is associated with the MJO. POAMA also showed enhanced skill at up to 3 weeks lead time in predicting rainfall throughout the tropical Indo-Pacific when a Madden-Julian Oscillation (MJO) is present in the initial

	conditions during October-March. POAMA was found to be capable of skilfully predicting the SAM index out to about 2 weeks and it reproduced the SAM-Australia climate teleconnection reasonably well in most seasons. Developed a state-of-the-art ensemble generation and initialisation strategy for the multi-week forecasts of POAMA-2. POAMA has been successfully upgraded to version 2 and has forecasts running in real-time. Assessment of the skill of POAMA-2 shows that the multi-week forecasts of temperature and rainfall over Australia are more skilful and reliable than from the previous version (POAMA-1.5). Products and skill of POAMA-2 have been communicated orally and in writing to the BOM operational section related to WATL development. Multi-week experimental products (both hindcast and real-time) have been added to the POAMA website (http://poama.bom.gov.au/) Seven scientific journal articles published from the project, three published CliMag articles, 24 conference/seminar/training/poster presentations associated with the project were undertaken. Recommendations for operational product development for the Bureau's Water and the Land (WATL) website have been made.
Outcomes	Improved understanding of the processes that provide multi-week predictability, both in observations and POAMA. A strategy for the optimal generation of ensembles targeted to the intra-seasonal/multi-week time-scale. An extension of the real-time POAMA/ACCESS system to multi-week timescales (including prototype experimental products to be made available via WATL - in a companion project: "An intra-seasonal outlook service for Australia"). Potential use of POAMA for multi-week forecasting to make farm decision regarding irrigation scheduling, power supply scheduling, timing of hazard burning, and timing of planting, harvesting and fertiliser application. A follow-on project "*Predictions of heat extremes on the multi-week timescale*" (MCV00031); begun in June 2011 and is due for completion in December 2013.
Benefits	Potential benefits of farmers using multi-week forecast include: Reduced input costs to farmers through appropriate timing in planting, harvesting and fertiliser application. Increased profits from appropriate timing in planting, harvesting and fertiliser application. Significant reductions in erosion risk which will lead to a reduction in nutrient and sediment runoff into sensitive water ways and marine ecosystems. Enhanced scientific knowledge.
MCV00010: Understanding frost risk in a variable and changing climate	
Project details	Organisation: CSIRO Sustainable Ecosystems via Climate Adaptation Flagship Period: July 2010 to July 2013 Principal investigator: Steven Crimp
Rationale	Frost damage remains a major problem for viticulture, horticulture, cereals and other agricultural industries in Australia. In 2006 late frosts resulted in widespread economic losses. In Victoria over half the annual fruit production was lost in response to a single event totalling $105 million in lost revenue. In the same year $90 million of frost related damage was recorded in the WA wheat growing region. In the northern grains region direct frost damage to winter cereals was estimated to be $100 million each year. In southern Australia, despite observed warming in both maximum and minimum temperatures, the number of spring frosts had increased as had the date of last frost for many regions. The paradox appeared to be directly related to changes in southern Australian synoptic circulation patterns. Whether the increase in occurrence of late spring frost was transient or had become a permanent feature of southern Australian production risk was a critical research issue with important practical applications. Improving the understanding of changes in major synoptic features and hence drivers of frost risk was seen as an important first step in determining the changing nature of frost risk.
Objectives	To identify key climatic drivers responsible for frost occurrence from both observed and climate model data and examine trends in these drivers. To identify likely future changes in the climatic drivers in response to enhanced greenhouse gas concentrations and how these might interact with phenological responses to anticipated global warming to change realised frost risk.
Activities and Outputs	A spatial analysis of frost occurrence (start- and end-dates), frost frequency and changes in frost extremes was undertaken. Undertook synoptic typing where periods of frost occurrence are linked with specific synoptic circulation types for northern Victoria, WA and southern NSW. Developed Goyne plots for a range of sites across Victoria that examined the interaction of frost and flowering for three representative wheat cultivars Undertook preliminary analysis of high resolution General Circulation Models (GCM) data to

	examine the behaviour of blocking highs across 30 year period centred on 2030. A broad literature survey was undertaken to determine: if similar research had been done elsewhere, an effective working definition of frost, trends in frost occurrence, interactions between frost and crop yields, etc. The project found that there was very little peer reviewed material that explores the historical changes in Australian frost occurrence and no peer reviewed articles that examine historical changes in frost period were found. Australian studies showed statistically significant increasing trends in the incidence of cold nights and frosts since 1960s particularly across the southern parts of NSW and Victoria. Analyses of data showed an average increase of 4 frost days per decade since 1970 and an increase of around 5 cold nights per decade over the same period for NSW and Victoria and more modest increases in cold nights in WA. The project found that research undertaken internationally demonstrated statistically significant declines in the number of frosts as well as the frost window over much of the continental US and parts of northern Europe. Analysis of BoM data revealed an increasing trend in frost numbers over southern NSW and northern Victoria; over the west and across SA the average number of annual frost had mostly remained unchanged. From the BoM data, there was an observed broadening in the period over which frosts occur across the entire southern parts of Australia. GCM data analysis preliminary results showed a further 5°S southerly displacement of the high pressure systems during the September to November period. Case study results showed that sowing wheat variety Axe before mid May, and Yitpi before 30th of April exposes them to significant frost risk. Ideal sowing time for Axe was found to mid May to mid June in northwest of Victoria and late May to mid June in eastern Victoria. The ideal window for sowing Yitpi was found to be late April to mid May across Victoria. The findings of this project were presented to senior agronomists at BCG and was also discussed with farmers (Steven Crimp pers. comm., 2012) A presentation was made to Grape and Wine Research and Development Corporation (GWRDC) and a number of workshops were held with Minnipa and Mallee stakeholders. Ground Cover articles were produced (Ground Cover Issues 85 and 95). A draft journal paper has been prepared; this examines the global teleconnections with Australian frosts.
Outcomes	Some of the farmers in northern Victoria have adopted early dry sowing. However this is done not just to mitigate frost risk but also to maximise in-crop rainfall (Steven Crimp pers. com. 2012). Potentially increased skill in frost risk forecasts using daily, three hourly and hourly station and gridded data from BoM. Increased awareness and knowledge by both Wine and Grains industries of the current and future changes in frost risk. Potential improved farm management practices to reduce crop frost damage.
Benefits	Potentially, reduced loss of farm produce due to frost damage. Potentially, industry-wide reduced costs due to frost damage. Enhanced scientific and industry capacity to simulate and forecast future frost risks.
MCV00011: Climate drivers and weather features for Australia	
Project details	Organisation: Bureau of Meteorology Period: February 2010 to June 2010 Principal investigator: Ceri Lovitt
Rationale	There had been limited understanding of the systems that drive Australia's weather/climate. This lack of understanding could be dealt with by taking a systems approach. The systems approach would recognise change and the fact that to think in averages and analogue years was totally inappropriate for a climate as variable as Australia's. A systems approach was also important because it underpinned dynamic modelling. Therefore the more climate forecast users understand the climate system, the better prepared they are to interpret the outputs of dynamic modelling climate forecasting for their own purposes.
Objectives	To correct the previously hastily prepared climate drivers and weather features sets as were prepared for the DAFF funded Climate Change Awareness set of workshops in Vic, Qld, SA and WA. To prepare similar documentation for the remaining states (NSW Tas and NT).
Activities and Outputs	Developed web ready tables of Climate Drivers and Synoptic features for NSW, NT and Tas. Improved the existing web ready tables of Climate Drivers and Synoptic features for Qld, Vic, WA and SA. Undertook a preliminary review of all synoptic features for all states and availed them for uploading via Econnect on Climate Kelpie website.

Outcomes	An improved understanding of climate drivers and synoptic features thus leading to enhanced climate risk management. Enhanced resource use sustainability from optimised farm practices. The type of information presented through this project received international interest from the Florida State University which now seeks to provide a similar setup for southern USA. Potentially reduced social impact of extreme droughts/floods as farmers can better prepare for such.
Benefits	Potentially, reduced income losses or increased input cost savings for farmers. Enhanced industry capacity to foresee and make decisions about the future. Potential contribution to community resilience.
MCV00012: Multi-week climate outlook products for Australia	
Project details	Organisation: Bureau of Meteorology Period: October 2009 to June 2011 Principal investigator: Andrew Watkins
Rationale	Consultations with users had suggested that there was an increasing demand for forecasts that fill the gap between weather forecasts (7 days) and the seasonal outlooks (3 months). Multi-week forecasts of both rainfall and temperature could enable within-season farm planning, highlight seamless nature of weather/climate, and add value to both the weather forecasts and seasonal outlooks. There was need to examine how the experimental forecast outputs given by BoM's POAMA could be turned into information that can be readily accessed and understood by the farming community.
Objectives	To develop a scientifically and technically sound framework for the implementation of a multi-week forecasting system, including products tailored for Australian agriculture through the Water and the Land (WATL) website.
Activities and Outputs	Produced and circulated demonstration (non-operational) multi-week forecasts for assessment. Undertook recalibration of POAMA outputs and discussed significant issues with National Climate Centre and the Centre for Australian Weather and Climate Research scientists. Developed software that enables calculation of skill and calculated skill scores for the inflation of variance (IOV) technique as well as for a bias correction technique and the raw POAMA output. IOV was selected as it had the best skill score. Completed a product assessment report, including a user analysis in consultation with MCVP stakeholders, Climate Champions and other users. Internally discussed a number of prototypes.
Outcomes	Contribution to enhanced ability of farmers to plan their operations with minimum ecological impact e.g. through optimised N applications, and dry seed using direct drilling to minimise erosion and improve soil moisture retention ahead of anticipated rains. Better management of cost risk and better ability to take advantage of conditions with greater surety. Potential reduced stress for farming families from better climate risk management. Potential contribution to farming communities' resilience.
Benefits	Potential benefits include: Reduced income losses and/or increased input cost savings for Australian farmers. Contributions to environmentally beneficial outcomes e.g. reduced off-farm nutrient run-off, reduced soil erosions through accommodation of upcoming climate events in management decisions. Contributions to more resilient farming communities. Reduced stress for farming families.
MCV00013: Temperature extremes and cropping in Western Australia	
Project details	Organisation: Department of Agriculture and Food, Western Australia Period: March 2010 to May 2013 Principal investigator: Ian Foster
Rationale	Frost from climate variability remained a cropping risk and also there was a perceived relative lack of appreciation for the role of temperature apart from frost. The incidence of high temperature extremes was predicted to increase, with frequency and area affected by high temperatures expected to increase markedly. It was deemed likely that farmers would need to make sowing and variety choices not only to minimise frost risk but also to avoid high temperature risk during grain filling. There was therefore a need to investigate the impact of temperature on cropping in WA. The findings would not only inform farmers but breeding programs and agronomic research as well.
Objectives	To assess temperature risks across WA grainbelt under current climate. To assess changes in temperature risks and impact on cropping in South West WA under projected future climate. To develop strategies and options for managing seasonal temperature risk and related

	recommendations for plant breeding.
Activities and Outputs	Published a paper titled "The impact of temperature variability on wheat yields" by Asseng, S., Foster, I. and Turner N., 2010, in Global Change in Biology, 10, 1365-2486. Produced a conference paper on options for managing risk, and trade off with possible yield decline, this was presented at Agronomy Conference 2010, Crop Updates 2011. Another paper was presented at the Crop Updates 2012 and the Drought Pilot workshop in November 2011 on changes in frost and high temperature risk in spring. Due to sub-contracting issues with CSIRO and Murdoch University some of the project outputs will be delayed and the overall project will be delayed by an additional year at no extra cost. Expected outputs: Development of profiles of daily temperature risks and report of changes to key dates, such as dates of first and last frost, as well as high temperature occurrences. An investigation of changes in weather patterns over southern WA over the 20th century via publicly available Reanalysis data. An additional analysis of changes in weather patterns using DAFWA automatic weather station (AWS) records for 1990s and 2000s. Some experiments including APSIM simulations to study the benefits and risks of variable sowing dates versus fixed sowing dates. Appointment of a regional development officer to work with grower groups on cropping management decisions.
Outcomes	Potential project outcomes include: Increased awareness of the significance of temperature extremes and the need for climate risk management. Better informed breeding and agronomy research thus leading to varieties that are better adapted to temperature extremes. Better management, planning and financial decisions on weather and climate risks for WA grain growers.
Benefits	Potentially, reduced grain produce losses due to extreme temperatures (frost and heat). Enhanced agronomic and related scientific knowledge about grains and temperature extremes. Contributions to improved south west Western Australia farming communities' resilience.
MCV00014, MCV00017, MCV00018, MCV00019, MCV00022, MCV00023, MCV00024 and MCV00027: Management and Communication of Managing Climate Variability Program	
Project details	Organisations: GRDC and Econnect Communications Period: July 2008to June 2013 Principal investigator: GRDC and other contracted personnel (Note: The following eight management and communication projects did not have individual detailed project reports available for this evaluation. Hence, the description of these projects is limited and describes the projects more generally than for other projects.)
Rationale	There was a need to fund projects/personnel to facilitate efficient and effective management and administration of the Managing Climate Variability Program. Similarly there was a need to fund communication strategies that would help spread the program's outputs and outcomes to increase adoption encourage adoption.
Objectives	To develop a MCV program communication strategy. To manage the MCV program communication website, workshops, magazine articles and discussion forums. To support the MCV program administration, program committee and independent Chair, and evaluation of planned projects.
Activities and Outputs	There are eight projects covered in the administration and communication investment; these are: MCV00014: Communication support MCV00017: Communication support and administration MCV00018: Website MCV00019: Communication products MCV00022: Program Officer MCV00023: Program management committee MCV00024: Independent chair MCV00027: Monitoring and evaluation of planned projects Some of the outputs for this group of projects are: Organisation of workshops for Climate Champions (CCs) participants. Interview all CCs on-farm and write stories and collect photos and audio visual materials for Climate Kelpie and other outlets. Provision of on-going communication support for CC participants. Liaison with the CC participants and processing of their quarterly payments and payments of travel expenses. Maintenance and updating of the Climate Kelpie and the MCVP website. Moderation of the 'Ask a Farmer' discussion forum.

	Writing and designing of climate magazine (CliMag) twice a year.
Outcomes	Monitoring and administration of the MCV program. Enhanced sharing of MCVP information and technologies with farmers (e.g. Climate Champions) and other stakeholders through articles, websites and workshops. Potential contributions to more speedy adoption of better climate management strategies.
Benefits	Increased knowledge sharing among researchers and industry people. Increased farm incomes and/or reduced losses due to use of climate variability information and tools to manage climate risk.
MCV00015: MCVP Coordination	
Project details	Organisation: Colin Creighton, Beverley Henry Period: July 2008 to June 2013 Principal investigator: Colin Creighton, Beverley Henry
Rationale	There was a need for an MCV program science manager to coordinate the program's activities and work with all MCV program researchers, industry leaders, and stakeholder organisations.
Objectives	To coordinate day-to-day activities of the MCV program. To support the Program Management Committee (PMC) and the GRDC Manager to help ensure the program meets its goals and objectives for research, development and knowledge and adoption. To provide monthly reports with invoice on program activities and its performance to the PMC. To provide strategic advice on MCVP research, development and investment priorities. To monitor and manage the MCV research program – including project proposal development and progress report review. To oversee the implementation of the MCVP knowledge and adoption strategy. To continue to lead the implementation of MCVPIII and the development of future investments as appropriate. To work with the GRDC Manager to broker support and investment from current and new partners in MCVP. To provide the primary point of contact for the program for a wide range of organisations and individuals. To forge effective relationships with other organisations involved in climate research including CSIRO, BoM and ABARES to ensure a coordinated and cooperative approach to investment in research and development. To help facilitate the integration of activities of the program with other initiatives of program partners.
Activities and Outputs	Beverley Henry was appointed the MCV program coordinator; her roles in program development and delivery were to: Work with the MCVP Chair and industry leaders to gain support and resources. Work with the Program Management Committee (PMC) and agricultural industry clients to develop and then detail strategic investment directions. Work with the climate science and agricultural science research communities to develop and then formulate project proposals for review and approval through the PMC. Work with research providers to ensure that the research projects deliver quality outputs relevant to Australian agriculture. Work with other contract and GRDC staff to ensure outputs are communicated in forms that foster adoption of climate risk management. Undertake any other activities as necessary to ensure cost effective and efficient delivery of the science portfolio on behalf of all investors and clients.
Outcomes	Enhanced MCV program coordination. Enhanced program effectiveness and efficiency.
Benefits	Potential contribution to efficient research resource allocation for the MCV program. Better information sharing and potential increased adoption of climate risk management strategies.
MCV00028: Climate analyser DSS tools	
Project details	Organisation: RPS Australia East Pty Ltd Period: December 2010 to August 2012 Principal investigator: David Freebairn
Rationale	There was an observed challenge in turning raw weather observations (data) and forecasts into information that farmers could use. There was a need to bridge the gaps between data, information and better informed practice. Multi-week forecasts were improving in skill and this presented an opportunity for tactical decision making. There was a need for a 'climate analyser' that is readily accessible and meets the needs of different Australian agricultural producers.
Objectives	To design, based on user needs and from a user question perspective, an easier interface for farmers to access climate data and climate forecasts, fostering the transition of more farmers to implementing climate risk management strategies. To deliver a series of simple decision support products that integrate climate data and forecasts required by agriculture and beyond the mandate of BoM and its agriculture orientated services-

	Water and the Land. To build on a series of competent but ageing tools, some of which are no longer serviced by their original custodians, that have been proven to be useful but need updating and linking to climate forecasts where sensible.
Activities and Outputs	A refined set of questions that growers ask and can be answered by application of climate data and forecasts. A set of next generation, user friendly climate risk management tools (e.g. software for tools for use over the internet, tablets, mobile phones and personal computers). CliMate, a suite of free climate analysis tools delivered on iPhone, iPad and iPod, was launched in late 2012 and had achieved 3,000 downloads by the end of January 2013.
Outcomes	Potential outcomes include: Increased access to and use of best available risk assessment tools. Improved management of climate risk by agricultural producers. Reduced stress and improved confidence in decision making. Increased input use efficiencies. Potentially, reduced off-farm nutrient/chemical run-off and nutrient losses.
Benefits	Increased knowledge and potentially improved accessibility of climate decision support tools. Potentially, reduced or optimised input costs to maximise incomes. Potentially, reduced negative environmental impacts such as soil erosion and nutrient losses owing to the enhanced producers' ability to foresee extreme conditions. Potential contributions to community resilience.
MCV00029: Specifying Australia's climate variability in the context of a changing climate	
Project details	Organisation: University of Newcastle Period: June 2011 to September 2012 Principal investigator: Anthony Kiem
Rationale	Several studies had demonstrated that out to at least 2030 time horizon, coping with, and responding to, climate variability was of much higher importance than dealing with the projected impacts of anthropogenic climate change. That is, much of the likely change (apart from for example the increasing frequency of extreme weather events), to at least 2030, appeared to be broadly within the variability of the known (i.e. instrumental) climate record. This was consistent with the knowledge that to manage climatic risk in Australia you have to solve two problems: spatial variability and temporal variability. There was therefore a need to improve the ability to cope with existing and historical variability. This would help farmers to improve their management of climate risk.
Objectives	To demonstrate the importance of climate risk management taking into account the impacts of both natural climate variability and anthropogenic climate change. To demonstrate across Australia the variability that has is already experienced and needs to be taken into account as part of climate risk management. To put the changing nature of Australia's climate for each station into context. To highlight the need for climate forecasts that are physically-based, regionally-specific and practically useful (e.g. with respect to lead-time, accuracy and preciseness).
Activities and Outputs	Analysis of variability and trends, and impacts of key drivers such as ENSO, IOD and SAM completed on available records from 103 BoM temperature stations and 152 rainfall stations to give national coverage. Analyses include temperature averages and extremes, daily and seasonal rain and a soil moisture estimate (derived from 20% fallow rainfall). Planned analyses of wheat yields, severe weather etc were not able to be done because of the unforseen limitations of the data. The project report concentrates on analysis and discussion of outputs for Inglewood, Balranald and Corrigin (or comparison stations Inverell, Kerang and Cunderdin where data was not available) as selected in consultation with participants in the CCP. Results are presented with over 100 figures and tables. Analyses to identify significant trends (based on breakpoints) or changes that have occurred over the period of instrumental record (recognising that when no trend is identified that conclusion is based on the data available and the statistical tests employed, and further, that trends identified may be related to changes in sites or instrumentation). Web ready plots and data files for each variable and station. One abstract was submitted to and accepted by the Climate Change Research Strategy for Primary Industries (CCRSPI) conference in Melbourne in November 2012. An abstract was submitted and accepted for oral presentation at the AMOS National Conference in February 2013 in Melbourne (Anthony Kiem pers. comm., 2013). The project leader has consulted relevant personnel through workshops, conferences and meetings to find the best ways to present the analyses to end-users, but action on the consultations is currently lacking (Anthony Kiem pers. comm., 2013). A journal paper was produced for publication.
Outcomes	Enhanced scientific knowledge relating to Australia's climate variability.

	Contributions to improved farmer understanding and climate forecasting skill assessments depending on measures taken to promote outputs and their interpretation to potential users. Potential contributions to improved farmer knowledge leading to increased uptake of practices that deliver beneficial climate risk management outcomes. Capacity to undertake further analyses based on the software developed for the project. (The report advises that some analyses such as breakpoint are preliminary and further analysis of trends may be warranted).
Benefits	Potential contributions to improved decision making that mitigates against environmental issues such as wind erosion, water borne erosion, excessive nutrient loss, excessive recharged to groundwater and excessive chemical loss. Potential contributions to enhanced sustainability and profitability from matching fertiliser applications and irrigation to plant needs, forward irrigation to reduce heatwave impacts, and better crop sowing and/or variety selection to avoid frost/heat damage. Enhanced climate variability scientific knowledge.
MCV00030: Adding value to climate risk management decision support systems	
Project details	Organisation: Birchip Cropping Group Inc. Period: July 2011 to December 2012 Principal investigator: Tim McClelland
Rationale	Water availability is the primary constraint to crop production in Australia. Australia's climate, and in particular rainfall, is among the most variable on earth, and consequently crop yields vary from season to season. In order to remain profitable, crop producers must manage their agronomy, crop inputs, marketing and finance to each season's yield potential. Scientists have attempted to support farmers' capacity to respond to this problem by developing APSIM. Yet, farm managers and their advisors had rarely reciprocated the scientists' enthusiasm for developing these tools. More recently, Yield Prophet has had a measure of acceptance and adoption among innovative farmers leading to valuable impacts in terms of assisting farmers to manage climate variability at a paddock-level. With many utilising APSIM to assist decision-making, it was essential that the accuracy of the tool was at a level which facilitates advantageous decisions. There was a need to improve the accuracy of APSIM in order to facilitate increased adoption and utilisation of the tool.
Objectives	To identify gaps in current research knowledge that limits the accuracy and application of APSIM. To improve accuracy of Yield Prophet simulations. To include heat shock/stress in the modelling of cereals phenology.
Activities and Outputs	A desktop review of simulations from previous seasons to determine the likely causes of inaccurate simulations. Development of a soil characterisation selection tool designed to help growers and consultants to overcome soil classification difficulties. The selection tool was tested on the Yield Prophet test site before loading onto the Yield Prophet live site. A literature review of the effect of heat shock on wheat and barley yields. Completed phenology and grainfilling trials at three sites across SA, Vic and Qld. Incorporation of field trials results into the improvements of APSIM simulations. Two draft papers will be written for peer review, covering (1) maximum grainfilling potential of wheat and barley varieties and (2) quantitative evaluation of drivers of wheat growth stage development in eastern Australia.
Outcomes	Potential outcomes include: Improved accuracy of crop yield simulations. Increased confidence in use of APSIM as a decision support tool. Better management of climate risk by farmers. By matching crop inputs with potential yield in a given season, Yield Prophet subscribers may avoid over- or under- investing in their crop, thus attaining input use efficiency increases. Contributions to reductions in negative environmental impacts from off farm nutrient run-off.
Benefits	Potentially improved decision making that mitigates against environmental issues such as wind erosion, water borne erosion, excessive nutrient loss, excessive recharged to groundwater and excessive chemical loss. Potentially, enhanced sustainability and profitability from matching fertiliser applications and irrigation to plant needs, forward irrigation to reduce heatwave impacts, better crop sowing to avoid frost damage. Contribution to building and maintaining farming community resilience. Enhanced scientific capacity.
MCV00031: Predictions of heat extremes on the multi-week timescale	
Project details	Organisation: Bureau of Meteorology Period: June 2011 to December 2013 Principal investigator: Debra Hudson

Rationale	There was a notable gap in prediction capability beyond one week and shorter than season. This was because it was difficult to provide skilful predictions for intra-seasonal (multi-week) timescale, particularly from the second week to the first month of the forecast. Over the past few years, with improvement of dynamical prediction models, skilful intra-seasonal predictions based on general circulation models were now being delivered operationally internationally. In Australia there had been increasing demand for intra-seasonal forecasts, particularly from the agricultural community, and in response, recent work funded by the MCV program had begun investigating the potential for using BoM's seasonal forecast model, POAMA, for forecasting for this timescale. This project builds upon this work by investigating the capability of POAMA to predict extreme heat over Australia for forecast ranges of less than one month. This is a follow-on project from the project "*Improving multi-week predictions*" (MCV00009) (Debra Hudson, pers. comm., 2013).
Objectives	To understand the large-scale climatic processes (e.g. state of El Nino) that lead to episodes of extreme heat over Australia. To examine the ability of POAMA to simulate and predict these large-scale processes. To explore and define the ability, or skill, of POAMA for making predictions of heat extremes for forecast timescales of less than one month. To identify potentially skilful products, to help guide the development of intra-seasonal products for use by farmers.
Activities and Outputs	Completed a literature review documenting the primary drivers of heat extremes over Australia, the usage of heat extreme indices and definitions of a heatwave and the current capability to predict heat extremes on multi-week timescales. The literature review results indicated that how a heatwave is defined is an important issue when it comes to heatwave prediction. The literature review undertaken also showed that there was a gap in the scientific literature on understanding the drivers of heatwaves across Australia. This project has potential to make significant contributions in filling this gap. Assessed POAMA-2's capability to forecast maximum temperatures above the upper tercile. POAMA-2's multi-week forecasts of maximum temperature above the upper tercile over Australia were found to be more skilful and reliable than the previous version (POAMA-1.5); this is a similar finding as in project MCV00009. In general, the most skilful time of the year was found to be for forecasts initialised during spring (i.e. Sep, Oct, and Nov) and the skill tends to be focused over eastern Australia. Developed a histogram as an experimental forecast product that could be used for identifying upcoming heat extremes (http://poama.bom.gov.au/histogram_mw.shtml). Promotion of project, project results and the experimental products through BoM's website, Climate Champions and CliMag articles. Seven scientific papers have been produced as outputs from this project and its forerunner (MCV00009) (Debra Hudson, pers. comm., 2013). Harry Hendon who is part of the CAWCR team currently represents Australian on the steering committee of the World Meteorological Organisation's sub-seasonal to seasonal prediction planning group (http://www.wmo.int/pages/prog/arep/wwrp/new/S2S_project_main_page.html).
Outcomes	Increased scientific understanding of the nature of extreme heat events. Increased reliability of forecasts of heat extremes on multi-week timescales for farmers. Contribution to help farmers to plan operations with ecological and economic benefits e.g. through appropriate irrigation scheduling, timing of hazard reduction burning, scheduling of planting, harvesting and fertiliser applications. Enhanced opportunities for Australian researchers to take part in international research and benefit from international research efforts as a research partner. A novel world-class product - without MCVP investment it is likely that multi-week forecasts would probably not exist for Australia (Debra Hudson and Oscar Alves pers. comms., 2013)
Benefits	Potentially, reduced income losses or increased input cost savings for farmers. Enhanced industry capacity to foresee and make decisions regarding upcoming heat extremes. Improved scientific knowledge about climate forecasting.
MCV00032: Northern Australia/Monsoon prediction	
Project details	Organisation: Bureau of Meteorology Period: May 2011 to April 2013 Principal investigator: Matthew Wheeler
Rationale	Previous research had already shown that there were several promising drivers of weekly-to-monthly predictability in northern Australia, including the El Nino-Southern Oscillation (ENSO), the Madden-Julian Oscillation (MJO) and persistent ocean temperature anomalies around Indonesia. Combining the influence of multiple drivers while taking into account their complex interactions was a major challenge for making predictions. Nonetheless, each of these climate drivers were relatively well represented in the then latest version of POAMA, which is the key

	prediction tool available for weekly-to-monthly predictions by BoM, and has the capacity to model the full complexity of climate interactions. At the same time, farmers and graziers in northern Australia had been calling out for prediction products that meet their particular needs. Therefore, it was deemed timely to invest in the development and delivery of climate products for northern Australia focussing on the dynamically-based POAMA model.
Objectives	To investigate agriculturally relevant climate variability and predictability in tropical/northern Australia within the framework of POAMA. To improve the simulation and prediction of climate variability as part of the transition to dynamical forecasting for Australia. To deliver monsoon related climate prediction products for agriculture and other users. To provide guidance for future POAMA improvements.
Activities and Outputs	Investigated the mechanisms and limits to predictability of northern Australia wet season rainfall. Identified the early wet season (pre-monsoon transition) as being the most predictable on the inter-annual time scale. POAMA was able to capture the seasonally varying air-sea interaction that is the primary driver of the loss of seasonal predictability during the peak of the monsoon season. As with most coupled models, northern Australia was found to be too dry in both versions of POAMA (a dry bias). The dry bias was corrected for in the design of the onset prediction scheme, and results were presented at the Australian Meteorological and Oceanographic Society (AMOS) conference in February 2012. POAMA was also found to be unable to represent the observed trend in onset date that has occurred, particularly in the interior of Western Australia and the southern parts of the Northern Territory. An article was published in CliMag (Edition 21) in September 2011 to promote the project. Project overview and preliminary onset forecasts were presented at the National Climate Centre (NCC) climate meeting (September 2011) Madden-Julian Oscillation (MJO) phase forecasts were developed and placed on the POAMA web page. Two computer codes for the wet season onset prediction and for the MJO forecasts display are to be written within this project and prototype prediction products produced in 2013. Work has begun on the initial web-page mock-ups for display of forecast products (in collaboration with CAWCR-NCC). A poster titled “Managing Climate Variability in Agriculture: Predicting the Onset of the North Australian Wet Season” was presented at the AMOS 2012 conference. A PowerPoint presentation was given at the 10th International Conference on Southern Hemisphere Meteorology and Oceanography in April 2012. A conference paper was prepared for CAWCR modelling workshop on monsoons, November 2012 (Matthew Wheeler pers. comm. 2012). A journal paper on “The role of air-sea interaction for prediction of Australian summer monsoon rainfall” was published in the Journal of Climate, vol 25 pages 1278-1290.
Outcomes	Actual and potential outcomes include: More informed decisions particularly by the grazing industry across much of northern Australia. Improved management particularly in ENSO years from forecasts with longer lead times of earlier or later monsoon onset compared with current SOI-based forecasts. Important guidance for the development of POAMA-3. Increased understanding of skill for predicting climate variability in tropical/northern Australia within the framework of POAMA.
Benefits	Contribution to economically beneficial decisions by farmers in northern Australia e.g. reduced input losses when the climate is unfavourable and increased benefits when it is favourable. Contribution to environmentally beneficial decisions by farmers in northern Australia e.g. a forecast of a late wet season could foster decisions to reduce cattle herd numbers thus reducing overgrazing and soil erosion risks. Contributions to building more resilient farming communities. Enhanced scientific knowledge and understanding of drivers of monsoon variability and predictability. Potential R&D funds cost savings from testing POAMA system forecast skill over a month lead as opposed to nine months for seasonal forecast (Debra Hudson, pers. comm., 2013)
MCV000XY: A pilot study linking multi-week climate forecasts to N fertiliser decisions *(project not yet contracted as at February2013)*	
Project details	Organisation: South Australian Research and Development Institute Period: September 2012 to September 2013 Principal investigator: Peter Hayman
Rationale	Farmers had long been advised as part of best management practices to avoid the application of nitrogen fertiliser on moist soils prior to heavy rain. This project focuses on using weather forecasts to adjust the timing and in some cases the rate of N application.

	The premise of the project was that recent advances in the science, availability and communication of weather forecasts from 1 to 7 days and multi-week forecasts of 2 – 8 weeks had an unrealised potential in managing nitrogen fertiliser. After interactions with farmers and advisers it was believed that these weather forecasts were under-utilised. The short to medium term forecasts needed to be combined with soil moisture and an understanding of plant demand and nitrogen dynamics. This is a proof-of-concept project using case studies from the grains and dairy industries.
Objectives	To link recent developments in the communication of weather forecasts through websites such as Water and the Land (WATL) with detail on rainfall amount and chance for the coming four to seven days to N decision making.
Activities and Outputs	Expected outputs include: Parameterising of APSIM for a grains case study and DAYCENT for a dairy case study on N management. Developing an excel spreadsheet framework for N management given uncertain rainfall events. Assessment of the framework by farmers, farm advisers, BoM's climate scientists, MCVP management committee and other experts.
Outcomes	Expected outcomes include: Successful proof-of-concept leading to use of weather forecasts to adjust the timing and in some cases the rate of N application by farmers. Application of the concept to other industries such as horticulture, sugar, etc. Potential enhanced climate risk management by Australian farmers.
Benefits	Potentially, enhanced information for better N fertiliser decisions. Potentially, reduced input costs during unfavourable conditions and/or increased profitability from taking advantage of good conditions. Potentially, contributions to ecologically beneficial outcomes from reduced off-farm N run-off. Potentially, enhanced scientific knowledge.
MCV000XZ: Multi-week climate outlook products for Australia (Phase II) *(project not yet contracted as at February2013)*	
Project details	Organisation: Bureau of Meteorology Period: April 2012 to March 2013 Principal investigator: Andrew Watkins
Rationale	Consultations with users had suggested that there was an increasing demand for forecasts that fill the gap between weather forecasts (7 days) and the seasonal outlooks (3 months). Multi-week forecasts of both rainfall and temperature could enable within-season farm planning, highlight seamless nature of weather/climate, and add value to both the weather forecasts and seasonal outlooks. Providing such outlooks via the already successful Water and the Land (WATL) would fill this substantial gap. Phase I (MCV00012) of this project took raw experimental model output and turned it into prototype forecast products which were trialled with key end-users. This involved calibrating the raw model output so that it better aligned with real-world observations. Phase II (this project) will build on the lessons and techniques learnt in Phase I. The key is to assess all aspects of the model data and its delivery prior to start of an operational service. So, when a multi-week forecasting service is introduced to the farming community, users will be confident that what they see on the website or hear in an interview is understandable, usable, accurate and ultimately will assist them in increasing their productivity and improve their climate risk management options.
Objectives	To apply (to POAMA-2.4) those lessons learnt in Phase I (POAMA-1.5). To develop a trial prototype system (as opposed to the test mode in Phase I). To respond to the feedback from MCVP Climate Champions regarding the usefulness of various two to four week rainfall forecast test products. To maintain a continued evolution of the web interface, including testing by a selected set of registered users.
Activities and Outputs	Expected outputs include: Main project output is a prototype multi-week rainfall forecasting service based on POAMA-2.4 forecasts. A publicly available report detailing the multi-week system and first suite of forecast products. Summary reports articles in CliMag and other industry newsletters such as Groundcover so that users can give feedback suggestions and also start applying the products within their climate risk management decision making. An internal report discussing the problems and solutions with the POAMA-1.5 model and how they were managed with the move to POAMA-2.4.
Outcomes	Expected outcomes include: Improved multi-week forecast skill and reliability Enhanced ability of farmers to plan their operations with minimal ecological impact.

	Better climate risk management by farmers through taking advantage of good conditions and minimising impact of poor conditions.
Benefits	Potential benefits include: Reduced income losses and/or increased input cost savings for Australian farmers. Contributions to environmentally beneficial outcomes e.g. reduced off-farm nutrient run-off, reduced soil erosions through accommodation of upcoming climate events in management decisions. Contributions to more resilient farming communities. Reduced stress for farming families.