

# The Value of Earth Observations from Space to Australia

Report to the CRC for Spatial Information December 2015



Australian Government  
Geoscience Australia



Australian Government  
Bureau of Meteorology



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## EXECUTIVE SUMMARY

### Introduction

This report was commissioned by the Cooperative Research Centre for Spatial Information (CRCSI) on behalf of Geoscience Australia (GA), the Bureau of Meteorology (BOM) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

The goal of the project was to address the gaps in past economic assessments by examining in greater detail the current and potential economic benefits resulting from new and emerging Earth Observations from Space (EOS) applications.

Key objectives were to:

- reassess the estimates made in earlier reports for the year 2010
- examine new and emerging applications in the case study areas
- estimate the likely socio-economic value of EOS in 2025 for the Australian economy.

### Findings

The total direct economic benefits identified from the use and application of EOS data from the case studies were found to be:

- \$496 million in 2015
- \$1,694 million expected by 2025.

The total social and environmental benefits identified from the use and application of EOS data were found to be:

- \$861 million in 2015
- \$1,329 million by 2025.

Many of the benefits from the case studies arise in important sectors of the Australian economy, including agriculture, aviation, tourism and recreation, petroleum, mining, water, property, and insurance. The results by subject area are shown in Table E 8.

On this basis of initial calculation, it was estimated that the combined impact of the use of EOS services resulted in employment in 2015 being around 9,293 higher than it would otherwise have been without EOS. This figure is expected to increase to 15,997 by 2025.

### Denial of service in the future

The evidence collected for this report reveals the increasing importance of EOS in many important areas of government and industry. If a complete denial of service were to occur, the economic and social impact would be far higher than the values that have been estimated in the case studies. A sustained denial of service would cause a disruption to most of the applications and services discussed in this report.

Lack of EOS data would have serious consequences for meteorological modelling and weather forecasts, it would reduce the effectiveness of ocean monitoring and it would seriously limit the effectiveness of land cover monitoring by both governments and industries such as agriculture and mining, except in limited cases where alternative technologies could be engaged. As a result, a significant loss of productivity in these areas could be expected.

For this reason, the cost of a complete denial of service is likely to exceed by some margin the values of EOS services that have been discussed in this report.

TABLE ES 1 – SUMMARY OF FINDINGS							
Activity	Sectors	Impact	Nature of benefit	2015	2025	Potential employment impacts 2015	Potential employment impacts 2025
				\$million	\$million		
Weather forecasting	Agriculture, aviation	Economic	Increase in value added	75.8	199.1	903	1,474
Ocean observation	Great Barrier Reef	Social/ environmental	Sustainable ecosystem	825.0	1275.0	7593	10,146
	Petroleum and shipping	Economic	Increase in value added	13.3	29.7	11	26
Landscape and land cover monitoring	Government	Social/ environmental	Sustainable land cover	20.7	39.2		
	Property	Economic	Increase in value added	64.4	128.8	384	768
Agriculture	Crops and pastoral, biosecurity	Economic	Increase in value added	84.7	754.7	402	3,583
Water management	Water sector	Economic	Increase in value added	39.5	80.0		
	Water resources	Social/ environmental	Enhancing habitat and catchment ecology	14.9	14.9		
Natural disasters	Insured costs plus social costs	Economic	Increase in value added	213.0	495.0		
Mining	Licence to operate	Economic	Increase in value added	5.0	6.7		
Total Economic				495.7	1,694.0	9,293	15,997
Total social/ environmental				860.6	1,329.1		
NOTE. THIS PROJECT SCOPE DID NOT INCLUDE ECONOMY-WIDE MODELLING OF THE DIRECT ECONOMIC EFFECTS ON GDP AND INCOMES. THE TOTALS THEREFORE ARE DIRECT EFFECTS AND NOT OUTCOMES FOR THE ECONOMY AS A WHOLE.							
SOURCE: ACIL ALLEN							

Government agencies from other nations supply many of the EOS services on which Australian governments and industry rely. There are mechanisms and intergovernmental agreements in place that establish these supply arrangements. It would be important to ensure that these mechanisms are sufficiently robust to protect the EOS supply chain on which Australian governments and industry rely.

#### Comparison with the 2010 report

ACIL Tasman examined the value of EOS in 2010 from three perspectives: the direct contribution of the EOS sector to the economy; the productivity impacts in other sectors; and other social and

environmental benefits accruing to society (ACIL Tasman, 2010). The estimates in the 2010 report were orders of magnitude in terms of economic benefits.

The 17 case studies undertaken for this report confirm the estimates made in 2010 and suggest that the contribution has grown since that time. The case studies also suggest contribution will continue to grow as newer higher resolution sensors become available and as data from EOS are integrated into applications.

TABLE ES 2 – SUMMARY OF COMMENTS ON 2010 RESULTS			
	2010 estimate \$ billion	2015 \$ billion	2025 \$ billion
<b>Contribution to GDP</b>			
Direct value added by EOS industry	1.4	1.8	2.5
Productivity impact of EOS for other sectors	1.9	2.0	3.0
<b>Social and environmental benefits</b>			
Natural resource management, ecosystems	1.0	1.5	2.0
NOTE: THE FIGURES IN THIS TABLE ARE ORDERS OF MAGNITUDE ESTIMATES INFORMED BY THE 17 CASE STUDIES UNDERTAKEN IN THIS REPORT.			
SOURCE: ACIL ALLEN			

Current and future estimates based of the findings of the case studies for this report are compared with the findings in the 2010 report in Table ES 2.

Realisation of these benefits will depend on:

- the impetus for innovation and adoption of new these emerging applications, particularly in agriculture, and in land cover, land use and landscape monitoring.
- development and cost of competing remote sensing technologies such as airborne techniques.

The ability of EOS to deliver current and archived data over large areas is a potential competitive advantage.

#### *Caveat*

Many private sector organisations surveyed were not able to share direct benefit and cost information for commercial reasons. In these cases, ACIL Allen estimated productivity impacts from desktop research and, where possible, confirmed the orders of magnitude with those organisations.

# 1 INTRODUCTION

## 1.1 Background

This report has been prepared for the Cooperative Research Centre for Spatial Information on behalf of Geoscience Australia, the Bureau of Meteorology and CSIRO.

An initial economic assessment of the current contribution to the economy by Earth Observations from Space (EOS) was undertaken in 2010 (ACIL Tasman, 2010). This study did not materially consider the potential benefits from new and emerging applications, and did not seek to estimate the number of jobs that may potentially be created as a result of new businesses taking advantage of the lowered technical and financial barriers to EOS. These gaps in the analysis made it difficult to assure government that investment is being made with the future in sight, rather than simply looking to sustain the current state.

This project aimed to address the gaps in existing assessments by examining in greater detail the potential economic benefits resulting from new and emerging EOS applications.

A companion study has also been prepared which analysed risks of ongoing supply and reliability of EOS data.

Seven areas were chosen for detailed study following an initial survey of service providers and users. The areas selected were:

- weather forecasting
- ocean observations
- agriculture
- water
- monitoring land cover and landscape change

- natural disasters
- onshore mining.

A second survey of around 30 selected stakeholders was undertaken by telephone to gather data on 17 case studies drawn from these areas. In many cases, private sector organisations were not able to disclose economic data for commercial reasons. In these cases, it became necessary to resort to research and analysis of data in the public domain to estimate benefits from the best available public data.

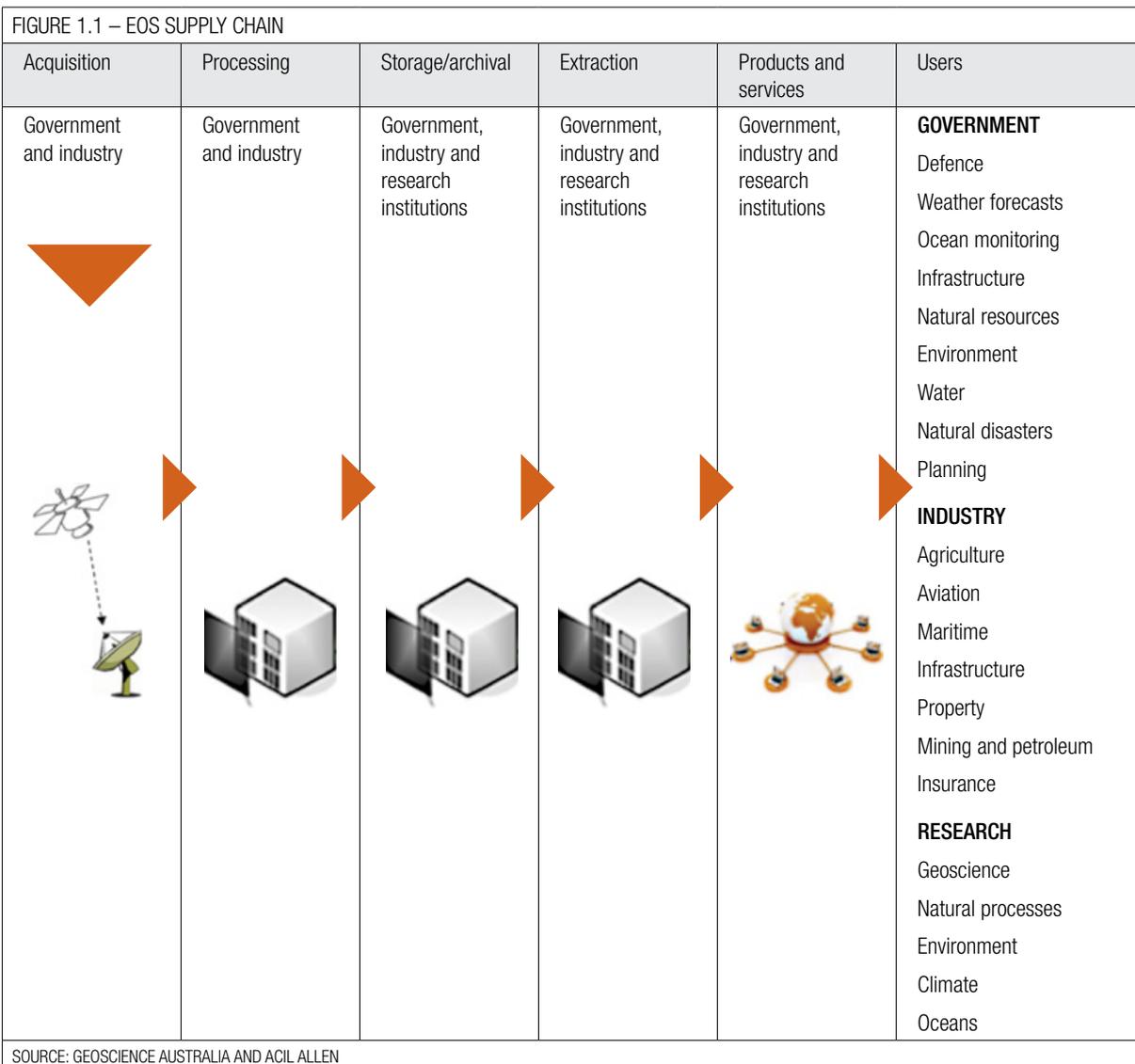
## 1.2 Methodological issues

### 1.2.1 EOS supply chain

EOS data and related products and services are enabling technologies. They are generally not an end product in themselves. They are inputs at the start of a supply chain that can involve many stages of value adding and application development towards an end product or service.

An illustration of the supply chain is provided in Figure 1.1. The supply chain commences with the acquisition of raw data from satellite sensors. Satellite operators can be government or private, and some operators may provide additional services. It is understood that the value of sales by the private satellite operators to customers in Australia is currently around \$10 million per year.

Processing, storage and archiving is an important segment in the supply chain. Archival EOS data is important for many applications such as landscape and land cover monitoring. Extracting the data and developing applications is the step where EOS data are embedded into geographical information systems and models which deliver products and services that are used by government, industry and researchers.



There are no statistics in the Australian Bureau of Statistics (ABS) collections on the size of the different elements in the supply chain. Revenue figures for companies are generally commercial in confidence. Consultations in the industry suggest that the total revenue for private operators in the supply chain is of the order of \$200 million to \$300 million per year. This is a considerable growth on the estimate in 2010. This growth trend is expected to continue.

### 1.2.2 Economic approach

Estimating the value of data from EOS presents a number of challenges. Firstly, a substantial part of the data is free and hence there is no market price on which to base an estimate. Secondly, the data once released is non-rival. This means that more than one user can access it simultaneously. Finally, the benefits that accrue to the downstream users.

One approach to assessing the value of EOS data is to estimate the consumer surplus through willingness to pay studies. Consumer surplus is the difference between the price a consumer is prepared to pay for a good or service and the price that the

consumer has to pay. It represents the value to consumers of a good or service. This approach was examined in one of the examples cited in this report.

An alternative approach is to examine the impact of EOS services on the productivity of downstream users of the data. This accounts for the fact that EOS services are enabling technologies. The productivity impacts are then translated into an increase in value added in a sector. Value added is the difference between the revenue received from the sale of a good or a service and the cost of intermediate goods consumed in producing that good or service. Gross value added is the main component of Gross Domestic Product. The productivity impact approach was used in the majority of the examples cited in this report.

Further discussion of these different approaches to estimating economic value is provided in Attachment A.

### 1.3 Assessing scenarios

#### 1.3.1 Attribution, additionality and the counterfactual

This project requires an assessment of the benefits that may be attributed to the use of EOS in 2015 and what might be achieved by 2025. When assessing the impact of an EOS service it is important to address the question of attribution and additionality:

- Attribution means the extent to which EOS has added value to the overall benefit.
- EOS is an enabling technology for other systems and services, and cannot be credited with all of the benefits that might arise from the use of that system or service.

- Additionality means the extent to which EOS has added additional value to that which would have otherwise occurred with alternative sources of data.

To address these issues we have utilised the concept of an evaluation scenario and a counterfactual or reference scenario.

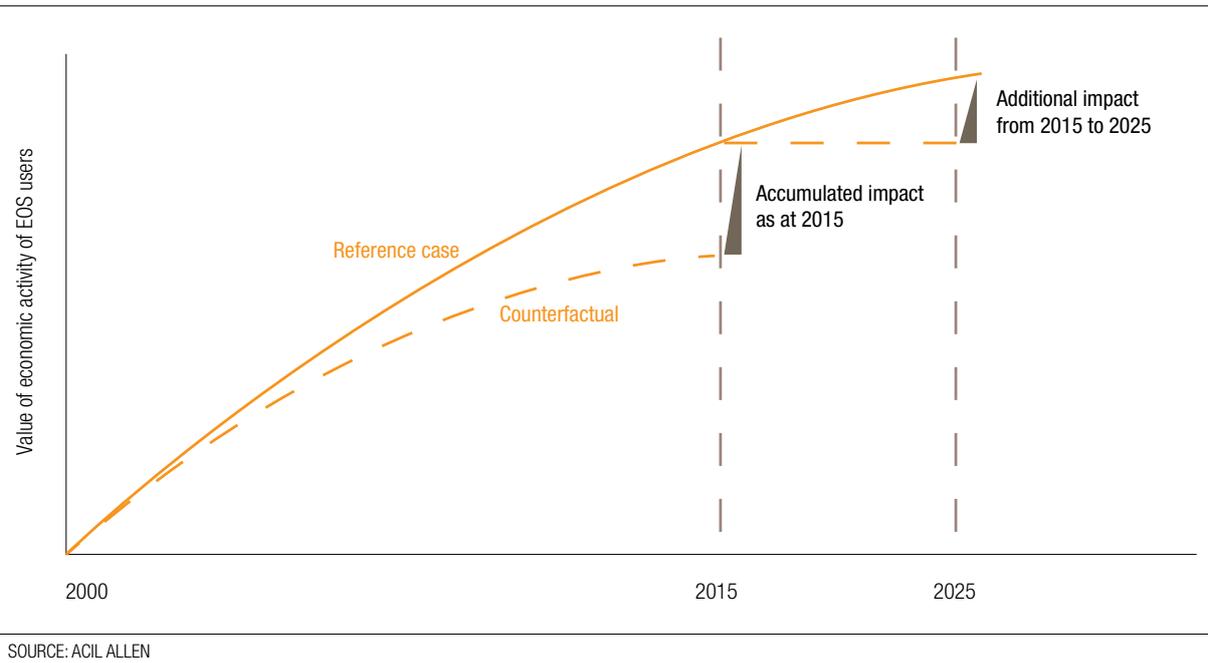
- The evaluation scenario is the case with EOS services.
- The counterfactual is the situation where the best alternative to EOS is deployed in its absence.

In some cases, current services could not be delivered without EOS. In such cases the counterfactual would have to be based the level of service that might have been delivered even though it would have been significantly less effective or completely ineffective. For example, this would be the case for meteorology.

When assessing the difference between the evaluation and the counterfactual scenarios, it is important to take into account the marginal changes in economic welfare. This has been observed in this report by clearly identifying the evaluation and counterfactual scenarios for each case study.

The difference between the evaluation scenario and the counterfactual is illustrated in Figure 1.2. The economic value in 2015 is defined as the difference between the evaluation case and the counterfactual shown as the accumulated impact as at 2015. The additional value at 2025 is also shown. The total benefit in 2025 is the sum of these two estimates.

FIGURE 1.2 – EVALUATION APPROACH



SOURCE: ACIL ALLEN

### 1.3.2 Denial of service

This report also addresses the denial of service situation. A denial of service would represent the situation without the benefit of earth observations from space.

A complete and long-term denial of service would have low probability, but if it occurred, would require a fundamental re-engineering of the operating procedures of many government and private organisations as well as a fundamental adjustment by the community to a world without EOS.

This is discussed in Section 9.2 of the report.

## 2 WEATHER FORECASTING

### 2.1 Introduction

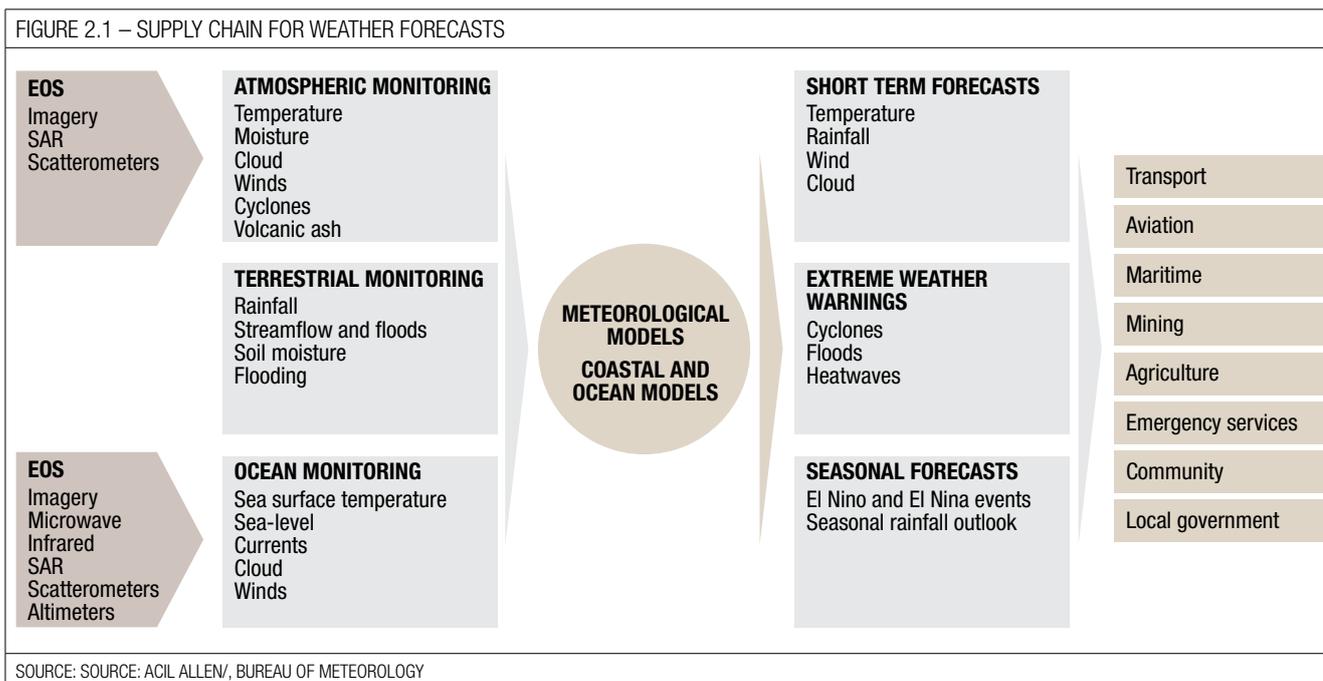
Accurate and reliable weather forecasts are important to many sectors of the Australian economy as well as to society as a whole. The use of EOS in ocean monitoring and meteorological monitoring has contributed to a significant improvement in short-term and seasonal forecasts. This chapter focuses on examples that illustrate the benefits that improved short-term and seasonal forecasts have delivered to broad acre agriculture, to the aviation sector and to the community.

### 2.2 Current EOS applications

The Bureau of Meteorology (BOM) issues outlooks on rainfall and temperature, streamflow forecasts, extreme weather events, volcanic ash warnings and seasonal climate prediction services. The Bureau also delivers seasonal climate prediction services. These services are derived from a vast array of observations, and data collected from ocean, atmospheric and terrestrial monitoring.

These data are fed into meteorological models that in turn produce both short-term and seasonal weather forecasts used by many industry sectors to plan production, plan operations or prepare for adverse weather conditions. Critical dependencies include agriculture, aviation, emergency services, offshore operations, mining and any industry or activity that is dependent on weather conditions.

An illustration of the relationship between the monitoring, the models, the outputs and the sectors that draw on these outputs is shown in Figure 2.1. Recent studies by the BOM have shown that withholding satellite observations from the models degrades forecast timeliness by around 3.5 days in the Southern Hemisphere, which limits the provision of accurate forecasts to around 1 day ahead and renders the forecast models unviable without EOS. The BOM draws on inputs from many satellite sensors for its meteorological models. Among the high priority inputs are atmospheric sounder data, geostationary imagery, ocean vectors, winds, pressure, moisture and elevation.



Improvements in weather forecast quality are being achieved through improved forecasting models, advanced data assimilation techniques and high resolution EOS. The Australian Community Climate and Earth System Simulator (ACCESS) is the BOM's operational weather forecasting model, which also supports the Bureau's seasonal climate prediction service. The Bureau is in the process of acquiring a new supercomputer to support the next version of ACCESS.

The seasonal climate prediction service was converted from a statistical based system to a dynamic forecasting system in May 2013. The new system is referred to as the Predictive Climate Ocean Atmosphere Model for Australia (POAMA). POAMA is heavily dependent on ocean observations, which in turn are dependent on data provided by EOS.

The BOM draws on data from an array of sensors and satellites. Details of the satellites and sensors are discussed in a separate report "Risks of Data Supply of Earth Observations from Space for Australia" prepared by Symbios Communications Pty Ltd. Some of the most important EOS sensors used by the BOM in fulfilling its functions as a short-term and seasonal weather forecaster include the following:

- **Advanced Sounders**
  - Advanced Sounders provide high spectral resolution sounding of atmospheric parameters (temperature and humidity), with vastly improved accuracy. Instruments include AIRS (Aqua), CrIS (Suomi-NPP) and IASI (Metop-A/B/C).
- **Microwave Sounders**
  - Microwave sounders provide all weather sounding of atmospheric parameters (temperature and humidity). Instruments include AMSV and later NOAA satellites, and Metop and ATMs on NPP.
- **Advanced Scatterometers**
  - Advanced Scatterometers such as ASCAT provide a representation of soil moisture conditions that are important for forecasts of precipitation, temperature, droughts and floods. Surface soil moisture observations from ASCAT (METOP satellite) are assimilated into the Bureau's models.
- **Radar Altimeters**
  - Altimeter instruments emit radar waves to measure the distance between the satellite and the ocean surface. Several types of observations are derived from this measurement, including wave height and wind speeds over the oceans and surface currents.
- wind speed and direction and interaction with Sea Surface Temperature
  - delivered by WindSat and ASCAT
- near real time significant wave height (NRT SWH) and sea surface height anomalies
  - delivered from Jason 2, Cryosat 2 and Sentinel 2
- multi-purpose Visible and Infrared imagery from polar orbiting and geostationary satellites
- radiance data for investigation of clouds, land-water boundaries, snow and ice extent, ice or snow melt inception, day and night cloud distribution, temperatures of radiating surfaces, and sea surface temperature, through passively measured visible, near infrared and thermal infrared spectral radiation bands
  - heavily used by weather forecasters in day-to-day operational activities
  - advanced very high resolution radiometers (RT HRPT AVHRR) delivered by NOAA Polar Orbiter Operation Satellites
  - MTSAT and Himawari (Geostationary satellites).

The satellites employed by the BOM are under continuous review as legacy satellites end their operating life and newer, more capable satellites are launched. The Bureau is reviewing a 10-year replacement program to ensure that it has the necessary capability to maintain and improve the effectiveness of its forecasts.

Remote sensing from Earth observations satellites has improved the ability of the BOM to forecast short-term weather by 3 to 4 days (Le Marshall, Lee, Jyng, Gregory, & Roux, 2013). This includes wind, rainfall and extreme weather events that are important to many sectors of the economy but are particularly important to aviation, agriculture, marine activities and emergency services

Seasonal forecasts released by the BOM are used in dry land and irrigated agriculture, water resource planning, catchment management, flood plain management and natural resources management. The BOM Seasonal Climate Outlook was moved from a statistically based seasonal forecast system to a dynamic model known as the Predictive Ocean Atmosphere Model for Australia (POAMA) in 2013. This significantly improved the accuracy of the forecasts.

The Seasonal Climate Outlook provides information on the El Niño Southern Oscillation (ENSO) phenomenon and information on the probability of exceeding median rainfall in the following three months (Crean, J; Parton, K; Mullen, J; Hayman, P, 2014).

Some State Governments have also developed rainfall prediction systems. For example, the Queensland Department of Environment and Heritage Protection issues forecasts based on

the Southern Oscillation Index (SOI) phase system.<sup>1</sup>

In the case of ocean monitoring, remote sensing from EOS is the only effective way in which measurements of sea surface temperature, sea level differentials and ocean currents can be collected over the offshore area.

Such measurements allow scientists to augment other ocean observations with the necessary inputs to form judgements on ENSO phenomena. Similarly, the ability to monitor cloud cover, atmospheric conditions and winds on a wide scale is also only possible with Earth observations satellites.

### 2.3 Future EOS applications

The relatively recent move from statistical analysis to meteorological models for climate outlooks has significantly enhanced the timeliness and frequency of the short-term and seasonal forecasts produced by the BOM. Development of dynamic climate models can be expected to lead to further advances in climate forecasting. This will require inclusion of further data derived from EOS sensors with likely greater frequency and resolution than in the past.

The launch of the Himawari 8 satellite will provide significantly higher quality data compared to the former MTSAT satellite on which many meteorological observations have depended up until now. Himawari 8 and subsequently Himawari 9 have been designed to be dedicated weather satellites that can provide data on atmospheric winds, sea surface temperature, water vapour and solar radiation. Providing coverage every 10 minutes, it will facilitate calculation of the Normalised Difference Vegetation Index (NDVI) and will have the potential to support an entirely new set of land and ocean

<sup>1</sup> The SOI is calculated using the pressure differences between Tahiti and Darwin. It gives an indication of the development and intensity of El Niño or La Niña events in the Pacific Ocean. Sustained negative values of the SOI below -8 often indicate El Niño episodes that are usually accompanied by sustained warming of the central and eastern tropical Pacific Ocean, a decrease in the strength of the Pacific Trade Winds, and a reduction in winter and spring rainfall over much of eastern Australia. Sustained positive values of the SOI above +8 are typical of La Niña episodes that are associated with stronger Pacific trade winds and warmer sea temperatures to the north of Australia and an increased probability that eastern and northern Australia will be wetter than normal.

surface energy balance and land cover monitoring applications in addition to the ocean and cloud imagery applications they are designed to service.

A summary of the improved spatial and temporal resolution of Himawari imagery is provided in Box 2.1

## 2.4 Case studies in agriculture

The use of objective data and digital imagery is increasingly becoming a priority for farm enterprises wishing to stay competitive in Australia. Australian farming enterprises must continue to improve productivity through innovation if they are to stay internationally competitive. The use of objective data and precision farming technologies have become a priority for a growing number of agricultural enterprises in Australia.

Precision farming systems depend on the status of soils, water, crops and pasture to more effectively plan planting cycles, fertiliser application and harvesting times to increase yields and productivity. Accurate forecasts of rainfall in dryland farming and water availability for irrigated agriculture are required to support efficient farming operations.

Historical weather, soil and production data can be used in conjunction with knowledge of the performance of particular crop varieties to formulate optimal crop planting strategies. These are then used in conjunction with weather forecasts to optimise planting times for crops as well as cropping strategies.

Both short-term and seasonal weather forecasts are important to optimising planting times. A wide range of agricultural enterprises from grain growing, mixed farming and horticulture use these forecasts. For example, a typical mixed farming enterprise in south-eastern Australia is engaged in winter cropping in rotation with pasture and fallow activities, lamb production and merino wool production. These farmers must weigh up

### BOX 2.1 – HIMAWARI 8

Himawari 8 was launched in 2014 and became operational in 2015. It will deliver improved spatial and temporal resolution which will provide a number of benefits including:

- improved capacity to locate the centre of Tropical Cyclones over the ocean, leading to improved forecast tracks and more reliable intensity estimates
- improved resilience and business continuity from satellite backup to Radar based TC tracking near the coast to support the forecast and warning process
- dramatically improved satellite imagery available for web and mobile channels
- improved fire weather services through manual identification and tracking of secondary wind changes
- enhanced detection and prediction of severe storms, especially for areas outside radar coverage
- improved volcanic ash detection leading to earlier identification of threat areas for aviation
- increased instrument sensitivity leading to improvements in the resolution and accuracy of satellite derived wind measurements, thereby improving the skill of the forecast models
- enhanced ability in determining icing conditions.

SOURCE: CSIRO

seasonal conditions, soil moisture and cropping strategies in advance of the winter planting season. For example, they will base a decision on whether to plant a grain crop or a fodder crop on their expectations of rainfall during the winter season. A fodder crop might deliver higher returns if the season is dry, whereas a grain crop is likely to deliver higher returns if the season is wet. The quality of decision making depends crucially on the accuracy of rainfall forecasts over the winter cropping period (Crean, J; Parton, K; Mullen, J; Hayman, P, 2014).

Seasonal rainfall forecasts are important to the timing of planting and application of fertiliser. Optimal planting times depend on a number of factors including soil moisture and precipitation. If crops are planted early in the season and rains do not materialise, growers lose production, and in extreme cases, can lose their crop. However, if growers decide to plant late in the season, they must assess the optimal time on a week-by-week basis. Growers must continually update their weather assessments to get this timing right.<sup>2</sup>

The same logic applies to fertiliser. There is little point in applying fertiliser if rains do not arrive. Growers seek to optimise the timing of fertiliser application to maximise the benefits of its application taking into account expected rainfall.

Planting and fertiliser strategies are a risk management exercise for which short-term and seasonal weather forecasts are an essential input.

#### 2.4.1 Broad acre agriculture

The example selected for assessing the benefits of EOS in agriculture is the use of weather forecasts to assist farmers in making planting and production decisions.

There is some discussion of the value of weather forecasts in the literature. Johnson (1997) explored the value of weather information (Johnson & Holt, 1997) while Marshal et al (1996) examined risk attitude, planting conditions and the value of seasonal forecasts (Marshal, G; Parton, K; Hammer, G, 1996). Peterson and Fraser (1996) examined the value of seasonal forecasting technology in Agricultural Systems (Peterson & Fraser, 2001). Crean et al (2013) examined the applicability of state contingent theory to the representation of climatic uncertainty at the farm level. This theory takes into account the impact of different weather states on the ability of farmers to reduce uncertainty (Crean, Parton, Mullen, & Jones, 2013).

#### 2.4.2 Study of mixed farming in Central West NSW

In a subsequent study of mixed farming in Central West NSW, Crean et al (2014) explored how production plans based on initial expectations of the state of forthcoming rainfall patterns are updated as seasonal forecasts are updated. He shows that earlier assessments of the value of weather forecasts using an expected value approach overestimate the value of weather forecasts because they underestimate the effectiveness of farm management decisions already in place.

The modelling drew on a Bayesian analysis of probabilities prior and post the issue of seasonal forecasts to allow for staged decision-making and used APSIM, a model designed to simulate farming systems (Keating, Carberry, & Hammer, 1996).

Bayesian analysis begins with a prior belief regarding the probability distribution of an unknown parameter such as the probability of future rainfall. After learning information from

<sup>2</sup> Personal interviews with a selection of grain growers in Western Australia.

observed data such as a rainfall forecast, the expectation about the unknown parameter is adjusted to obtain a posterior probability distribution. This approach reflects the decision-making process of farmers, whereby initial decisions are based on their prior expectations about weather during a forthcoming winter planting season and updating those expectations as seasonal forecasts are issued. The analysis is based on four factors:

- The level of skill involved in the forecasts.
  - Skill reflects the performance accuracy of the seasonal forecasts as compared to the actual outcomes, and is based on historical rainfall data.<sup>3</sup>
- the date for planting crops
- soil moisture at the beginning of the planting season
- the weather state at the beginning of the planting season.

A summary of the calculation of economic value developed in the Crean paper is reproduced in Table 2.1.

The immediate inference from these results is the importance of forecasting skill and time of planting to the value of weather forecasts to farmers.

The paper then examined two seasonal weather forecasts: the BOM Seasonal Climate outlook; and the SOI index calculation issued by the Queensland Department of Environment and Heritage.

#### BOM Seasonal Climate Outlook

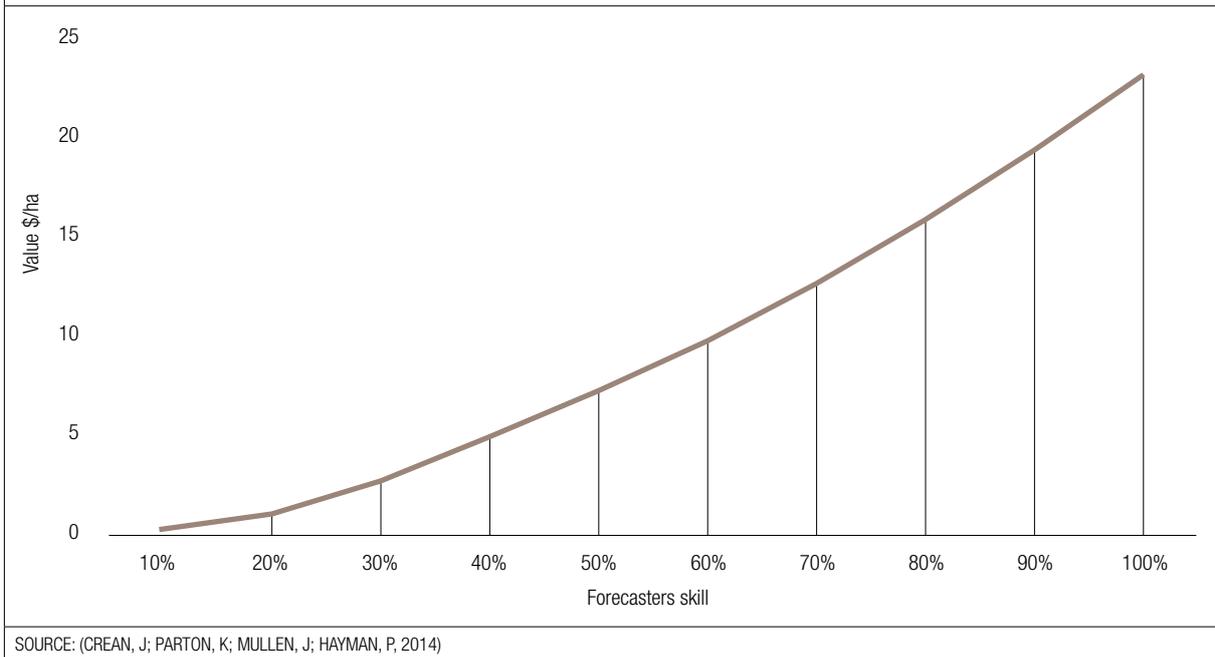
Using historical data on seasonal forecasts (produced using the older statistically based system rather than the newer POAMA, the paper finds that the level of forecasting skill in the area under study in the Central West of NSW was 20 per cent. This was found to have an overall economic value of \$0.96 per hectare. From Table 2.1 this represented 4.1 per cent of the value of a perfect forecast system.

Forecasting skill	Planting date	Planting date	Planting date	Overall
	20 April	19 May	5 June	
	\$/ha	\$/ha	\$/ha	\$/ha
10%	0.38	0.20	0.00	0.20
20%	1.62	1.08	0.00	0.96
30%	4.77	2.59	0.51	2.62
40%	8.80	4.57	1.26	4.80
50%	13.26	6.58	2.10	7.13
60%	17.96	8.94	3.00	9.71
70%	22.68	11.81	4.03	12.58
80%	27.43	15.16	5.35	15.78
90%	32.48	19.02	6.87	19.35
100%	37.83	23.23	8.45	23.18

SOURCE: (CREAN, J; PARTON, K; MULLEN, J; HAYMAN, P, 2014)

<sup>3</sup> Skill is defined by the formula  $\sigma = \frac{\pi(f|s) - \pi(s)}{1 - \pi(s)}$  where:  $\sigma$  = the forecasting skill;  $\pi(f|s)$  = conditional probability of forecast given (weather) states; and  $\pi(s)$  = the prior probability of states based on climatology.

FIGURE 2.2 – VALUE AGAINST FORECASTER'S SKILL



SOURCE: (CREAN, J; PARTON, K; MULLEN, J; HAYMAN, P, 2014)

A graph of the economic value of the forecast versus skill is shown in Figure 2.2. The chart illustrates how the relationship is concave upwards, implying that there are increasing returns to improving the accuracy of the forecasts.

The paper found that increasing the level of skill (the predictive accuracy of the forecasts) to 40 per cent would increase the annual value of the forecast system to \$4.80 per hectare. ACIL Allen understands that this level of skill could be achieved through improved forecasting with the POAMA.

#### Queensland Government SOI phase system

The Queensland Government's SOI phase system approach to predicting seasonal rainfall patterns is based on the observed correlations between SOI phases and patterns of rainfall in eastern and northern Australia. Using the same methodology, the paper calculated an annual value of the SOI phase system at \$0.10 per hectare. However, if the timeliness of the forecast (that is the availability of the forecast relative to the timing of decisions) were improved, then the annual value of the SOI system was found to increase to \$3.55 per hectare.

#### Findings

An important finding of the paper is that the value of seasonal weather forecasts in this context was critically dependent on:

- the level of skill in the forecasts, which is a measure of the predictive accuracy of the forecasts
- the time of planting
  - Earlier planting provided the greatest scope for land cover and input change (such as fertiliser).
- the timeliness of the forecasts
  - The earlier the forecasts become available the more time is available for farmers to adjust their strategies accordingly.

#### 2.4.3 Broad acre agriculture in Western Australia

Petersen et al (2001) studied the value of seasonal forecasting in Western Australia in 2001 and found that none of the seasonal forecasting systems that had been developed at that time were of practical value to Western Australian farmers (Peterson & Fraser, 2001). The paper concluded that a seasonal

forecasting technology that provided a 30 per cent decrease in seasonal uncertainty would increase annual profits of farmers in the Merredin Region of Western Australia by approximately 5 per cent.

ACIL Allen's consultations with the Australian Export Grains Innovation Centre (AEGIC) and interviews with wheat growers in Western Australia confirmed the value of improving forecasting methodologies for wheat growers in Western Australia. Grain growers in Western Australia rely on seasonal forecasts to optimise planting times. Growers operate a crop rotation plan and commit resources to a planned harvest as early as February. The growing season is three months from April and accurate seasonal forecasts are critical to scheduling planting and fertiliser application.

Accurate seasonal forecasts are extremely important to growers' gross margin. Growers can generally expect a return of about 30 per cent on their investment. The difference between planting at the most optimal time and not planting at the most optimal time can be 15 per cent of their gross margin.

ACIL Allen's interviews with grain farmers suggested that around 95 per cent of farmers in Western Australia actively use short-term weather forecasts and about 70 per cent of farmers use seasonal forecasts to develop their planting strategies. The findings from the interviews broadly aligned with the per hectare estimates shown in Figure 2.2 above.

#### 2.4.4 Estimated economic Impacts in 2015

Impacts were estimated for two farming enterprises:

- mixed livestock and crops
- wheat and other crops.

Estimates for mixed livestock and crops were based on the research paper by Crean et al (2014) cited above and interviews with farm management consultants and farmers (Crean, J; Parton, K; Mullen, J; Hayman, P, 2014).

Estimates for wheat and other crops were based on interviews with wheat farmers in Western Australia, farm consultants and researchers.

Details of the methodology for estimating the economic impacts of improved weather forecasting in agriculture along with details of the calculations are provided in Appendix B.

##### Counterfactual – without EOS scenario

This case assumes the situation that would have arisen without the benefit of data from EOS in the short-term and seasonal weather forecasting process. Under this assumption:

- interpolation of point-based observations across Australia would be almost impossible without satellite-based adjustments and it would be impossible to run a predictive climate model such as the POAMA effectively.
- skill levels (accuracy of forecasts) would be approaching zero.<sup>4</sup>

A conservative assumption of a skill level of 10 per cent was assumed for this case, which is one of the lowest points on the skill chart in Table 2.1. This corresponds to an economic value of \$0.20 per hectare.

<sup>4</sup> Personal communication, Professor S Phinn, University of Queensland, October 2015.

The adoption rate in the counterfactual was estimated to be 40 per cent based on the consultations discussed in Sections 2.4.1 to 2.4.3 above.

Evaluation case – with EOS scenario

The evaluation case has been defined as the current situation with data from existing EOS and dynamic modelling. It is unlikely that the full benefits of dynamic modelling would have been achieved by 2015.

We have estimated that forecasting skill level would have increased to 30 per cent with an economic value of \$2.62 per hectare. The adoption rate has been assumed to be the same (40 per cent).

Evaluation

The net impact of EOS on a per hectare basis for mixed livestock and crops was estimated as follows:

Increase in economic value  
 = Value in evaluation case – value in counterfactual  
 = \$2.62 - \$0.20 = \$2.42 per hectare

TABLE 2.2 – IMPACT OF EOS IN WEATHER FORECASTING – AGRICULTURE IN 2015		
	Units	Australia
Cropping and livestock	ha	6,536,227
Improvement in gross margin	\$/ha	2
Level of adoption	%	0
Total value added	\$	4,745,301
		-
Wheat and other crops	ha	13,527,974
Improvement in gross margin	\$/ha	6
Level of adoption	%	1
Total value added	\$	20,291,961
		-
Total value	\$	25,037,262

SOURCE: SEE APPENDIX B.1

The net impact of EOS on a per hectare basis for wheat and other crops was estimates as follows:

Increase in economic value  
 = Value in evaluation case – value in counterfactual  
 = \$5.00 per hectare

The level of adoption was assessed to be 30 per cent taking into account advice from stakeholders and the rate of adoption of precision farming in both sectors.

Employment impacts

The employment impacts have been based on the direct impact on the agricultural sector. The estimated impact was 478 FTE.

2.4.5 Estimated economic Impacts in 2025

For projecting future benefits, the counterfactual and the evaluation case were defined as follows:

Counterfactual – without EOS scenario

For the counterfactual, it is assumed that there is no improvement in satellite sensors, accuracy or frequency, and no improvement in meteorological modelling. That is, the current state continues until 2025.

Evaluation case – the with EOS scenario

For the evaluation case, it is assumed that newer satellites such as Himawari 8 and 9 will significantly improve the accuracy and frequency of remote sensing and will also support improvements in dynamic meteorological modelling to the extent that the skill score increases to 50 per cent (with an economic value of \$7.13 per hectare).

It has also been assumed that the adoption rate will increase to 85 per cent (see Table B.2 in Appendix B). This is considered reasonable given the expected improvement in accuracy and with younger farmers coming into the production cycle.

TABLE 2.3 – IMPACT OF EOS IN WEATHER FORECASTING – AGRICULTURE IN 2025		
	Units	Australia
Cropping and livestock	ha	6,536,227
Improvement in gross margin	\$/ha	6
Level of adoption	%	1
Total value added		32,262,816
		-
Wheat and other crops	ha	13,527,974
Improvement in gross margin	\$/ha	9
Level of adoption	%	1
Total value added		103,489,002
		-
Total value		135,751,818
SOURCE: SEE APPENDIX B.1		

#### Employment impact

The direct impact on employment in the agricultural sector has been estimated in proportion to the impact on value added, giving a potential employment impact of around 641 FTE by 2025.

#### 2.4.6 Caveat

The calculations for the above estimates were based on extrapolating estimates of benefits per hectare for wheat and mixed crops, and mixed livestock and crops, enterprises across Australia. Agricultural enterprises vary in rainfall and composition between regions. Accordingly, these estimates should be regarded as broad indications only.

## 2.5 Case studies in aviation

### 2.5.1 The aviation sector

The air and space transport sector in Australia generated total revenue of \$23.2 billion in 2013-14 and employed 40,000 people. Value added for the industry was \$6.33 billion, representing around 0.42 percent of GDP.

Domestic airline flights in Australia have increased at a compound annual growth rate of 2.0 per cent over the past ten years; while international flights into and out of Australia have increased at 4.8 per cent per year (BTRE, 2015). Passengers flown have increased by 4.2 per cent and 5.5 per cent per year for domestic and international flights, respectively (Figure 2.1). The higher growth in passengers carried reflects the introduction of wide-bodied aircraft on some sectors. General aviation also logs significant hours as shown in the third chart in Figure 2.3.

Safety is a critical priority for all air travellers and aviation weather services are fundamental to safety in flight planning and execution. A review of safety reports by the Australian Transport Safety Bureau indicates that environmental and operational factors had delivered the highest level of reported safety occurrences at around 70 per 100,000 hours of flying each, compared with around 40

### KEY FINDING 1 – AGRICULTURE

#### 2015

Based on the above assumptions, the direct value to Australian broad acre agriculture from the use of improved weather forecasts enabled by EOS were estimated to be \$25.0 million in 2015. The details of this calculation are set out in Table 2.2.

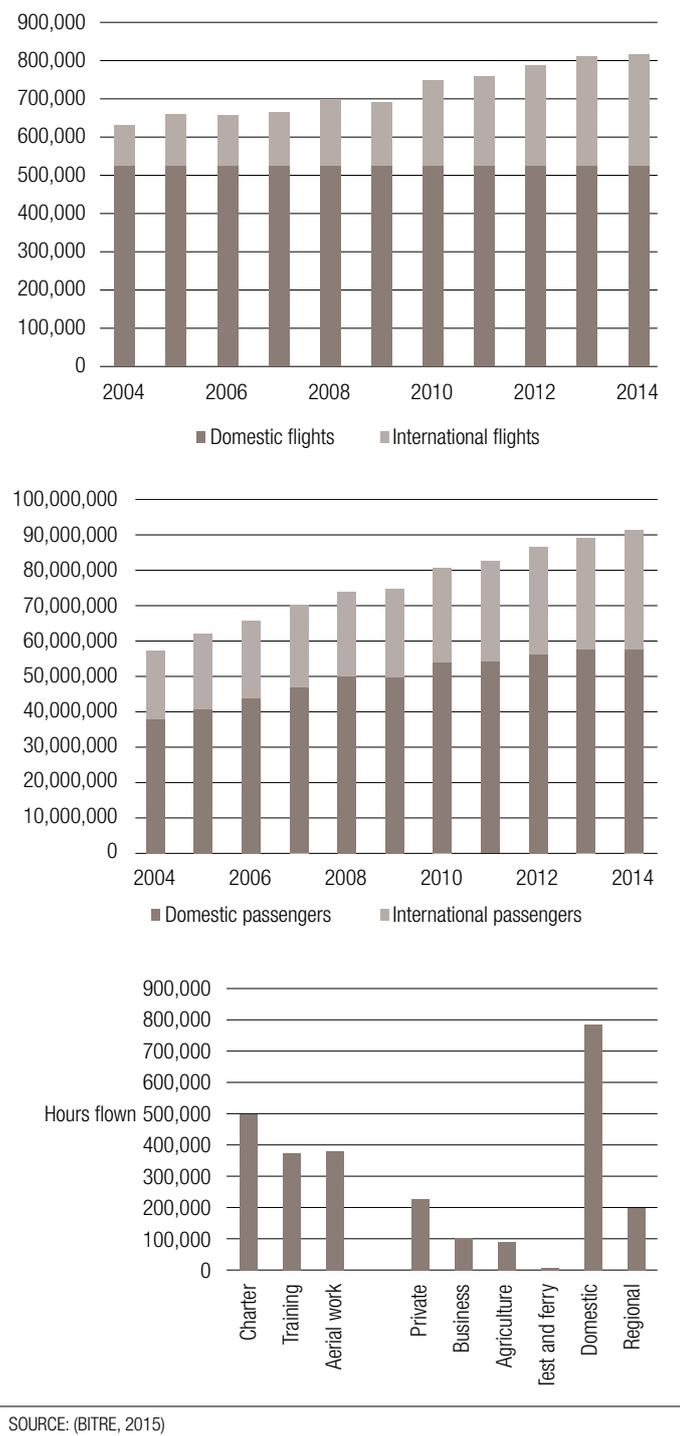
The direct employment effects were estimated to be 119 FTE in 2015.

#### 2025

Based on the above assumptions the value to Australian broad acre agriculture from the use of improved weather forecasts enabled by EOS has been estimated to be \$135.8 million in 2025. The details of this calculation are set out in Table 2.3.

The direct employment effects were estimate to be 641 FTE by 2025.

FIGURE 2.3 – AVIATION STATISTICS



SOURCE: (BITRE, 2015)

occurrences per 1000,000 hours flying for technical issues and 20 per 100,000 occurrences for airspace events (ATSB, July 2014). A significant number of the environmental related occurrences were associated with clear air turbulence and windshear.

Relatively speaking, weather events do not feature significantly in aviation accidents. However, aviation weather services are critical elements for flight planning and execution.

### 2.5.2 Other industry sectors dependent on the aviation sector

Other industry sectors depend on the aviation sector. Tourism is critically dependent on the airline industry. The tourism industry employed around 11,537 full-time and part-time employees in 2013-14, representing around 4.6 per cent of Australia's workforce. The value added by the Tourism industry in 2013-14 was \$39.9 billion, which is around 2.7 per cent of GDP. The knock-on effects of interruptions and cancellations in the aviation sector to the Tourism sector are significant, and will be discussed later in this report.

Other industries dependent on aviation include freight transport, some areas of horticulture, and the mining sector to support fly-in fly-out arrangements.

As these examples illustrate, issues that affect the efficiency of, or delivery of, services by the aviation industry have significant implications for other important industry sectors in the Australian economy.

### 2.5.3 Aviation weather services

Airservices Australia is the official provider of the Aeronautical Information Service, which includes the BOM's aviation weather forecasting products. This service includes observations, forecasts, warnings and advisories, and is provided within the technical and regulatory framework of the International Civil Aviation Organization (ICAO) and the World Meteorological Organization (WMO).

The Bureau's aviation weather services provide aeronautical meteorological observations, forecasts and warnings, and climatological warnings including:

- Terminal Aerodrome Forecasts (TAF)
- Trend Type Forecasts (TTF)
- Aerodrome warnings and weather reports
- Area forecasts
- Area QNH (barometric pressure adjusted to sea level)
- Upper Level Analysis and Prognosis charts
- World Area Forecast System Wind and Temperature charts
- World Area Forecast System Significant Weather charts (SIGWX)
- Forecast Route Sector Winds and Temperatures
- Selected route forecasts for high density routes
- International TAF Bulletins according to major route corridors
- SIGMET (Significant Meteorological Information)
- AIRMET (Airmen's Meteorological Information)
- Volcanic Ash Advisories
- Tropical Cyclone Advisories
- Aerodrome Climatological Information
- Aerodrome Weather Information Service (AWIS).

Remote sensing from EOS and terrestrial observations are the foundation on which these products are developed. EOS data is particularly important for short-term forecasts, cyclone warnings and volcanic ash warnings.

#### 2.5.4 Short-term forecasts and flight planning around airports

Short-term forecasts are important for flight scheduling and planning. SIGMET is critical to flight planning and risk management for aviators. Information on thunderstorms, low cloud, fog and mist are important to the management of aircraft movements at airports.

There are three levels of weather situation criteria at airports:

- Weather situations that have no impact on take-offs and landings.
- Intermediate events that might delay landings by 30 to 60 minutes. These events require extra fuel for circling.
- Events requiring diversion to another airport caused by major meteorological events including thunderstorms, low cloud and fog.

The airlines pay a fee for these services. The total revenue generated for the Bureau is understood to be around \$35 million.<sup>5</sup>

An important goal for modern aircraft management is reducing the cost of diversions and circling caused by weather events at destination airports. Diversions are expensive for airlines and passengers alike. Modern flight scheduling seeks to minimise these by loading sufficient fuel onto each aircraft prior to departure to allow the aircraft to circle the destination airport until weather patterns clear. Carrying additional fuel increases the fuel load and

<sup>5</sup> Personal communication.

fuel consumption. Pilots must estimate how much fuel to carry based on expected weather conditions at the destination aerodrome. Short-term weather forecasts at the destination are the critical elements in calculating this requirement.

Weather predictions at aerodromes are most important for international flight planning, where fuel must be loaded at least a day ahead. EOS has significantly improved the forecasting capability for short-term forecasts that span more than one day. EOS observations are also important for domestic flight fuel planning.

#### 2.5.5 Severe weather warnings

Severe weather events that are of concern to the airline industry in Australian air space include cyclones, severe storms, ice conditions and volcanic ash events. Data from weather satellites underpin monitoring and modelling of such weather events as well as the day-to-day observations that contribute to meteorological warnings.

The BOM has traditionally drawn on data from MTSAT, the low Earth orbiter A-train and the NOAA satellites for incidents of low cloud and fog both around airports and en route.

Information on cloud formations, turbulence and potential icing conditions are also important information for aircraft en route.

Flight planning is critically dependent on early identification of the incidence of major storms and cyclones. Forecasting of such events is heavily reliant on EOS for identifying and tracking severe weather warnings.

The value to the aviation industry of more accurate weather warnings is realised

in efficiencies in flight scheduling, lower fuel costs through reducing unnecessary diversions and cancellations and, most importantly, in ensuring safe skies for the travelling public.

#### 2.5.6 Volcanic ash

Volcanic ash is composed of fine pulverised rock accompanied by a number of gases that are converted into droplets of sulphuric acid and other substances on the fuselage and in engines. It is highly dangerous to aircraft and their passengers. It can damage aircraft jet engines causing loss of thrust and possible engine failure. In addition, there is an abrasion of engine parts, the airframe and parts protruding from the aircraft, and possible clogging of the fuel and cooling systems.

Volcanic ash represents a danger to the safety of aircraft and a potential cost in terms of damage to aircraft. International airlines are willing to undergo extensive and very expensive re-routing if there is any possibility of ash contact on their regular routes.

Delays to aircraft departures from Bali during 2015, caused by volcanic ash clouds, underscore the problems that volcanic ash can cause for airline schedules and for the travelling public. A brief overview of past volcanic ash incidents is provided in Box 2.2 and a summary of the annual frequency of volcanic ash clouds is shown in Figure 2.4

Figure 2.4 shows that a total of 26 serious eruptions were recorded around the world between 1953 and 2009. If serious eruptions since that time were added, the total number of serious eruptions recorded would be of the order of around 29 between 1953 and 2015.

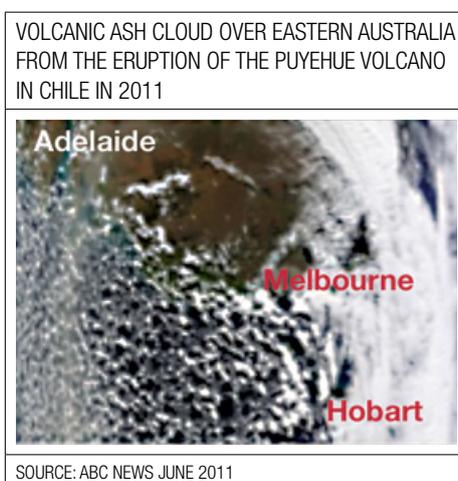


Figure 2.5 shows cancellations by month as a percentage of total aircraft flights for the airline industry in Australia. The highest percentage was 5 per cent in June 2011. The Puyehue-Cordón Caulle eruption in Chile noted in Box 2.2 caused this. Cancellations per month under normal circumstances appear to range between 1 per cent and 2.5 per cent per month.

Nine Volcanic Ash Advisory Centres around the world advise the international aviation industry of the location and movement of clouds of volcanic ash (Figure 2.6). The area covered by the Australian Volcanic Ash Advisory Centre includes Indonesia, Papua New Guinea and part of the Philippines. This area has seen some of the biggest eruptions known in history.

The Australian Volcanic Ash Advisory Centre (VAAC) uses satellite information, ground reports from vulcanological agencies, pilot reports, meteorological knowledge and numerical models to track and forecast ash movements so that aircraft can safely fly around the airborne ash. Satellite imagery



**BOX 2.2 – VOLCANIC ASH EVENTS**

In June 1982, a British Airways 747 suffered severe damage and had all four engines flame out upon encountering ash from Mt Galunggung in Indonesia, causing altitude loss to 12,000 feet before being able to restart some engines and make an emergency landing in Jakarta.

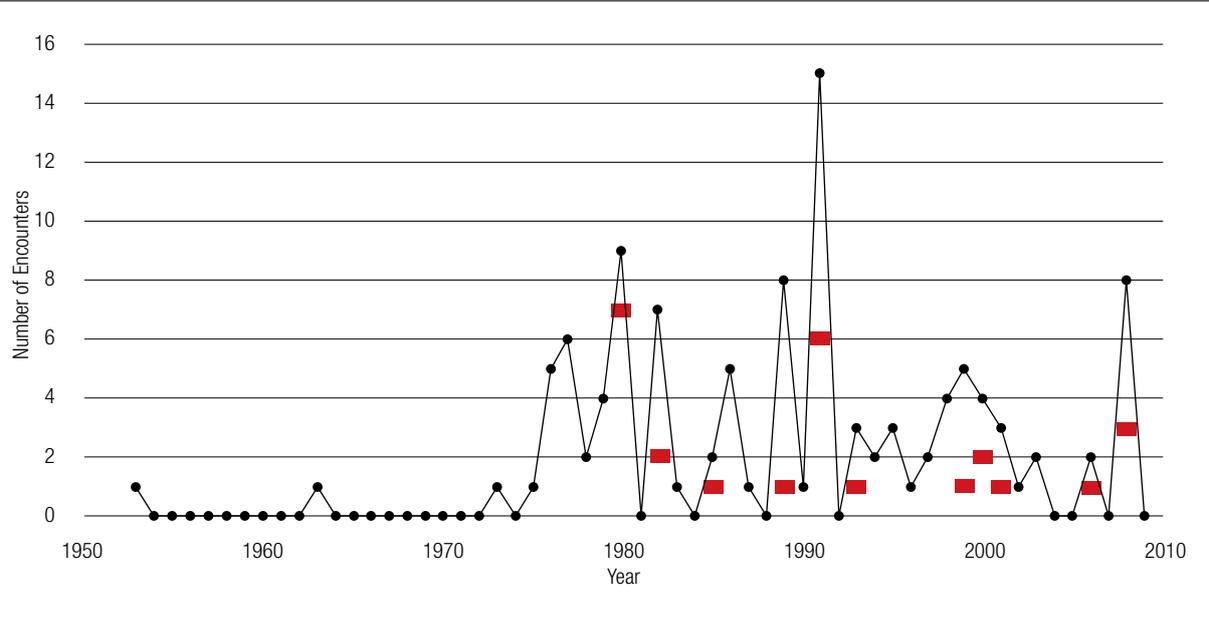
Three weeks later the same event happened to a Singapore Airlines 747, which lost two engines and made an emergency landing. Since then, there have been many aircraft encounters with volcanic ash.

On 14 April 2010, Iceland's Eyjafjallajökull volcano erupted causing interruption in global airline traffic including flights originating from and terminating in Australia.

In June 2011, a volcanic ash cloud from an eruption at the Puyehue-Cordón Caulle volcanic eruption in Chile closed Australian airports for between 24 and 48 hours. Winds had carried the ash cloud from Puyehue a great distance at high altitude and the ash remained present for several days at distinct altitude bands between 20,000–35,000 feet over New Zealand and southern Australia, disrupting flights between Adelaide, Melbourne, Perth, and all of Tasmania and New Zealand. This disrupted 120 flights for Virgin Australia, affecting 120,000 passengers (including those on other flights that were indirectly affected). The flow-on effect to other airports was significant with some travellers reportedly delayed for up to two days (ABC News Jun 2011).

SOURCE: (VOLCANIC ASH ADVISORY CENTRE, 2015)

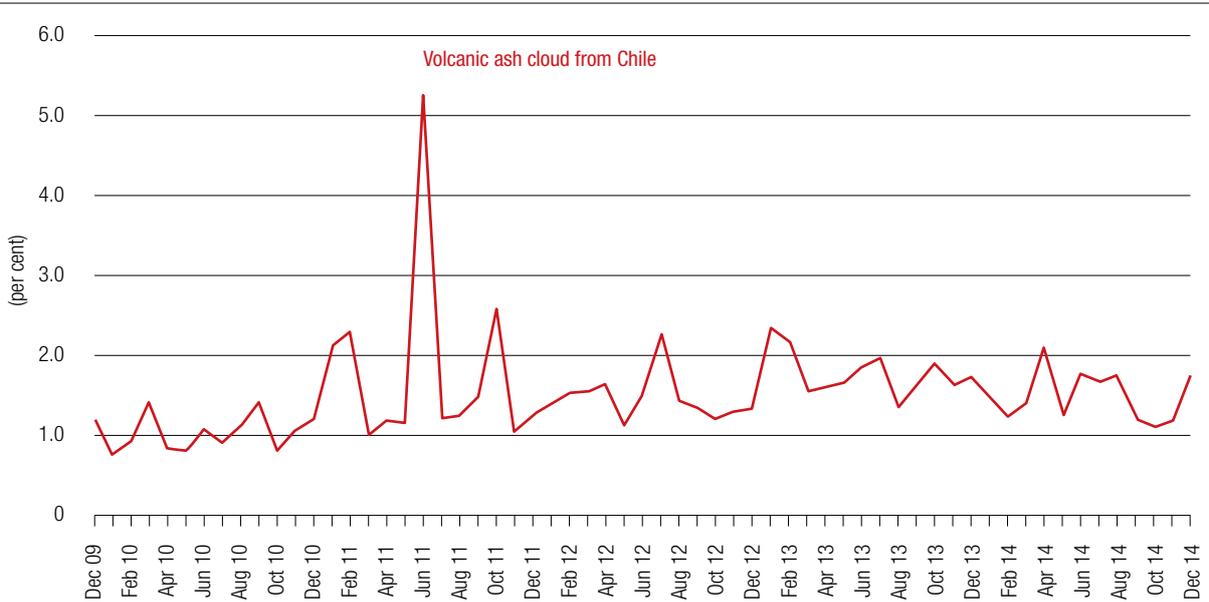
FIGURE 2.4 – ANNUAL FREQUENCY OF AIRCRAFT ENCOUNTERS WITH VOLCANIC ASH CLOUDS



NOTE: THE NUMBER OF HIGHER SEVERITY ENCOUNTERS IS INDICATED WITH RED SQUARES

SOURCE: (GULFANTI, CASADEVALL, & BUDDING, 2010)

FIGURE 2.5 – CANCELLATIONS BY MONTH TOTAL AIRLINE INDUSTRY



SOURCE: (BITRE, 2015)

can be used without enhancement to detect volcanic ash plumes. However, the latest techniques rely on multi-spectral satellites to identify areas of volcanic ash.

Figure 2.7 shows the geographic location of advisories issued by the Australian VAAC in 2014. A total of 1,550 advisories were issued in that year. The accuracy of volcanic ash warnings is critically dependent on remote sensing from EOS.

### 2.5.7 Estimated Economic impacts for aviation in 2015

#### Counterfactual – without EOS scenario

The counterfactual would represent a situation where aviation weather reports produced by the Bureau do not benefit from EOS imagery or SAR data. While this is difficult to conceptualise, it would mean that all aviation weather data would have to be based on local weather observations, data collected by technologies such as weather balloons, and communications technologies for transmitting weather data by traditional telecommunications. This would represent a degraded aviation weather service.

#### Evaluation case – with EOS scenario

This represents the current situation with meteorological modelling based on a range of observations but highly dependent on remote sensing from EOS. Accurate weather forecasts provide a number of benefits to the aviation sector as well as to the travelling public, including:

- reduced risk of the costs of extreme weather events
  - this could be in avoidance of the costs of accidents resulting from bad weather
  - lower costs on average from reduced diversions and delays
  - lower costs associated with delays and cancellations.

- higher levels of safety for passengers and crew
  - resulting from improved awareness of the timing, location and severity of extreme weather events and volcanic ash events.

There is limited data on the average annual costs of flight cancellations and diversions from weather-induced incidents. Two examples of cost impacts that have been examined for this report are discussed below.

To estimate the likely value of EOS to airline operations we examine three aspects of EOS and improved weather forecasting:

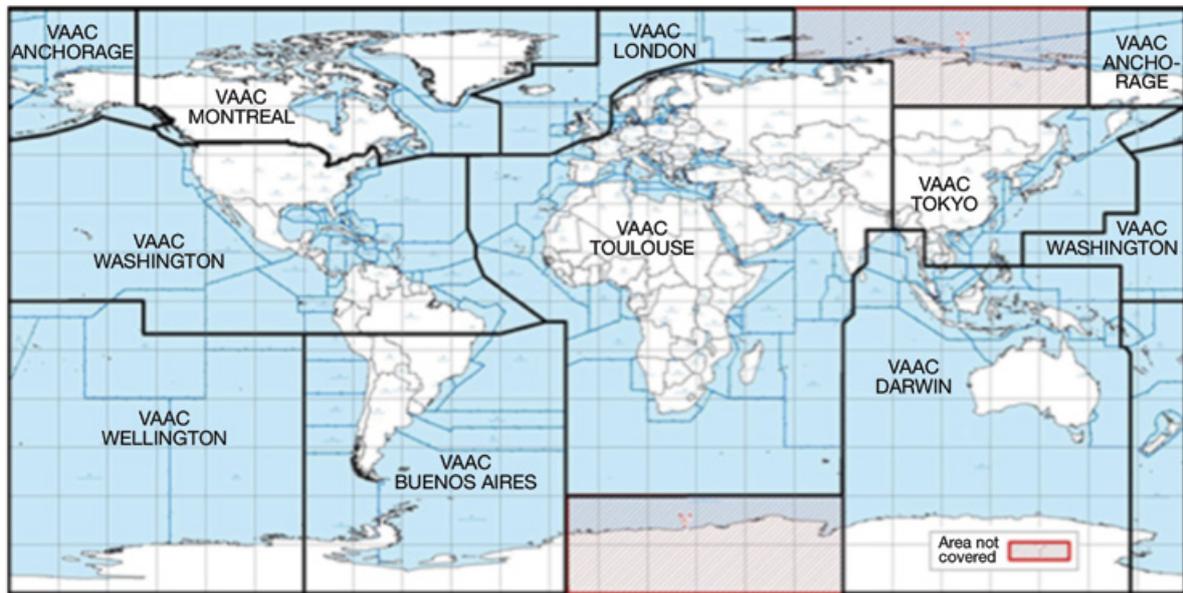
- the impact on flight delays and cancellations for domestic airlines
- the impact on diversions for both domestic and international airlines
- the impact on avoidance of volcanic ash events.

#### Impact on delays and cancellations for domestic airlines

Weather forecasts are important to pilots for formulating flight plans and risk management, as well as for air traffic controllers in managing flight movements. The savings for airlines are in optimising fuel loads and flight routes to minimise the need for diversions. The airlines also benefit commercially from the ability to provide timely flight information to passengers. For passengers, the benefits are reduced time lost in unnecessary diversions and greater certainty about travel arrangements.

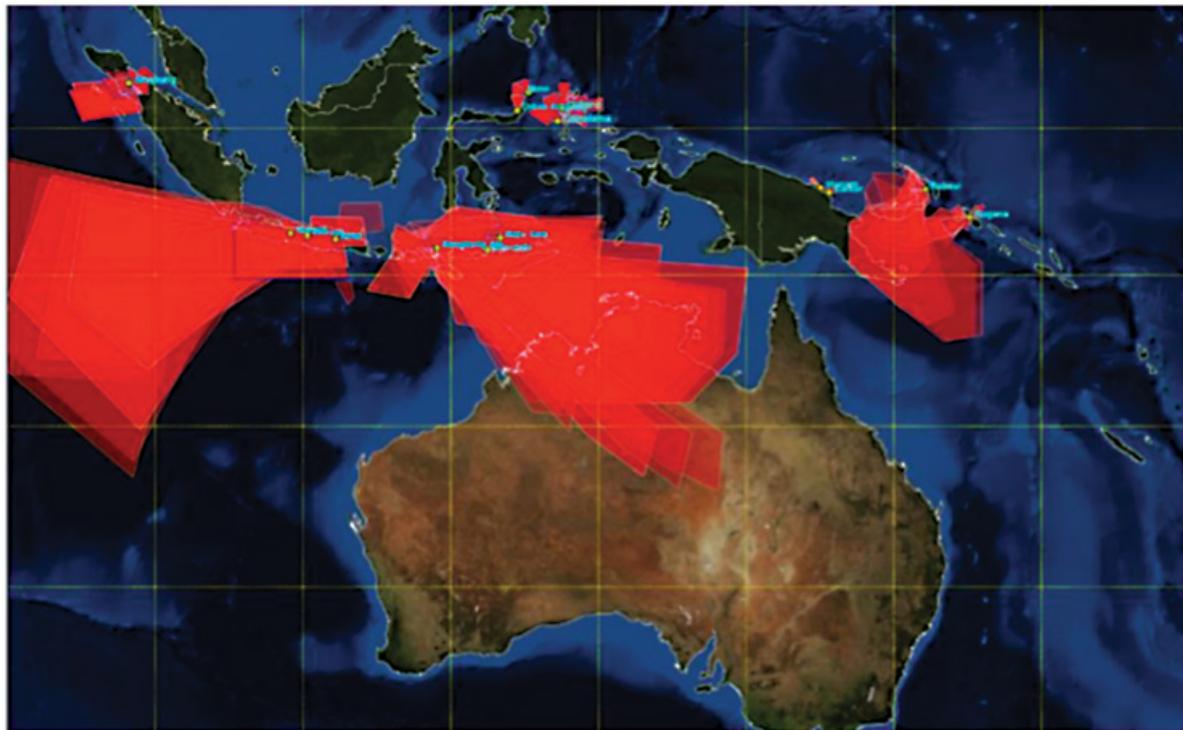
Delays and cancellations for domestic airlines occurred in 19.7 per cent of all domestic flights in 2013-14. (BITRE, 2015). If it is assumed that the opportunity cost of an adult passenger is \$43 per hour and that 50 per cent of the passengers are working adults and the average passenger delay is 45 minutes, then the annual cost of delays would be \$182.7 million (Table 2) (RTA, 2009).

FIGURE 2.6 – VOLCANIC ASH ADVISORY CENTRES AROUND THE WORLD



SOURCE: VOLCANIC ASH ADVISORY CENTRE ([HTTP://WWW.BOM.GOV.AU/INFO/VAAC/INDEX.SHTML](http://www.bom.gov.au/info/vaac/index.shtml))

FIGURE 2.7 – VACC VOLCANIC ASH ADVISORIES FOR 2014



NOTE: A TOTAL OF 1550 ADVISORIES WERE ISSUED IN 2014

SOURCE: VACC PERSONAL COMMUNICATION

Following discussions with industry stakeholders, ACIL Allen estimates that improved aviation weather forecasts that might be attributed to the use and application of EOS have resulted in a 10 per cent improvement in performance with respect to delays and cancellations. This results in a benefit of \$18.3 million (see Table 2.4).

Impact on diversions for both domestic and international airlines by 2025

Short-term weather forecasts at destination airports assist pilots in planning fuel requirements to avoid the need for a diversion. This is particularly important for international long haul flights for which a diversion would be highly expensive.

ACIL Allen has estimated the fuel costs and opportunity costs to passengers of a diversion from Sydney to Brisbane and return for two types of aircraft (Boeing 777-300ER and 737-800, which are widely used in international aviation and in domestic aviation, respectively). The costs for one diversion are summarised in Table 2.5. Details of this calculation are provided in Appendix B.2.

The estimate of fuel costs for a typical diversion is estimated to be \$19,110 for an international flight and \$8,736 for a domestic flight. Additional landing

fees and crew costs would be incurred which are estimated to be between \$5,000 and \$8,000 per diversion for domestic and international flights, respectively. This is likely to be lower than costs for diversions in Western Australia where alternative airports are further afield. This cost does not include an allowance for crew change over, which could be significant for international flights.

The opportunity cost of air travellers' lost time has been estimated to be \$45,150 for international flights and \$10,320 for domestic flights, assuming half of the travellers are employed for which the opportunity cost of time is equivalent to the productive working time foregone.

These amounts total to \$24,056 for domestic flights and \$72,260 for international flights.

Consultation with the industry indicates that any diversion or delay has significant knock-on effects for other flights. Hence, the cost of a diversion is likely to be significantly higher than the figures in Table 2.5. However, because of the uncertainty associated with calculating knock-on effects, the single diverted flight has been used as an estimate of costs arising from of a diversion.

The impact of EOS on short-term weather forecasts has been to improve the accuracy of the forecasts by around 3 days. EOS provides more

Item	Units	
Cancellations and late planes		19.7%
Average lost time by passengers	hours	0.75
Annual passengers numbers		57,515,180
Number of passengers affected		11,330,490
Lost time	hours	8,497,868
Opportunity cost of passengers of working age	\$/hour	43.00
Proportion of passengers of working age		50%
Cost	\$/year	182,704,159
Improvements		10%
Value	\$/year	18,270,416

	Domestic (B737-800)	International (B777)
	\$	\$
Fuel costs	8,736	19,110
Additional landing fees and other fees	5,000	8,000
Opportunity cost of travellers' time	10,320	45,150
Total cost of diversion	24,056	72,260

SOURCE: SEE APPENDIX B.2

Item	Units	Domestic	International	Total
Total arrivals		640,344	86,778	
Proportion of flights diverted without EOS		0.20%	2.00%	
Diversions without EOS		1,281	1,736	
Percent reduction with EOS		30.00%	30.00%	
Diversions avoided		384	521	
Cost per diversion	\$	22,309	65,438	
Cost saved	\$	8,571,184	34,071,473	
Cost of fuel in circling - 90 minutes	\$	2,685,142	7,959,972	
Value of EOS in reduced diversion costs	\$	5,886,042	26,111,500	31,997,542

SOURCE: ACIL ALLEN

accurate and reliable severe weather warnings. Based on consultations with the industry, ACIL Allen considers that it would be reasonable to assume that the use of EOS in support of aviation weather forecasts has reduced the incidence of diversions by around 20 per cent for domestic flights and 30 per cent for international flights.

There is no published data available on diversions of either domestic or international flights. We have estimated that diversions under the Counterfactual (no EOS scenario) would be 0.2 per cent of domestic flights and 2 per cent of international flights. The assumptions for international flights are higher because of the higher distances and flying times involved.

The avoided costs included in ACIL Allen's analysis are the additional fuel and landing charges for a diversion plus the opportunity cost of time lost for 50 per cent of the passengers. An amount was deducted in recognition of the fuel used in circling the destination airport to avoid diversion (a circling time of 90 minutes was assumed). The calculations are summarised in Table 2.6. The resulting estimates are \$7.6 million for domestic flights and \$31.1million for international flights – a total of \$38.7million.

Impact on costs associated with volcanic ash events

Volcanic ash events can cause far more severe cost impacts for airlines in terms of both safety risks as

well as widespread forced cancellations. While the costs are significantly higher than other types of weather events, the frequency of occurrence is lower.

Oxford Economics estimated that the total global aviation sector losses in the first week of the Eyjafjallajökull volcano eruption in Iceland in 2010 was US\$2.2 billion and the visitor spending impact was around \$1.6 billion. The total cost impact was therefore US\$3.6 billion at the end of the first week. This rose to US\$5 billion in subsequent weeks.

The total impact on global GDP was estimated to be approximately US\$7 billion (Oxford Economics, 2012). The net impact on UK GDP from this incident was estimated to be £466 million including direct and indirect effects. This represented about 0.4 per cent of tourism's GDP in the UK.

Estimates reported in the press of the cost of the Puyehue Volcano eruption in Chile in 2011 to Australian airlines and the tourism industry were of the order of \$42 million. This is likely to be a conservative estimate (see Appendix B.3 for details).

There is limited information in the literature on how improved volcanic ash warnings have resulted in minimising the costs to airlines, to industries that depend on the airlines and to passengers. It would be reasonable to assume that better information from EOS would provide early warnings that

would allow airlines to prepare for severe weather events and advise passengers at an earlier time than without EOS. Furthermore, EOS data would reasonably allow earlier resumption of operations.

The average number of encounters of aircraft with volcanic ash clouds appears to be around 132 reported incidents of volcanic ash and around 29 major incidents since 1953 (Gulfanti, Casadevall, & Budding, 2010). These figures suggest an average reporting incidence of around 2 volcanic ash events per year and about 0.46 major events per year. Using the latter frequency and the cost of the Chilean eruption in 2011 as a guide, this suggests that the average annual damage from serious volcanic eruption events in Australia could be of the order of  $0.46 \times 42 = \$19$  million. This figure would include all events around the world.

While it is acknowledged that volcanic ash events can affect all nations because of the knock-on impacts, this figure is not likely to reflect the situation in Australia. It should be noted at this point that the Australian VAAC team issued 1,550 advisories for potential events in Australia in 2014. For the purpose of this report and assuming that some of the future volcanic ash events will occur in the Northern Hemisphere, we have chosen a figure that is half of the global figure—\$9.8 million—as representative of the average annual cost of significant volcanic ash events in Australia.

Assuming that the marginal impact of EOS through the work of the VAAC reduced the costs of volcanic ash events under the Counterfactual by 25 per cent, this would suggest that the value of the use of EOS for this purpose might be of the order of \$2.5 million per year (see Appendix B.3 for details of the calculation).

#### Summary

The estimates of the value of EOS in support of improved aviation weather forecasts are:

- reduced impact of cancellation and delays for domestic flights - \$18.3 million
- reduced diversions for domestic and international flights - \$ 30.0 million
- reduction in average annual costs from major volcanic ash incidents - \$ 2.5 million
- a total of - \$ 50.8 million

ACIL Allen has estimated the impact on employment to be around 790 FTE in 2015 based on the proportionate impact on the value added from aviation and tourism. Details of this calculation are provide at Appendix B.3.

#### 2.5.8 Estimated Economic impacts for aviation in 2025

The newer weather satellites, such as Himawari 8, will significantly improve the data available for aviation forecasts by increasing the bands from 5 to 16 and delivering significantly higher amounts of data for input into the models that provide the local forecasts for aviation purposes in the areas 5 nautical miles around airports. This will significantly improve flight-planning capability for both domestic and international flights. When combined with new developments in precise GNSS and advances in cockpit instrumentation, this is likely to improve the risk assessment capabilities of both pilots and air traffic management. This in turn is likely to lead to better management of the impacts of weather at airports, resulting in fewer flight delays, cancellations and diversions.

Based on discussions with representatives from the airline sector and the Bureau of Meteorology, ACIL Allen considers that it would be reasonable to assume that an improvement of a further 20 per cent in performance is likely to be achievable by 2025.

Further research and model development by the Volcanic Ash Warning Centre will lead to improved

## KEY FINDING 2 – IMPACT OF EOS IN AVIATION WEATHER FORECASTING

### 2015

The use of EOS in aviation weather forecasts delivered benefits in reduced cancellation and delays for domestic flights, reduced diversions for both domestic and international flights, and a reduction in average annual damage costs from major volcanic ash events totalling \$50.8 million by 2015.

### 2025

By 2025, it has been estimated that improvements in data services from weather monitoring satellites, combined with improved weather modelling applications, could lead to this value increasing to \$63.3 million.

prediction of the scale and height of volcanic ash clouds, which in turn would reduce the number of flight cancellations and allow earlier resumption of flights. This could also reduce the number of flight cancellations that are required in response to less severe volcanic ash incidents. We consider that a further 15 per cent improvement in performance is possible by 2020.

#### Summary 2025

Based on these assumptions, it has been estimated that the value of remote sensing using EOS for

aviation weather forecasts and warnings will result in the following benefits by 2025:

- Reduced impact of cancellation and delays for domestic flights - \$22.0 million
- Reduced diversions for domestic and international flights - \$38.3 million
- Reduction in average annual costs from major volcanic ash incidents - \$ 3.0 million
- Total - \$ 63.3 million.

ACIL Allen has estimated the impact on employment by 2025 to be around 832 FTE based on the proportionate impact on the value added from aviation and tourism.

#### 2.6 Summary of EOS benefits for weather forecasting

Two case studies were examined to assess the impact of EOS for weather forecasting. The total benefits for agriculture were \$25.0 million in 2015 and \$135.8 million in 2025. The total benefits to aviation were \$50.8 million in 2015 and \$63.3 million in 2025. The results are summarised in Table 2.7 below.

The potential employment effects from all of these examples were estimated to be:

- 903 FTEs in 2015
- 1,474 FTEs by 2025.

Sector	Category	2015 \$ million	2025 \$ million
Agriculture	Broad acre agriculture	25.0	135.8
Aviation	Reduced delays and cancellations for domestic flights	18.3	22.0
Aviation	Reduced diversions for domestic and international flights	30.0	38.3
Aviation	Reduced average annual costs of volcanic ash incidents	2.5	3.0
Total		75.8	199.1

SOURCE: ACIL ALLEN

### 3 OCEAN OBSERVATION

#### 3.1 Introduction

Australia has a vast area of ocean within its Exclusive Economic Zone (EEZ). This presents a number of challenges for monitoring of economic activity and ocean conditions and ecosystems.

Data from ocean monitoring is also an important input into meteorology. This aspect of ocean monitoring has been discussed in Chapter 2. This Chapter examines the use of remote sensing from EOS for environmental monitoring, managing offshore petroleum operations and monitoring oil spills.

#### 3.2 Current EOS applications

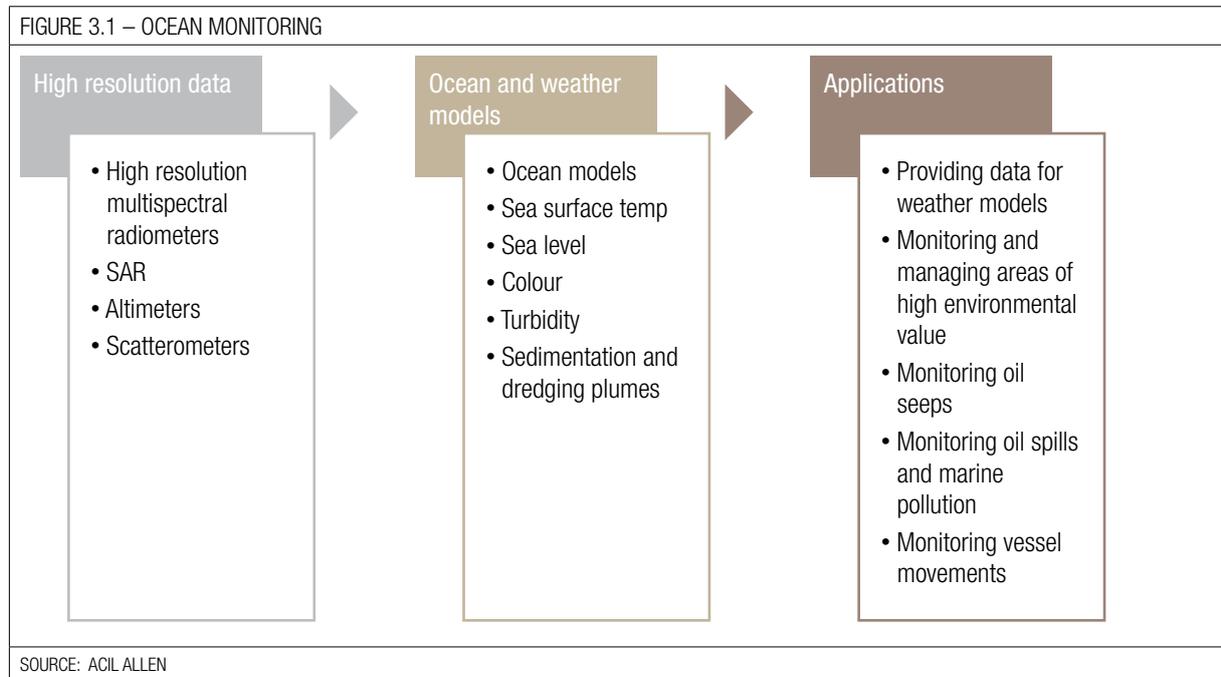
##### 3.2.1 Ocean observations in context

Ocean monitoring involves an array of technologies including direct sampling activities, remote sampling activities using autonomous devices, airborne surveys and remote sensing from EOS. The area of ocean that must be monitored is vast

and EOS have a comparative advantage over airborne and in-situ sensors observations. EOS are an important tool for monitoring water quality, sea surface temperature, sea level, turbidity and colour.

Sensors employed for this purpose include high-resolution multispectral radiometers, SAR, altimeters and scatterometers. Typical satellites/sensors involved in ocean observations include Aqua/Terra (MODIS), FY-3A/3B/3C (VIRR)<sup>6</sup> and Sentinel-1 (C-Band SAR) in addition to other satellites that identify clouds, rainfall, temperature and moisture.

EOS data are also inputs for hydrodynamic models, which in turn provide information on a wide range of ocean conditions including habitat mapping, flood plumes, organic matter and information for a range of products produced by the BOM and made available through portals such as the Water Quality Dashboard and eReefs.



<sup>6</sup> Multispectral Visible and Infrared Scan Radiometer.

The data from these sources is in turn used for analysis, monitoring and projections of ocean conditions by the scientific and research community as well as by environmental and resource management agencies such as the Great Barrier Reef Marine Park Authority. Ocean observations data can also be used for monitoring offshore operations including oil plumes and oil spills, shallow water bathymetry and monitoring plumes caused by dredging.

The relationship between the data collected from EOS for ocean observations, the products and applications is summarised in Figure 3.1.

Ocean monitoring plays an important role in weather forecasting but its use in environmental monitoring, management of marine parks and management of activities such as offshore oil operations, port and shipping operations is also very important to marine-related economic activity.

EOS also plays a role in monitoring illegal fishing and border protection. Its use in searching for Malaysian Airlines flight MH370 was well documented in the press.

*Environmental monitoring*

Parameters such as water sea surface temperature (SST), current, colour, wave patterns, surface winds and sea level are important inputs for both weather forecasting and ocean monitoring.

According to the report of the National Marine Science Committee released in 2014, EOS is one of the key data sources across a range of activities relating to national security, natural hazards, food security, biodiversity, climate change, resource allocation and urban coastline management (see Table 3.1 ) (National Marine Science Committee, 2014).

TABLE 3.1 – DEPENDENCIES IN OCEAN MONITORING

	National Security/ Hazards	Energy Security	Food Security	Biodiversity	Climate Change	Optimal Resource Allocation	Urban Coasts
<b>Vessels</b>							
Bluewater (MNF)	critical	critical	critical	critical	critical		
Polar (AAD)			relevant	critical			
Shelf – tropical	relevant	critical	critical	critical			relevant
Shelf – temperate			critical	critical			
<b>Experimental Facilities</b>							
SeaSim		relevant	relevant	critical	critical	relevant	critical
Other research aquaria			critical	critical			
Analytical facilities	relevant	critical	critical	relevant	relevant	relevant	critical
Research stations			relevant	critical	critical		
<b>Observing Systems</b>							
in situ – IMOS	critical	relevant	critical	critical	critical	relevant	critical
in situ – other		critical	relevant	relevant	critical	relevant	relevant
Earth Observation	critical	critical	critical	critical	critical	relevant	critical
<b>e-Research</b>							
AODN	critical	critical	critical	critical	critical	critical	critical
Other data, tools	critical	critical	critical	critical	critical	critical	critical
NCI			relevant	relevant		relevant	relevant
Other compute, n/works	relevant	relevant	critical	critical	relevant	critical	critical

= critical dependency
  = relevant

SOURCE: (NATIONAL MARINE SCIENCE COMMITTEE, 2014)

Monitoring of the blue water regions of the oceans is dependent on EOS because alternative means of collecting data such as airborne and terrestrial based monitoring are not economically feasible. In addition, EOS is suited for monitoring areas where data archives are important.

#### eReefs

eReefs is a collaborative project focused on the Great Barrier Reef, which delivers a web-based information platform to link environmental data and information on the movement and changes in water and water quality moving through catchments and into the Great Barrier Reef lagoon. This five-year project, commenced in January 2012, is the first step in building comprehensive coastal information systems for Australia.

The beneficiaries will be the mining and agricultural industries onshore, as well as the tourism and the fishing industry offshore. Agriculture and mining activities could become more sustainable, with greater public confidence in the management of environmental impacts from runoff. Industries directly dependent on the Great Barrier Reef, such as tourism and commercial fishing, will benefit through better management of water quality in the Great Barrier Reef Lagoon.

The project is a collaboration between corporate Australia (through the Great Barrier Reef Foundation and its partner BHP Billiton/Mitsubishi Alliance), operational and research agencies (the Bureau of Meteorology, CSIRO, the Australian Institute of Marine Science), Government (the Australian and Queensland Governments), the Science and Industry Endowment Fund, and Reef Managers (Great Barrier Reef Marine Park Authority).

Sustainable management of coastal systems that flow into the Great Barrier Reef and of economic activities in the Great Barrier Reef Marine Park are critical to sustainable operation of agriculture

and mining, urban and coastal development, fishing and tourism in the Great Barrier Reef Marine Park.

#### BLUElink

BLUElink was established in 2001 as a partnership between the CSIRO, Bureau of Meteorology and Royal Australian Navy with the goal of developing an operational forecasting system for the global ocean circulation around Australia. Littoral (surf-zone) applications include the development of capabilities for the prediction of waves, currents and morphological change in the littoral zone as part of Rapid Environmental Assessment activities for BLUElink partners.

Forecasting capabilities on regional-scales have also been developed, using a suite of ocean, atmosphere and wave models. The developed capabilities include a sophisticated user interface that allows BLUElink partners to independently set up and execute a model for delivery of a forecast.

Ocean forecasting is of value to the maritime industry, offshore petroleum operations and even the fishing industry. For example, ocean forecasts are important to the tuna fishing industry to assist in predicting where to fish.

#### Defining offshore national maritime boundaries

Geoscience Australia's Law of the Sea and Maritime Boundary Advice (LOSAMBA) project, provides advice on offshore jurisdictional limits, maritime boundaries and geoscientific aspects of the Law of the Sea.

The project also involves:

- administration and enhancement of web-based information systems, in particular the Australian Marine Spatial Information System (AMSIS) and the spatial framework for offshore resource activities

- the provision of advice, including written boundary descriptions, digital data and supporting maps, to assist Government Agencies with administrative processes in Australia’s maritime jurisdiction
- the provision of advice and support to Pacific Island Countries through the Secretariat of the Pacific Community (SPC) on offshore jurisdictional related issues.

Access to high-resolution, spatially controlled Earth observations data is essential to maintaining a high definition digital representation of Australia’s coastline, and significantly reduces the maintenance cost of this task.

### 3.3 Future EOS applications

The use of EOS data is expected to increase as higher resolution imaging becomes more available and new and services that are more frequent are launched. Its use in improving the timeliness and reliability of ocean monitoring is likely to increase as new satellites become available and as uptake of application software and devices increase.

For example, greater precision in forecasting and climate modelling will come from increased frequency of data that can be provided by Himawari 8.

Another service that could be put in place is one for oil plume monitoring. Such services are provided overseas as well as in some Australian offshore oil and gas operations.<sup>7</sup>

### 3.4 Case study on monitoring water quality in the Great Barrier Reef Marine Park (GBRMP)

Environmental monitoring is a growing need in waters in and adjacent to Australian marine parks. A key focus for this monitoring is in the Great Barrier Reef Marine Park (GBRMP) and this provides a good example of such monitoring. The GBRMP is the largest coral reef ecosystem on Earth. The reef is one of the richest and most diverse natural ecosystems on Earth, comprising thousands of reefs and hundreds of islands made of over 600 types of hard and soft coral and home to a large number of species of colourful fish, molluscs and starfish, plus turtles, dolphins and sharks. The unique environmental qualities of the reef were recognised in 1981 when it was inscribed on the World Heritage List.

The GBRMP, covering 348,000 square kilometres, directly supports marine tourism, commercial fishing, recreational activities including recreational fishing diving and boating, and scientific research and management. The value of these activities was estimated to be \$5.7 billion in 2011-12 supporting around 69,000 full-time positions (GBRMPA, 2014). The largest economic contribution was \$5.1 billion from commercial tourism as shown in Table

Activity	2011-12 value added (\$million)	Employment (FTE)
Tourism	5,176	64,338
Commercial fishing	160	975
Recreational use (including fishing)	244	2,785
Scientific research and management	98	881
Total Contribution	5,678	68,978
SOURCE: (GBRMPA, 2014), (DELOITTE ACCESS ECONOMICS, 2013)		

<sup>7</sup> Airbus Industries provide such services in Europe and in some parts of Australia. Some offshore oil and gas operators already subscribe to such services that provide next orbit acquisition, immediate analysis and delivery of imagery. To ensure a daily service, day or night, radar satellites from a number of systems can be utilised – TerraSAR-X, RadarSAT and Cosmos-Skymed and others. Currently Airbus DS has two radar satellites in orbit (TerraSAR-x and TanDEM-X flying in close formation (200 m apart) as they gather data for a Global DEM product (WorldDEM). In this configuration, any point on the Earth can be viewed around every 43 hours. A third SAR satellite launched in 2015 will reduce global revisit time to around 21 hours.

3.2. These industries depend on the maintenance of a healthy ecosystem.

Other activities that depend on a healthy ecosystem include cultural activities, and the experience of the reef offerings by communities in north Queensland as well as by visitors from other states and overseas.

There are other significant economic activities and defence activities that might be reasonably regarded as related to the GBRMP, although not dependent on it for their direct economic contribution. Shipping that transits the GBRMP services both the communities that live along the reef zone as well as facilitates important trade in goods and commodities, including coal, minerals and liquefied natural gas (LNG). The value of goods shipped through ports in or adjacent to the GBRMP in 2011-12 was of the order of \$40 million per year (Department of Environment and Heritage, 2014).

The mining industry in Queensland generates around \$77.6 million in value added, employing around 442,000 people and paying around \$2.5 billion in royalties. Around \$24.8 billion and 165,771 FTEs was generated by the mining industry in regions adjacent to the GBRMP (see Appendix B.4). A significant proportion of the minerals, coal and LNG exports are shipped through the ports adjacent to the region as well as through the marine park itself.

For 2011-12, the total value of Queensland's primary industry commodities (combined gross value of production and first-stage

processing) was estimated to be around \$15 billion. Queensland's overseas agricultural exports were worth \$8.9 billion that year, comprising 16 per cent of the state's overseas commodity exports (Department of Agriculture Fisheries and Forestry, 2014).

The above industries are important sources of income and employment in Queensland. However, their activities have the potential to degrade the ecological integrity and fish resources in the GBRMP. There is already evidence of potential overfishing in the reef with declines in fish catch from recreational fishers and some reports of declines in commercial fishing catches. There is also evidence of illegal fishing and poaching in protected areas of the reef.

Port dredging operations create turbidity in relatively wide areas in the waters adjacent to and in

the marine park area itself. Shipping activities in the reef are increasing and management of disturbances due to anchoring and introduction of imported marine species requiring continued monitoring. Sediment and runoff from agricultural and mining activities as well as urban runoff are also raising issues for managers of the marine park area.

Long-term monitoring of the condition of the reef by the Australian Institute of Marine Science has shown that poor water quality is having a detrimental impact on the health of the reef. Over the past 27 years, the reef has experienced a decline in coral cover.

TURBIDITY PLUME FROM OUTFLOW FROM JOHNSON RIVER



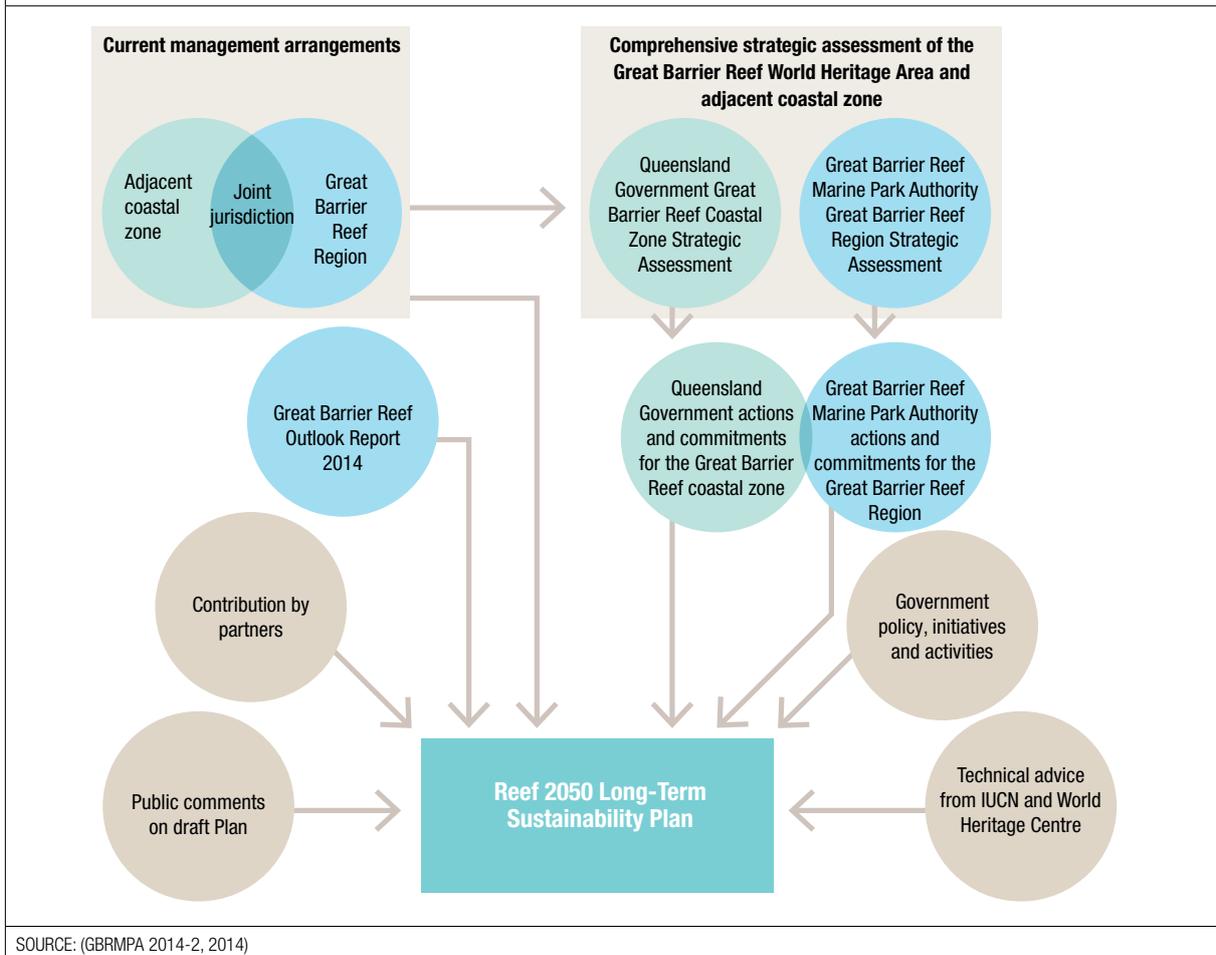
SOURCE: (GBRMPA, 2015)

TURBIDITY PLUME FROM DREDGE ACTIVITIES



SOURCE: (GBRMPA, 2015)

FIGURE 3.2 – INPUTS TO THE GBRMP LONG TERM SUSTAINABILITY PLAN



SOURCE: (GBRMPA 2014-2, 2014)

Elevated nutrient levels in the water, storms and thermal bleaching have been linked to this loss, encouraging activities of the Crown of Thorns starfish in particular, as well as damaging inshore seagrass areas that are important habitats for turtles and dugongs. Improving water quality is an important objective in sustaining the ecological values of the reef into the future (Commonwealth and Queensland Government, 2013).

While mining and agricultural activities are not directly dependent on the reef, management strategies to maintain water quality, biodiversity and protect of the reef's ecosystems define the operating parameters within which they operate.

### 3.4.1 Reef management sustainability plan

The long-term strategic plan for the GBRMP is outlined in the 'Reef 2050 Long Term Sustainability Plan' (Commonwealth of Australia, 2014). This plan draws on inputs from both Commonwealth and Queensland Government agencies, industry groupings and society as illustrated in Figure 3.2.

The management plan comprises specific objectives including:

- maintaining and enhancing outstanding universal value
- Protecting outstanding universal value of the World Heritage Area is a prime consideration when planning, development and management decisions in the region are made.

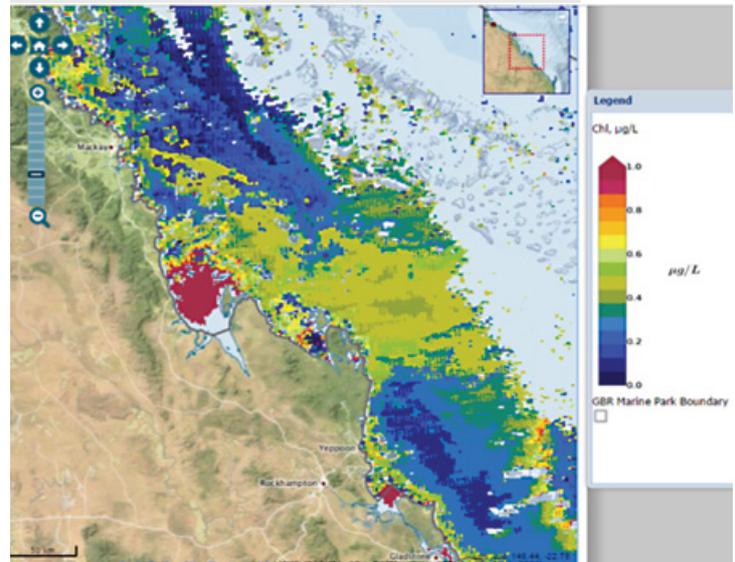
- Ecological processes in poor condition are restored.
  - Economic growth is sustainable and consistent with protecting outstanding universal value.
- 
- basing decision making on the best available science
    - Decisions are based on a full range of knowledge including scientific understanding, Traditional Owner and scientific knowledge.
    - Decisions take into account risks associated with climate change.
    - Management is adaptive and continuously improving based on monitoring programs.

The plan emphasises the need for adaptive management, in recognition of the associated risks involved and continuous monitoring of the waters and ecosystems in the World Heritage Area.

In 2013, the Commonwealth and Queensland Governments committed a total of \$375 million over five years to a reef rescue plan. Monitoring programs are a critical component of the implementation of this plan. The Marine Monitoring Program covers the Great Barrier Reef inshore environment and collects information on long-term changes in the condition of inshore water quality, seagrass and coral reefs. The Great Barrier Reef Marine Park Authority (GBRMPA) manages the program in conjunction with other research partners including the Australian Institute of Marine Science, James Cook University and the University of Queensland. The Commonwealth Department of Environment funds the program.

The Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (Paddock to Reef program) is a collaboration involving governments, industry bodies, regional natural resource management bodies, landholders and research organisations. As part of the Paddock to Reef

### BOX 3.1 – EXAMPLE OF OUTPUT FROM THE EREEFS WATER QUALITY DASHBOARD



This screenshot shows the intensity of Chlorophyll a in the Gladstone to Mackay region. Chlorophyll a indicates the presence of phytoplankton. While these plants are a natural part of the reef ecosystem, elevated numbers (a bloom) of phytoplankton signal elevated nutrient levels, especially nitrogen, in the water. Typical sources are runoff from excess fertiliser being applied to crops and, to a lesser extent in the Great Barrier Reef region, sewage contamination from urban areas.

SOURCE: [HTTP://WWW.BOM.GOV.AU/MARINEWATERQUALITY/](http://www.bom.gov.au/marinewaterquality/) ACCESSED ON 19 JULY 2015

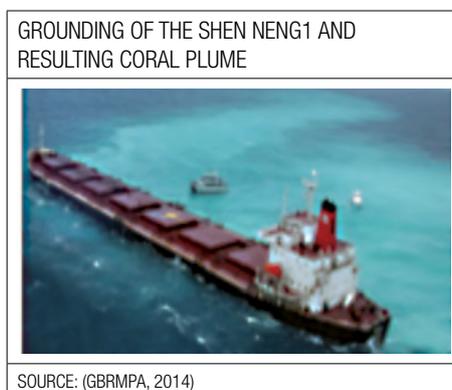
Integrated Monitoring, Modelling and Reporting Program, monitoring information is combined with data collected at the paddock and catchment level to produce an annual report card.

Remote sensing from EOS is now a critical input into these monitoring programs. Atmospherically corrected data provides normalised water reflectance or radiance (ocean colour), from which it is possible to discern light absorption and backscattering properties and derive concentrations of algae and cyanobacteria (through their photosynthetic pigments), non-algal particulate matter and coloured dissolved organic matter. From the spectral light absorption and light backscattering, it is possible to calculate the vertical attenuation of light from which turbidity and Secchi Disk transparency can be calculated.

MODIS Aqua provides a time series of water quality estimates nominally acquired on a daily basis for the GBRMP lagoon. The MODIS Aqua time series is processed by the eReefs system for marine water quality assessment in the GBRMP (V, Schroeder, King, & Dyce, 2013). An example of the output of the eReefs Water Quality Dashboard is provided in Box 3.1.

Remote sensing from EOS is replacing aerial surveys as it can cover larger areas at lower cost and can deliver archival data for time series analysis.

Data from EOS are correlated with direct observations and sampling. The selection of monitoring technique depends on resolution, area and frequency. Cloud cover can be a disadvantage but with sufficient frequency, most monitoring tasks for the reef can be met with EOS. The lack of an adequate base map showing



the composition and condition of coral reefs is a significant challenge yet to be addressed using EOS.

The Great Barrier Reef Marine Park Authority also uses EOS to monitor sea surface temperature (SST). SST is critical for the management of the impacts of sea temperature warming and coral bleaching. The Authority uses SST to implement policies in relation to coral sampling and fishing in sensitive areas at time of rises in sea level temperature.

Remote sensing from EOS have also be used to calibrate hydrodynamic plume models. For example, EOS observations revealed errors in the modelling of plume migration arising from dredging at Barrow Island (see Figure 3.3). There is potential to improve mapping of dredging plumes in the future with the assistance of EOS.

### 3.4.2 Estimate of economic impact in 2015

The following assumptions have been made for this evaluation:

Counterfactual – without EOS scenario

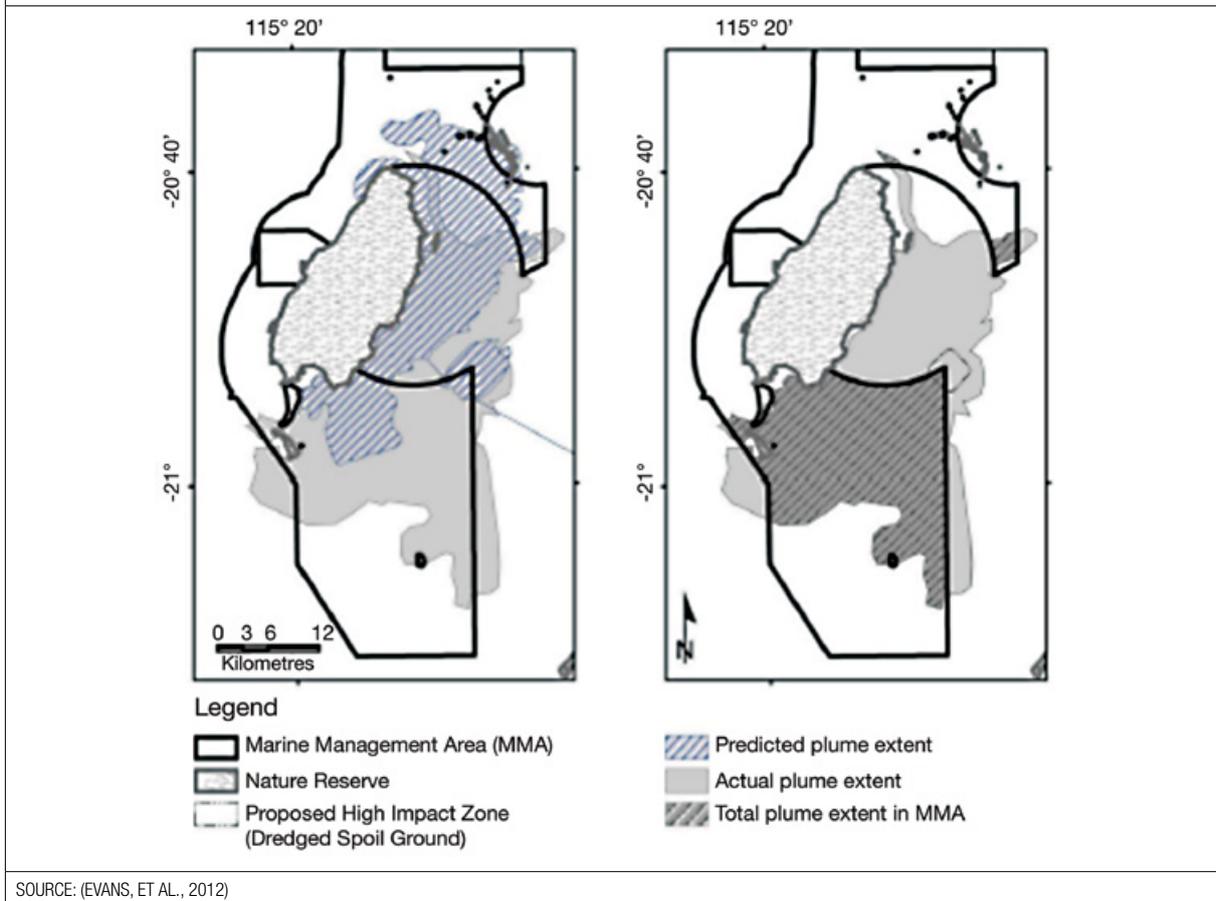
- There would be no remote sensing from Earth observations from space. Monitoring water quality in the reef area would be by aerial survey and direct monitoring from boats. Wide area monitoring of sea surface temperature would not be possible.

Evaluation case – with EOS scenario

- The current situation would apply with the current use to the use of EOS for water quality monitoring.

Assessing the value of EOS in the preservation of the GBRMP requires consideration of the following:

FIGURE 3.3 – COMPARISON OF ACCURACY OF PLUME MODELLING AND MONITORING FROM EOS



SOURCE: (EVANS, ET AL., 2012)

- maximising economic activity and employment particularly in mining, agriculture, shipping, tourism related activities and commercial shipping, while achieving the current environmental and heritage outcomes of the GBRMP
- the value to society of current state of the reef ecosystem
- the current cultural value to Indigenous Australians
- the current scientific and heritage value in the ecosystem as a World Heritage Area.

For this application, we have chosen to estimate the impact of EOS remote sensing on the value that the community places on a healthy reef ecosystem. There have been a number of studies undertaken

over the past 10 years investigating the socioeconomic value of the GBRMP. For example, Oxford Economics (2009) estimated the Total Economic Value (TEV) of the reef over 100 years to be \$51 billion in present value terms, or \$1.4 billion per annum. (Oxford Economics, 2009).

Stoeckl et al, (2014) adopted a different approach to estimating TEV by drawing on a life satisfaction (LS) survey of community benefits (Stoeckl, et al., 2014). Traditionally, economists have sought to place a monetary value on intangible benefits such as those associated with the environment and healthy ecosystems though survey techniques that assess the willingness to pay for intangible benefits. These methods can include stated preference or revealed preference surveys. Only stated preference surveys are capable of assessing non-use values such as bequest values. However, Stoeckl argues

that an alternative approach based on subjective assessment of overall wellbeing or life satisfaction offers an alternative and more direct way of placing a monetary value on both use and non-use benefits. This paper argues:

*“Those working in the LS field ask individuals, directly, to indicate how satisfied they are with their overall quality of life and then use statistical techniques to identify links between various goods (e.g. income, and whether or not the person has a nice view) and stated LS. The questions are asked in very simple terms by, for example, asking respondents to indicate, on a Likert scale, how satisfied they are with their overall quality of life.”* (Stoeckl, et al., 2014)

The Stoeckl study surveyed 1,500 residents who lived in the catchment area for the GBRMP, on 18 community-defined benefits and the contribution of these benefits to their overall quality of life. Three workshops were held to identify the community-defined benefits.

This study directly surveyed a community living in an area affected by or depending on the GBRMP employing a systematic approach to valuing the benefits. It estimated the collective monetary value of a broad range of services provided by the GBRMP to be between \$15 billion and \$20 billion per annum.

There is no aggregation of the total expenditure on monitoring of the reef in the public domain. Estimates provided from interviews suggest that around \$20 million per year is expended by organisations such as James Cook University, the Australian Institute of Marine Science, GBRMPA, the Queensland Government and others.

If this expenditure were to have been undertaken without the use of EOS it would likely have been less effective. It would have been based on greater use of more localised aerial surveys and direct monitoring from vessels. Use of GPS and

GIS mapping would have ensured that the data collected could be efficiently analysed. However, the cost of aerial surveys over a broad area would be significantly higher, even after taking into account the opportunity cost of data from satellite sources such as Landsat and MODIS (which are available for no charge).

A possible approach for assessing the economic value of EOS in this application would be to estimate the additional cost of doing the same monitoring using aerial surveys. However, interviews with officers in the GBRMPA, other research institutions and industry indicated that alternative techniques would not be able to meet all of the monitoring tasks that are currently performed with EOS.

The consequences of less effective monitoring and higher costs of monitoring would be less effective assessment of risk. In the immediate term, this would have led to poorer decisions and greater damage to reef ecosystems. Based on our interviews this could have led to 5 per cent greater damage than has occurred. This would translate to lower benefits per year of between \$750 million and \$1,000 million. ACIL Allen has adopted a midpoint of \$825 million for this report.

Consistent with this approach, we estimated that the current level of employment of around 69,000 in reef dependent industries would have been 5 per cent lower in the no EOS scenario; equivalent to 3,449 FTE in 2015 (see Appendix B.4). Under this scenario, the lack of EOS would have reduced the effectiveness of reef monitoring, resulting in increased regulation of activities that have the potential to damage the reef. Increased regulation would constrain the activities of these industries (such as the tourism industry) or reduce the demand for their services.

In addition, we consider that less effective management of the reef would also have affected reef related industries. Public concern about the impact

of mining activities has translated into political issues in recent years, as evidenced by the public reaction to unconventional gas and coal developments. ACIL Allen considers it reasonable to conclude that such public concern would translate into greater regulatory restraints on operations.

While it is difficult to be precise about the likely magnitude of such effects, it is considered that an impact of 2.5 per cent on economic activity and employment in reef related industries would have occurred without the broad scale monitoring management made possible by EOS. This would be approximately equivalent to 4,144 FTEs in the mining industry in areas adjacent to the GBR (see Appendix B.4)

In summary, the value of EOS in support of ocean monitoring in the GBRMP is estimated to be around \$850 million and the employment effects are estimated to be of the order of 7,593 FTE in 2015.

### 3.4.3 Estimate of economic impacts in 2025

For estimating the impact in 2025, the following has been assumed:

Counterfactual – without EOS scenario

- The existing level of use of EOS for water quality monitoring would continue until 2025 with no expansion of its use to other areas of the reef.

Evaluation case – with EOS scenario

- The use of EOS would continue to be expanded to cover all areas of the reef. It has also been assumed that the eReefs project would be expanded to cover all marine national parks in Australia.

Discussions with scientists in the GBRMPA, James Cook University and Curtin University in WA indicated that the potential for greater use of EOS

for monitoring around ports, marine parks and areas, and ports adjacent to marine parks is significant. Improvements in interpretation techniques and greater access to hyperspectral sensor data are likely to lead to improvements in the monitoring and analysis of dredging plumes and runoff waters into coastal areas as well as general habitat assessment. This includes baseline mapping and monitoring of the whole reef. The University of Queensland, with the support of funding from the Great Barrier Reef Fund, will undertake a pilot project on this task, which if successful, will be scaled to the whole reef in 2016.<sup>8</sup>

Assessing an exact level of use by the stakeholders consulted was difficult because of uncertainties associated with new and emerging satellite services, availability of funding and the likely new developments in modelling techniques.

In assessing the future economic benefits of EOS ACIL Allen made the following assumptions:

- newer satellite services would provide greater resolution and frequency of observations
- hydrodynamic modelling techniques would continue to be improved
- the use of remote sensing data from EOS, plus improved modelling, would be expanded to cover all of the sensitive areas of the GBRMP and other marine parks, and marine sensitive areas in Australia including Ningaloo Reef, areas around Barrow Island and marine parks in State and Territorial Waters.

The key areas of additional benefit would be derived from the wider adoption of EOS for ocean monitoring across the GBRMP and in areas in and adjacent to the most significant marine parks around Australia.

<sup>8</sup> See <http://www.barrierreef.org/sites/default/files/Science%20Forum%202015%20Communiq%C3%A9.pdf> accessed on 27 October 2015.

The benefits that might materialise in 2025 are potentially significant. Taking into account the likely level of further adoption of these methods in the GBR region and other marine parks in Australia, ACIL Allen has estimated that the value of the additional benefits would be approximately 50 per cent of the value calculated for 2015. This reflects the diverse nature of marine parks around Australia. This would result in total attributable benefits of \$1,275 million by 2025.

Employment impacts would also be more significant. If areas of high ecological or conservation value in and around marine parks are not appropriately managed, it is considered highly likely that community concerns when expressed through political processes would lead to constraints on industries that cause environmental damage to these areas.

Furthermore, such damage might be reasonably expected to also lead to lower economic activity in fishing and tourism in these areas. Assessing the employment consequences of this effect is difficult because of lack of data. However, based solely on the assessment in the GBRMP it would be reasonable to assume that lower activity in reef dependent industries under the counterfactual might result in a further loss of around 10,146 FTEs by 2025 (see Appendix B.4).

### 3.5 Case study – offshore oil and gas operations

The upstream oil and gas sector is an important contributor to the Australian Economy. Total revenue from sales of oil and gas for 2013-14 was \$36.5 billion and total taxes paid by the industry in that year were \$7.9 billion. The sector contributes around 3 per cent to national output, with value-added of approximately \$38 billion in 2013-14. For every dollar of domestic production, the oil and gas sector value-adds around 70 cents to Australian output. Under current capital expenditure projections, the oil and gas sector will employ over 35,000 people by 2029-30 (PWC, 2014).

Offshore oil and gas operations are important contributors to this economic picture. The most significant growth for offshore operations is in waters off the Carnarvon and Browse Basins in the north west of Western Australia and the Bonaparte Basin in the Northern Territory. Total revenue from offshore oil and gas operations in Western Australia in 2013-14 was \$27.6 billion, an increase of 11.8 per cent on the previous year. This increase was largely attributed to LNG (DMP, 2014). This is foreshadowed to increase sharply as new projects such as the Gorgon and Prelude projects come on stream in 2016 and 2017, respectively. Production from the Ichthys LNG project in the Browse Basin is to begin in 2016 and the Woodside Browse project is also on track to commence operations around 2024.

Offshore petroleum operations rely on a wide range of weather products. For example, Woodside Petroleum's North West Shelf operations receive feeds from the BOM for a range of weather data. Blue Link provides the foundation for web

#### KEY FINDING 3 – OCEAN OBSERVATIONS IN MARINE AREAS OF HIGH CONSERVATION VALUE

##### 2015

The economic impact of EOS for ocean monitoring around areas of high conservation value is estimated to be around \$825 million. Employment impacts are estimated to be around 7,593 FTEs in reef dependent and reef related industries.

##### 2025

By 2025, it is considered that the economic value of EOS for ocean monitoring in areas of high conservation value could have increased to around \$1,275 million. Employment impacts in reef dependent and reef related industries are estimated to have increased to around 10,146 FTEs by 2025.

mapping of environmental conditions that might affect operations. EOS data are used in a range of applications for spectral analysis, baseline mapping and monitoring. Improved weather forecasting helps lower costs for offshore operators in shipping, production scheduling, environmental monitoring and exploration.

The extent of these savings was the subject of a review and report prepared by Australian Academy of Technological Sciences and Engineering (2006). This report estimated the annual cost of severe weather on offshore operations to be \$114.7 million (ATSE, 2006). We examined the components of this amount and applied the same methodology to current and future offshore operations.

These estimates were then reviewed after consultation with Woodside Petroleum and the Australian Petroleum Exploration and Production Association (APPEA). The current estimates of these costs are discussed below.

#### Shipping Impacts

Offshore operations involve contiguous shipping movements including movements of floating operating platforms (FPSOs) and, in the near future, LNG carriers servicing floating LNG processing vessels (FLNGs).

Woodside uses EOS data to track vessels within the operating environment, including petroleum tankers and FPSOs, and for monitoring the operating environment to manage severe weather conditions. Meteorological data is used to track the projected paths of severe weather events, such as cyclones, to enable the timely disconnection and closing down of FPSO operations, which can take up to 12 hours depending on the conditions. This allows the

operators to optimise the disconnection times and protect the safety of workers and the infrastructure involved. It also allows the operators to minimise unnecessary disconnection times.

FPSOs disconnect and circle the storm centre that can take up to three days before they can return to reconnect. The ATSE report estimated the savings in the operation of FPSOs in Western Australian waters based on:

- 7 FPSOs operating in the region with daily operating cost for a tanker of \$30,000, and \$100,000 for an FPSO vessel.
- 3 occasions per year when a storm avoidance operation is required
- 7 FPSO vessels have tankers attached and a further three tankers are waiting for connection at any time, giving a total of 10 tankers.
- Total time lost for a tanker is 3.5 days and FPSO is 4.5 days.

This leads to an estimate of \$3.2 million for tankers and \$6.3 million a year for FPSO vessels. A conservative approach was taken to the annual cost of storm disruption by limiting the annual cost of disruptions to tankers of \$3.2 million, based on the opportunity cost of tanker operations. Translating this into 2015 dollars gives a figure of \$4 million (ATSE, 2006).

Consultations and analysis for this report confirmed these numbers for 2015 subject to adjustments for cost escalation since the ATSE report was published. This estimate will increase significantly with the commissioning of the new projects mentioned above. The Gorgon, Wheatstone



and Ichthys projects will be standard offshore production platforms. However, the Prelude, Scarborough and Browse projects will be FLNG.

By 2025, it is likely that a number of additional projects will be commissioned in waters offshore WA and the NT. There is considerable uncertainty around timing. The fall in oil prices and consequent fall in price expectations for LNG makes forecasting timing of potential new projects difficult. ACIL Allen's baseline assessment of projects in waters off the NT would include around 9 projects either in production or under construction in the period leading up to 2015 (see Appendix B.5).

The Bayu Undan project and the proposed Bonaparte LNG project should be excluded as they are located in the Timor Gap and are technically not in Australian waters. This leaves Ichthys (Blacktip), Scarborough, Wheatstone, Prelude, Gorgon Browse and Adabi as potential new projects that could be in operation by 2025.

There is insufficient information available to assess operational procedures apart from observing that Prelude and Scarborough will be FLNG operations. These new projects will potentially increase the value of lost production by a factor of 4 or \$16 million.

### 3.5.2 Economic impacts in 2015 and 2025

Counterfactual – without EOS scenario

This scenario assumes that offshore operations operate FPSO vessels without the benefit of EOS data in 2015 and 2025.

Evaluation case – with EOS scenario

This scenario assumes that offshore operations utilise EOS data for FPSO positioning and operations with offshore platforms.

Cost of deferred production from severe weather events

Severe weather events can also cause production shut downs. On the basis of the value of production from crude oil and condensate of around \$9.3 billion in 2013-14, assuming that half of this is produced using FPSO, the value of deferred production would be around \$13 million per day. Assuming 4 severe weather events per year, a delay in production of 5 days and lost production being effectively deferred until the end of the project (say 25 years), following the logic of the ATSE report, the present value in 2015 of deferred production would be \$41 million at a 7.5 per cent discount rate.

By 2025, this could potentially quadruple with new projects to around \$164 million.

Costs to exploration

Exploration jack-up rigs are evacuated in advance of extreme weather events. The ATSE report estimated the cost of closing down an exploration rig and transporting it and its crew to a safe location to be \$2 million to \$3 million. It also calculated the cost per day of exploration based on the level of exploration at the time and the assumption that 75 per cent of the exploration in WA is offshore. The value of expenditure on exploration in WA in 2013-14 was \$2,758 million. With these assumptions and assuming that a rig loses 3 days of exploration per storm and there are on average 4 severe storms per year, it is estimated that the cost of lost days would be around \$68 million per year.

Exploration in the Carnarvon, Browse and Bonaparte Basins has been at extremely high levels until recently. It is unlikely that these levels will significantly increase over the next 10 years and they will possibly fall with the lower expectations of oil and LNG prices over the short to medium term. It is reasonable to assume this figure would also be appropriate to apply for 2025.

Industry	Category	2015 cost \$m	2025 cost \$m	2015 EOS impact \$m	2025 EOS impact \$m
Shipping	Lost liquid transfer time	4	20	0.4	2
Production	Deferred production for 25 years	42	168	4.2	16.8
Exploration	Lost drilling time	68	68	6.8	6.8
Total value		114	256	11.4	25.6
Note: these figures are from 2006 and refer to ocean observations and weather forecasts generally.					
SOURCE: (ATSE, 2006)					

### Summary

The costs of extreme weather events are summarised in Table 3.3 along with an estimate of the contribution that EOS might make to reduce the impact of these costs on offshore operations. Forecasting extreme weather events is heavily dependent on EOS. Accurate weather forecasts enable tanker operators and offshore oil and gas operators to manage risks more efficiently and help to minimise the downtime caused by extreme weather events. It is difficult to estimate the greater efficiency that might be achieved as a result. The Zillman report estimated savings to be of the order of 10 per cent of the downtime costs. Consultations with industry have confirmed that this is a reasonable estimate (Freebairn & Zillman, 2002).

The impacts on value added for 2015 and 2025 are shown in Table 3.3.

The employment impacts were estimated based on the proportional impact on value added and were estimated to be relatively small at 11 FTE in 2015 and 26 FTE by 2025.

## 3.6 Case study – oil spill monitoring

### 3.6.1 Pollution of the marine environment from oil spills.

Oil spills in the sea can originate from shipping operations, and offshore oil and gas exploration and production. Their impact on the environment

### KEY FINDING 4 – BENEFITS FOR OFFSHORE OPERATIONS

#### 2015

The value of EOS to offshore operations is estimated to be \$11.4 million in 2015.

#### 2025

The value of EOS to offshore operations is estimated to rise to \$25.6 million by 2025

and clean-up costs varies depending on the size and source of the spill.

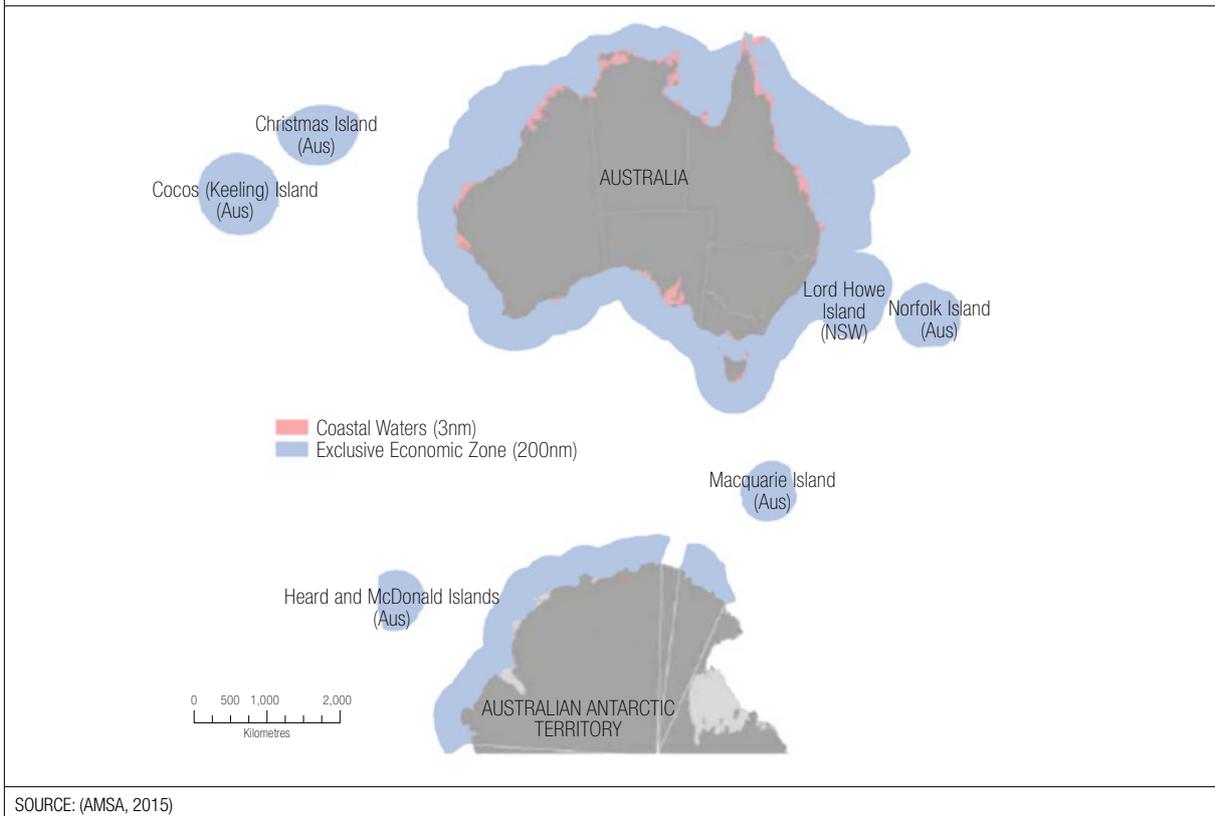
Oil spills from ships are a relatively frequent occurrence in Australian waters. A total of 21 events were reported over the past 20 years.<sup>9</sup>

Oil spills from oil and gas producing platforms can in some cases lead to catastrophic outcomes, as was demonstrated in the Montara oil spill event in the Timor Sea in 2009, and the blow out at the BP-operated Macondo oil field in the Gulf of Mexico on 20 April 2010. The Montara oil spill and clean-up cost the operator \$319 million and loss of its exploration licence (The Australian, 2010).

Oil spills can have devastating effects on the marine ecology and environment. Clean-up costs can be significant and reputational damage for the

<sup>9</sup> <https://www.amsa.gov.au/environment/major-historical-incidents/index.asp> accessed on 27 July 2015.

FIGURE 3.4 – GEOGRAPHIC SCOPE OF THE NATIONAL PLAN



polluters can be very serious. Governments and industry are very aware of the need to properly manage shipping and offshore petroleum operations in the marine environment and to develop effective monitoring programs as part of oil spill response plans.

### 3.6.2 The National Plan for Maritime Environmental Emergencies

The National Plan for Maritime Environmental Emergencies (National Plan) provides a single, national, comprehensive and integrated response arrangement to minimise the impacts of marine pollution from vessel casualties and spills from offshore petroleum facilities, as well as other environmental impacts arising from a maritime environmental emergency. The National Plan gives effect to Australia’s international obligations under:

- The International Convention on Oil Pollution Preparedness, Response and Co-operation 1990

- The Protocol on Preparedness, Response and Cooperation to Pollution Incidents by Hazardous and Noxious substances 2000
- The International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties 1969
- The United Nations Convention on the Law of the Sea 1982.

The Australian Maritime Safety Authority (AMSA) manages the National Plan, working with Commonwealth, State and Northern Territory governments, along with the shipping, ports, oil, salvage, exploration and chemical industries, and emergency services nationwide, to maximise Australia’s marine pollution response capability. The geographic coverage of the National Plan is vast as is illustrated in Figure 3.4. While most of the spills of concern are likely to be in waters around Australia,

coverage of this vast area requires EOS in conjunction with other observations technologies including aerial surveys and direct observations.

Under the National Plan, the responsibility for responding to oil spill incidents can be allocated to a “Control Agency” that becomes responsible for implementing the response. The control agency appointed varies according to the circumstances. It can be AMSA, a state government agency or an offshore oil operator. Whatever the arrangement agreed, AMSA monitors the progress using EOS along with other technologies.

Under an agreement with AMSA, some offshore petroleum operators are responsible for oil spill clean-up. Environmental management of the offshore oil industry is regulated by the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA). This organisation oversees offshore operations but under the regulations allocates responsibility to the operators. Consultations with industry stakeholders confirmed that the operators also rely on EOS for monitoring and response purposes, contracting with commercial providers of imagery and SAR for this purpose.

The Australian Marine Oil Spill Centre (AMOSC) in Geelong, Victoria, established in 1991 by petroleum companies, operates Australia’s major oil spill response equipment stockpile on 24-hour stand-by for rapid response anywhere around the Australian coast. The oil industry invested around \$10 million to establish the centre. AMOSC stored equipment around Australia to maintain a readiness for a quick response if required.

### 3.6.3 Use of EOS in oil spill monitoring

Worldwide, EOS are used by the offshore oil industry, government organisations responsible for monitoring oil spills from ships and other sources, and by organisations involved in the management of oil spills when they occur. In Australia, the major arrangements appear to be with Commonwealth

#### BOX 3.2 – EXAMPLE OF A COMMERCIAL OIL SEEPS AND SPILLS MONITORING SERVICE

Global Seeps is a product/service supplied by AIRBUS. It employs radar imagery held in archives and new acquisitions to detect oil plumes. These can be natural seeps from near surface petroleum reservoirs or may be man-made from ships or drilling platforms. The Global Seeps service analyses the plumes to differentiate the two. The common occurrence of natural seeps in an area is an indicator of near surface oil reserves and can be used to focus exploration activity.

This service is not time critical and monthly or less regular observations are adequate. The resolution used by Airbus DS from the TerraSAR-X sensor would be the 18 m ScanSAR mode with a 100 km swath. This wide swath allows for efficient monitoring of large areas.

SOURCE: AIRBUS

entities and the offshore petroleum industry. AMSA cooperates with States to provide access to its EOS arrangements.

AMSA uses SAR data to identify potential activities of interest and for monitoring containment and clean-up operations for identified spills. The organisation has a standing contract with the European based K-Sat for this purpose.

Commercial providers also supply EOS services to oil and gas operating companies to support the monitoring of oil spill incidents associated with offshore petroleum operations. An example of one system is provided in Box 3.2.

Both SAR and optical imagery are used for hydrocarbon spill surveillance. SAR is reported to be the

preferred option as the active pulse from space reacts with surface textures giving all-weather day/night imaging. In most areas, there would generally be two imaging opportunities per day, but there may be 1-3 day delays in tasking satellites and getting them in appropriate orbits to obtain useable imagery.

Key information that is available from these services includes:

- oil on water detection
- ship and rig detection even at coarse spatial resolutions
- analysis of wind and wave patterns.

Several commercial services provide these services to the oil industry. Some have agreements to provide satellite data from a range of satellite operators. Continuous imagery or one-off imagery is available on request (Chevron, 2013).

While EOS provides more confidence in the tracking and monitoring of vessel sourced pollution, it is not the sole technology used in monitoring oil spill incidents or for arranging the response to them. EOS can be used as a deterrent to the release of oil from ships but this is used more extensively in Europe than in Australia.

### 3.6.4 Economic impact in 2015

Counterfactual – without EOS scenario

Under the counterfactual scenario, monitoring by government and private companies would be wholly dependent on aerial surveys and direct monitoring from vessels. There would be no backup data for regulators and the costs of monitoring remote parts of the ocean would be significantly increased.

Evaluation case – with EOS scenario

The evaluation case includes the current use of EOS for the monitoring of oil spills in the ocean by regulatory authorities and the offshore industry.

Costs of spills

Average annual cost of oil spill response activities

A report prepared for the Australian Maritime Safety Authority (AMSA) examined the risk of pollution from marine oil spills in Australian waters (DNV, 2011). The report estimated a spill frequency quantity curve. The curve included estimates of oil spills from:

- trading ships at sea
- trading ships in port
- small commercial vessels
- offshore production

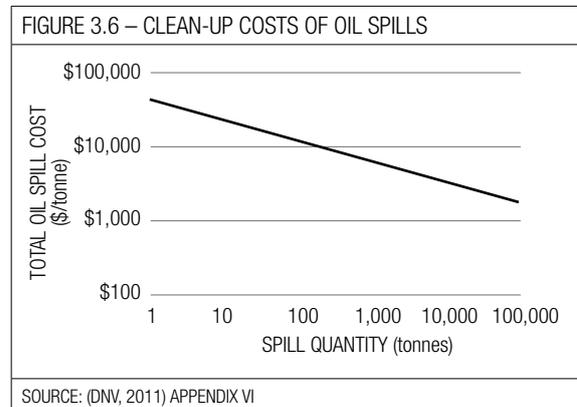
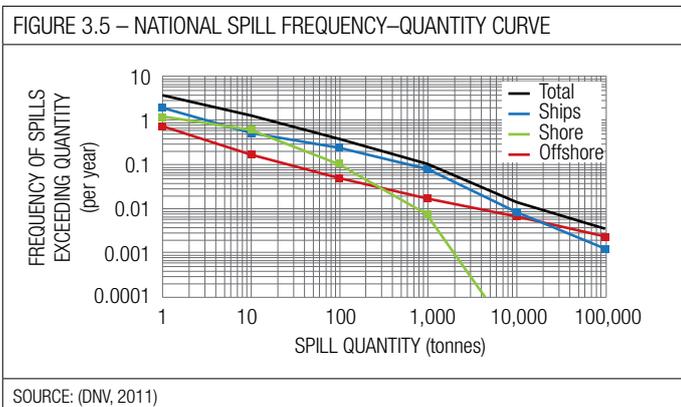
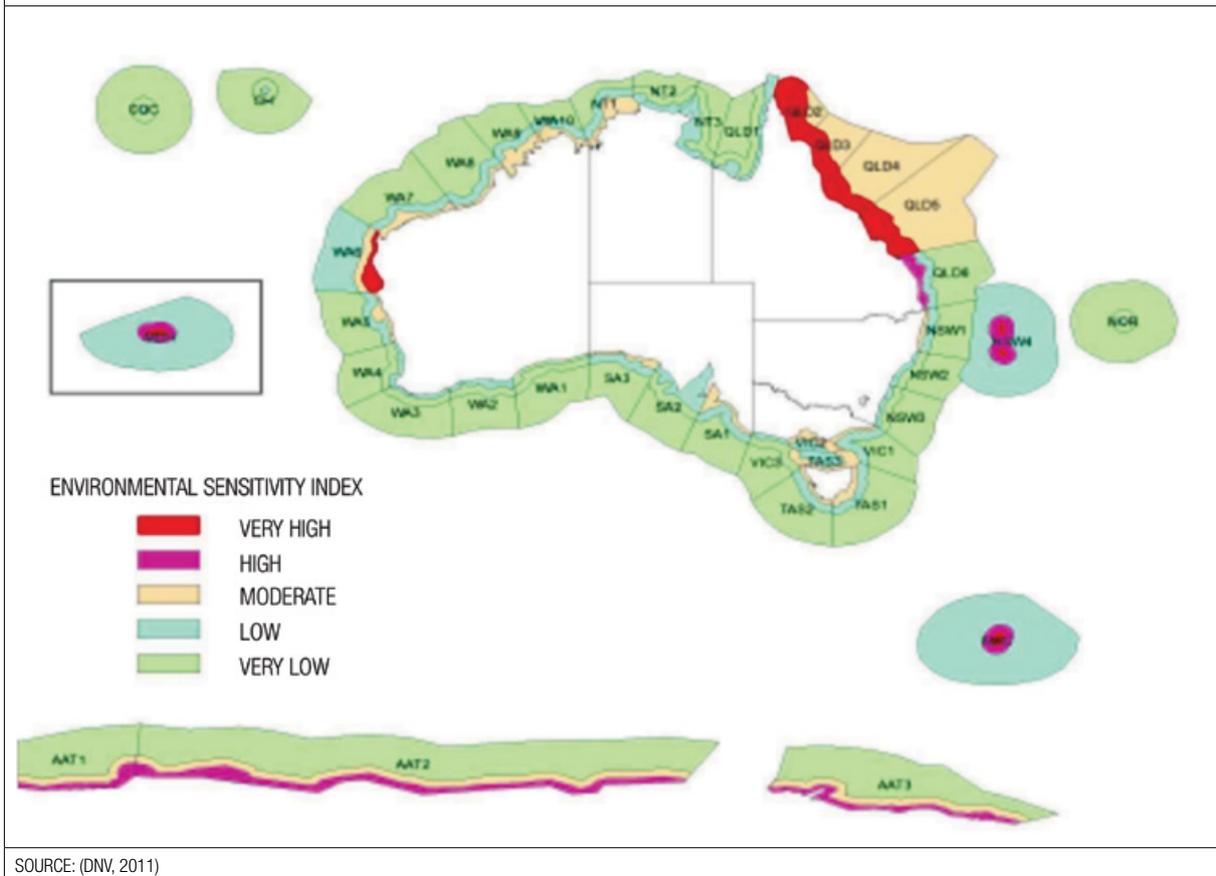


FIGURE 3.7 – ENVIRONMENTAL RISK INDICES



- offshore drilling

- shore based discharges.

The curve is reproduced in Figure 3.5.

Using this frequency quantity-curve, it is possible to estimate that the average annual spill for Australian waters is around 257 tonnes per year.

In an appendix to this paper, DNV provides an estimate of the clean-up costs of oil spills. These costs include:

- clean-up costs – expenditure on recovering or dispersing oil at sea and clean-up of affected shoreline, including disposal of recovered product

- commercial losses – actual compensated losses plus estimated value of damage to social resources

- environmental damage – estimate of the value of damage to natural resources.

The findings are summarised in Figure 3.6.

DNV then calculates an overall national environmental risk index that is summarised for 2010 in Table 3.4

The environmental risk index is greatest in the GBR region and in waters around the north west of Western Australia as shown in Figure 3.7.

AMSA draws on a number of technologies and services for its oil spill monitoring and response operations. One of these is EOS and data from the K-SAT satellite to monitor oil spills. These data are used as a crosscheck of other data and can cover more remote areas more economically than aerial surveys. A typical aerial survey costs between \$3,000 to \$15,000 an hour depending on scale and location. AMSA's contract with K-SAT costs around \$200,000 per year. Under this contract, AMSA can task the service at any time to inspect areas of suspected or confirmed oil spills. The service is used both to identify areas where spills may be suspected and to monitor response plans and clean-up operations.

The KSAT satellite focuses mainly on the Northern Hemisphere. There is a local commercial supplier of similar data. However, limitations on downlink capability precludes this option being used for this purpose in Australia.

AMSA can also draw on satellite services that can be made available in emergencies under the International Charter (Space and Major Disasters), to which Geoscience Australia is a signatory, as an additional mechanism to access remote sensing imagery and services during a major oil spill response. The Charter provides AMSA with access to additional satellite data in the event of extreme emergencies. For more details see Box 3.3

Under a counterfactual scenario, AMSA would not have access to any monitoring capability from EOS including access to imagery from the Space Charter. Without these services, the organisation would rely on direct observation, aerial surveys and reports from ships and ports. Monitoring would still take place but AMSA would lose capability to call for updated information particularly in remote areas.

### BOX 3.3 – INTERNATIONAL CHARTER SPACE AND MAJOR DISASTERS

The International Charter, "Space and Major Disasters", provides a unified system of satellite data acquisition and delivery through authorised users to areas affected by natural or man-made disasters.

The Charter was activated by Australia to receive satellite imagery, free of charge, during the Rena oil spill incident in October 2011 (New Zealand), and during the search for missing Malaysian Airlines flight MH370 in March-May 2014.

Under the Charter, during the Rena incident a number of satellite imagery types were received that greatly assisted the response efforts. The imagery used was mainly high-resolution and multi-spectral, but some SAR imagery was also used.

It was found that in an oil spill situation there are varying degrees of benefits in using different types of imagery. The SAR imagery captured during one of the spills clearly

showed the extent of the oil slick, whilst the high-resolution, multi-spectral imagery was useful for locating drifting shipping containers which had fallen overboard from Rena, both on the surface and sub-surface.

The main issue, however, was that of imagery acquisition frequency, which can be critical during an oil spill incident. Because of the fast dynamics of the oil slick and containers moving with the current, and the large delays between acquisition and final delivery of satellite imagery, the Charter images provided limited benefits.

The main benefit was the provision of a method for validating and quantifying the accuracy of the trajectory models generated for the spill.

Any advances in satellite based or ground based technology, leading to more immediate image acquisition and delivery, would greatly improve the benefits of such Earth observation systems during oil spill and other disaster situations.

SOURCE: (THE INTERNATIONAL CHARTER, 2015), AMSA PERSONAL COMMUNICATION

The marginal impact of the counterfactual case is likely to be less than 20 per cent. This would result in an impact in 2015 of 20 per cent of \$9.4 million = \$1.88 million. The cost of purchase of EOS associated with this benefit is likely to be of the order of \$0.8 million, giving a benefit cost ratio of around 2.4.

2025

Counterfactual – without EOS scenario

The counterfactual in 2025 assumes that the current level of remote sensing from EOS applies.

Evaluation case – with EOS scenario

By 2025 the risks associated with oil pollution in marine environments is based in part on an estimate of the change between 2010 and 2020 estimated by DNV (DNV, 2011). It has been assumed that these trends will continue to 2025. Risk is expected to be affected by:

- tripling of the number of offshore oil and gas operations in the offshore areas in the Carnarvon, Browse and Bonaparte Basins in waters to the north and north-west of Australia
- port traffic growth by around 80 per cent
- traffic growth by sea of around 81 per cent producing a 7 per cent increase in overall risk
- ship to ship transfer growth that increases risk by a further 7 per cent
- radar based VTS expected to reduce the probability of spills in affected ports by 84 per cent
- growth in shore based oil consumption that increases the risk of pollution from these sources by 7 per cent.

The impact is summarised in Table 3.4.

## KEY FINDING 5 – BENEFITS OF EOS IN OIL SPILL MONITORING

2015

The value of EOS in oil spill monitoring is estimated to be \$1.9 million. This represents a benefit cost ratio of around 1.3.

2025

The value of EOS in oil spill monitoring is estimated to rise to \$4.08 million by 2025. This represents a benefit cost ratio of around 2.9.

All estimates in the table, apart from offshore production, are based on DNV's 2020 scenario. This has been used as a proxy for the 2025 figures. This is considered reasonable given the uncertainty associated with the estimates. It is a conservative estimate for this reason.

The figure for offshore production has been adjusted to allow for the commencement of three new LNG projects of the North West Coast of Western Australia. Assuming a marginal contribution from EOS of 20 per cent, the benefit in 2025 is estimated to be 20 per cent of 20.4 = \$4.08 million. The costs associated with purchasing EOS data are estimated to have risen to \$1.4 million, which would yield a benefit cost ratio of 2.9.

Source	Environmental risk index \$ million per year	Share
Trading ships at sea	2.4	25.6%
Trading ships in port	4.9	51.8%
Small Commercial Vessels	0.1	1.1%
Offshore production	0.7	7.1%
Offshore drilling	0.3	2.9%
Shore based discharges	1.1	11.5%
Total	9.4	100%

SOURCE: (DNV, 2011)

### 3.7 Summary of EOS benefits for ocean monitoring

Three examples of the use of EOS in the application of ocean monitoring were studied for this case study:

- environmental monitoring of the Great Barrier Reef Marine Park
- weather warnings and forecasts for offshore oil and gas operations
- oil spill monitoring in Australian waters.

The findings are summarised in Table 3.6.

The impacts on employment were estimated to be:

- 7,605 FTEs in 2015
- 10,172 FTEs by 2025.

For calculation of employment impacts see Appendix B.10

Source	2025 (tonnes per year)	Change
Trading ships at sea	4.7	96%
Trading ships in port	12.0	145%
Small Commercial Vessels	0.1	0%
Offshore production	2.1	200%
Offshore drilling	0.3	0%
Shore based discharges	1.2	9%
	<b>20.4</b>	<b>115%</b>
Note: The figures for all items apart from offshore production are based on 2010 to 2020 estimates. Offshore production has been adjusted by ACIL Allen to reflect the start-up of three new offshore LNG in waters north of Western Australia.		
SOURCE: (DNV, 2011)		

Sector	Category	2015 \$ million	2025 \$ million
GBR	Environmental monitoring	875	1275
Offshore petroleum operations	Weather forecasting and warnings	11.4	25.6
Maritime	Offshore oil spill monitoring and response	1.9	4.08
<b>Total economic benefits</b>		<b>13.3</b>	<b>29.68</b>
<b>Total environmental and social benefits</b>		<b>875</b>	<b>1275</b>
SOURCE: ACIL ALLEN			

## 4 MONITORING LAND COVER, LAND USE AND LANDSCAPE CHANGE

### 4.1 Introduction

The use of remote sensing from EOS for monitoring land cover, land use and landscape change has become increasingly important to both government and industry. This use is likely to grow as improved application and services drawing on medium and high-resolution sensors are developed.

The applications of EOS in land cover and landscape monitoring span a number of sectors discussed in this report. The case studies in this chapter focus on two aspects of land cover and land use monitoring:

- monitoring land cover and landscape change by government for regulatory purposes
- land cover and land use planning and the cadastre.

Subsequent chapters address its use in agriculture, water, natural hazards and mining.

The relationship between the data, applications and users for the case studies presented in this chapter is summarised in Figure 4.1.

### 4.2 Current EOS applications

#### 4.2.1 Overview

Land cover and use and land management are critical linkages between human social systems and ecological systems. This relationship is illustrated in Figure 4.2.

Land cover monitoring is therefore becoming increasingly important for governments with respect to policies, programs and compliance for sustainable use of land and water resources, management of environment, maintaining biodiversity and biosecurity, and mitigating the impacts of natural disasters. It is also important to

FIGURE 4.1 – MONITORING LANDSCAPE CHANGE

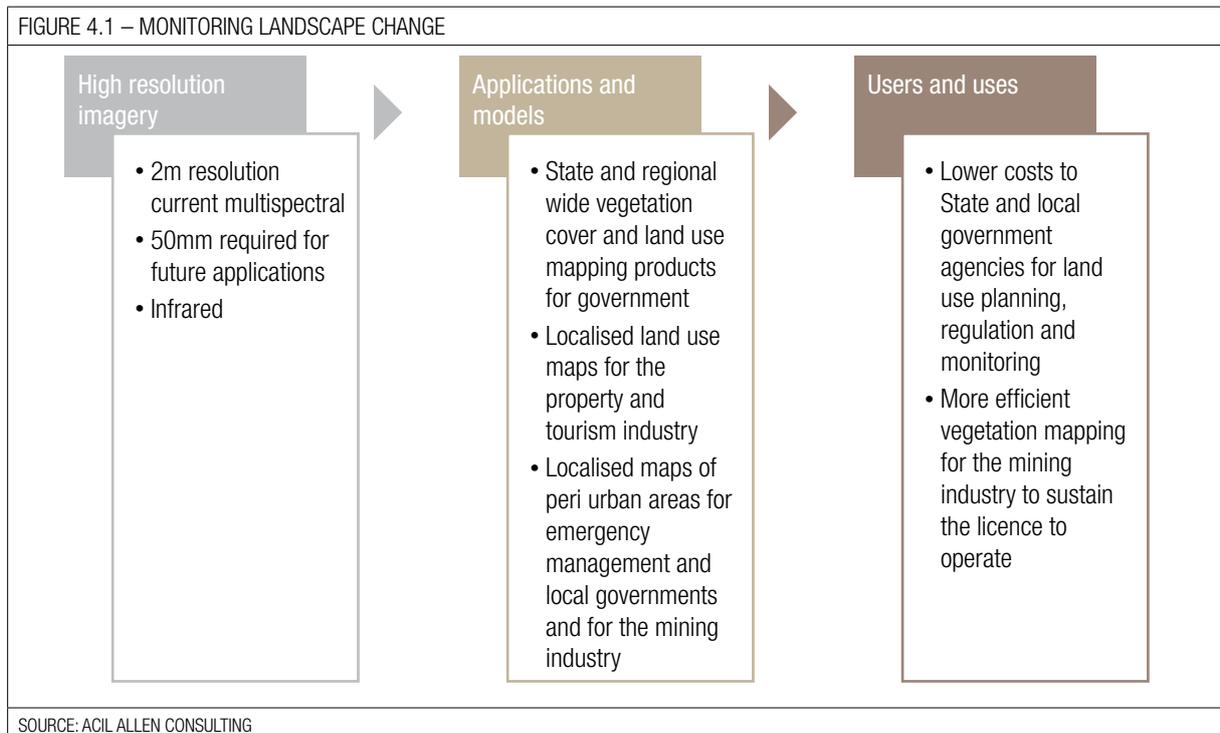
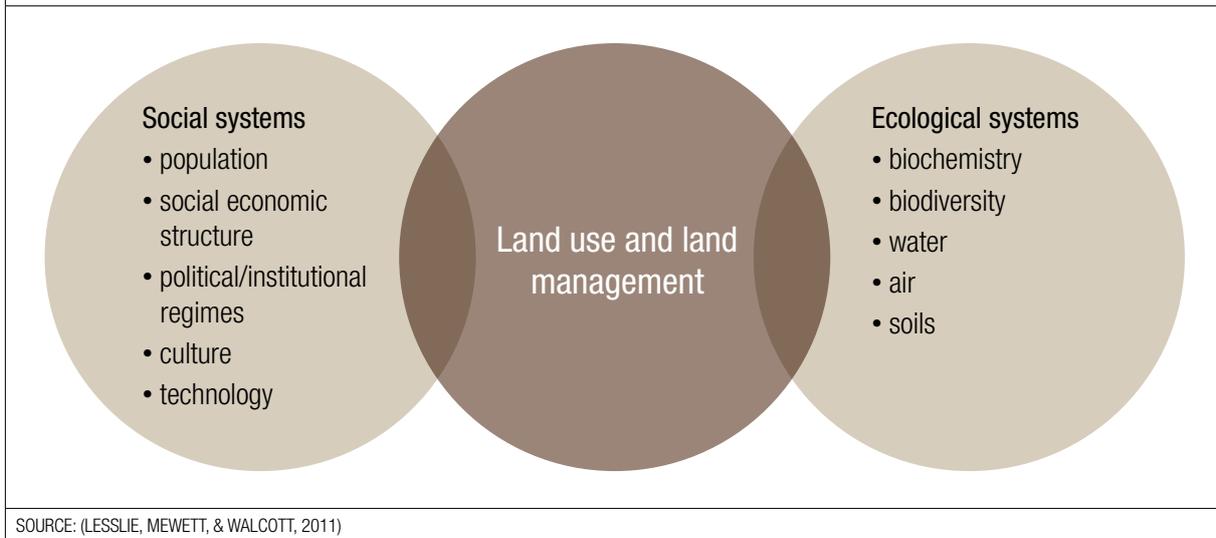


FIGURE 4.2 – LINKAGE BETWEEN LAND COVER AND LAND USE, SOCIAL AND ECOLOGICAL SYSTEMS



industries to both sustain their productive systems, such as in agriculture, or in meeting the requirements of licencing as in the mining and petroleum industries.

Competing priorities between mining and petroleum development and natural resources management are emerging as major issues for both policy makers and industry. Community concerns associated with land and water management and coal seam gas (CSG) and mining developments have emerged as political issues in some states. The recent moratorium on CSG exploration in NSW illustrates the challenge facing explorers and producers of gas. Similar issues arise in relation to the impact of dredging and agricultural run off on estuaries and coastal waters adjacent to the Great Barrier Reef Marine Park.

These issues, if not properly managed, threaten to increase perceptions of sovereign risk in the eyes of investors in the mining and petroleum sector.

Policy makers are looking for processes and protocols to resolve competing priorities in a way that enables sustainable economic development and sustainable natural resources management. A recent example of such a policy process was the

commissioning in 2013 of an independent review of Coal Seam Gas (CSG) activities in NSW and the following announcement of actions to ensure that land cover and water management issues are considered when applications for CSG exploration and development are being considered (O’Kane, 2014).

Ultimately, the successful resolution of these questions will depend on maintaining community confidence that the processes are in place to ensure that development of Australia’s mineral and petroleum resources proceeds in a sustainable manner.

EOS are critical to the monitoring of land cover, land use and landscape change. Satellite imagery is important for governments at all levels in the conduct of their regulatory responsibilities in relation to issues such as administering exploration and production titles and licences, monitoring compliance with land clearing approvals, and for flood declaration.

It is also important to industries such as mining and agriculture, whose activities have an impact on land use and land cover, in meeting these regulatory requirements.

The property sector is also beginning to use satellite imagery to monitor land cover and check on building and land use conditions when undertaking valuation activities of non-metropolitan properties.

#### 4.2.2 Land cover and land use as foundation spatial data

Land cover is one of 10 spatial databases that comprise Australia's Foundation Spatial Data Framework.<sup>10</sup> The Land Cover data set includes:

- **Dynamic Land Cover:** These data provide nationally consistent land cover information at 250 m resolution. They are essential for understanding and addressing a range of national challenges such as drought, salinity, water availability and ecosystem health.
- **Land Cover is the observed biophysical cover on the Earth's surface** including trees, shrubs, grasses, soils, exposed rocks and water bodies; as well as anthropogenic elements such as plantations, crops and built environments.
- **Fractional Ground Cover:** These data are the fraction of a satellite imaging pixel that is covered by a specific cover type such as green or photosynthetic vegetation, non-photosynthetic vegetation (e.g. stubble, senescent herbage, leaf litter) or bare soil/rock. Fractional cover can be used to characterise wind and water erosion risk, and can be used in conjunction with appropriate ancillary data to characterise soil carbon dynamics, grazing dynamics and stubble management practices.
- **National Vegetation Information System (NVIS):** NVIS provides a nationally consistent vegetation cover or community (based on vegetation structure and floristics) dataset

aggregated from jurisdictions. It provides a comprehensive means of describing and representing vegetation information based on establishing relationships between structural and floristic data.

- **National Forest Inventory (NFI) of Australia:** The NFI describes the extent and distribution of Australia's major forest types.
- **National Topographic Data:** This data contains elements that form key constraints in defining various land cover datasets and for mapping the built environment.
- **Australian Collaborative Land Use and Management Program (ACLUMP):** Land cover and land use mapping provides nationally consistent land mapping at catchment and national level. (ANZLIC, 2015).

These datasets depend on EOS data.

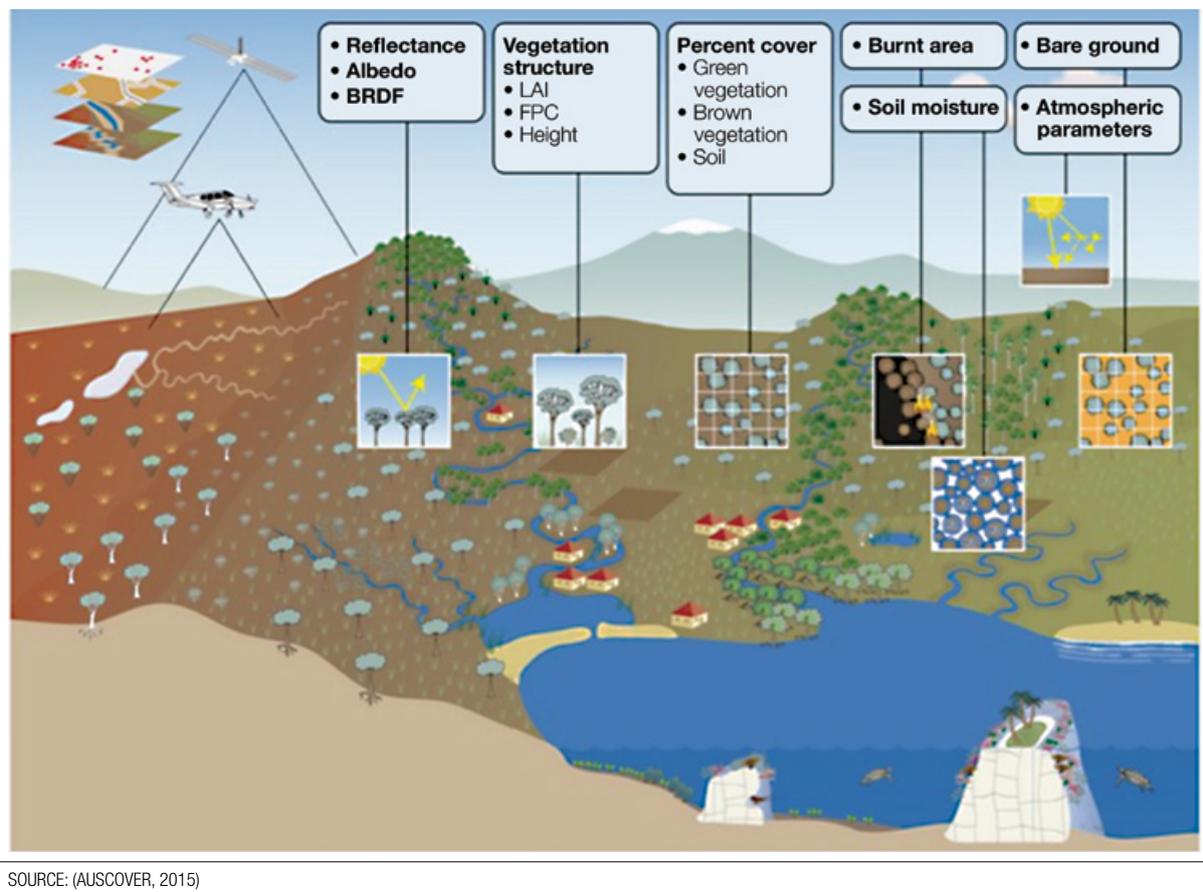
#### 4.2.3 AusCover and TERN

AusCover is the remote sensing data facility of the Terrestrial Ecosystem Research Network (TERN). AusCover provides a national expert network and a delivery service for Australian biophysical remote sensing time series data, continental-scale map products and selected high-resolution datasets over TERN sites.

AusCover is coordinated by CSIRO and supports a nationally consistent approach to the delivery and calibration/validation of key current and future core satellite-derived datasets. The primary goal is to assist in the production of ecosystem science data products designed specifically for Australian conditions. This is done by connecting relevant remote sensing science groups and their activities, providing infrastructure to support data collection,

<sup>10</sup> The Australian Spatial Data Framework comprises 10 spatial foundation datasets that have been developed collaboratively by the Australian and New Zealand Land Information Council.

FIGURE 4.3 – AUSCOVER FRAMEWORK



calibration, validation and associated technical documentation. The physical implementation of the AusCover data facility provides standardised, calibrated and validated biophysical data products, delivered via a 24/7 Distributed Data Archive and Access Capability (DAAC) linked to the AusCover Portal.

#### 4.2.4 Australian Collaborative Land Use Mapping Program (ACLUMP)

Australian Governments are collaborating in the development of land use mapping. ACLUMP promotes the development of nationally consistent land cover, and land use and land management practices information for Australia. ACLUMP has developed:

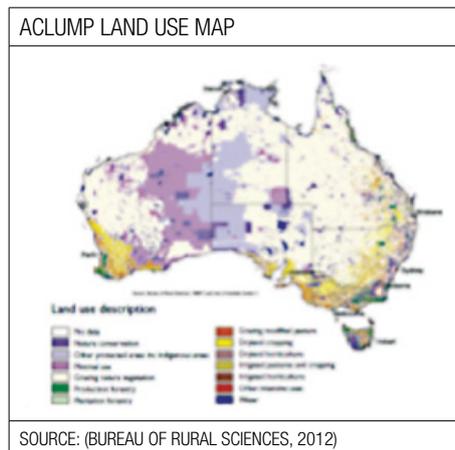
- a nationally consistent land cover and land use mapping at the continental and catchment scale

- coordination and standards
- national land cover and land use data directory and datasets
- national and regional reporting of land cover and land use and management practices.

In broad terms, the Commonwealth Government focuses on the national scale and the State/Territory Governments focus on the catchment scale. The program also involved collaboration with the Australian Bureau of Statistics, Geoscience Australia and the Terrestrial Ecosystem Research Network (TERN) (Bureau of Rural Sciences, 2012).

Remote sensing plays an important role in this collaboration. Australia's vast land mass makes EOS the most cost effective way of producing national

and catchment scale maps across the continent. Imagery archives, such as Landsat TM, MODIS and AVHRR, has resulted in their ready uptake in mapping programs. State agencies have also purchased commercial imagery such as SPOT-5 and ALOS imagery of large areas for mapping land cover, forestry and updating topographic mapping.



contribution of EOS to biosecurity is discussed further in Chapter 5.

#### 4.2.5 Queensland Land Use Mapping Program (QLUMP)

QLUMP is a Queensland Government initiative that has been operating for around 20 years. The Queensland Government said of this program:

Examples of the use of the program include:

- planning locust control, and implementation of Foot and Mouth, and Newcastle diseases preparedness exercises in Western Australia
- assisting in the management of sediment loads in the Gippsland Lakes
- supporting regional natural resource planning and investment strategies for industry development in South Australia
- supporting pest and disease response planning for horticulture in the Northern Territory.

These areas of endeavour are critical investments in Australia’s biosecurity, natural resource management and industry development in Australia. Biosecurity in particular is fundamental to Australia’s agricultural industry.

The cost of a disease outbreak in agriculture can be devastating to the industry. In 2015 the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) estimated that the profits of typical broad acre farms are \$12 000 to \$17 500 a year higher than they would be in the absence of an effective biosecurity system (Hafi, A; Addai, D; Zhang, K; Gray, E, 2015). The role and

The availability of consistent and reliable spatial information regarding land use is critical for sustainable natural resource management by the Queensland, Australian and local Governments, Natural Resource Management regional groups, industry groups, community groups and land managers (QLUMP, 2015)

QLUMP data is being used for a broad range of applications and was essential for the following activities:

- Agricultural Land Audit—for the identification of current areas of agricultural production
- Statutory Regional Planning—to guide land use planning and development in Queensland; in particular
  - the Regional Planning Interests Act (2014)—to identify priority agricultural areas and strategic cropping lands and to support development applications under the Act
  - further development of the cadastre.
- Great Barrier Reef Water Quality Protection Plan—identifying sources of nutrients and sediments in reef catchments. Land use maps are a key layer for the Paddock to Reef Monitoring Program

- identification and extent of cane growing and grazing areas included as part of the reef protection package's best management practice framework
- statutory and non-statutory planning—for example, defining the extent of urban footprints and rural living areas in the South East Queensland Regional Plan
- South East Queensland coastal management plan—developing vulnerability maps of the aquatic *Lyngbya cyanobacteria*
- development of irrigation estimates in groundwater irrigation areas
- identification of priorities for investments and extension work across the state and federal government agencies and the natural resource management regional groups
- biosecurity—identifying potential locations of Citrus Canker outbreaks; evaluating the risk of disease spreading across banana plantations in north Queensland
- monitoring and evaluation of natural resource impacts following natural disasters, including the recent tropical cyclones Larry, Yasi and Ita.

QLUMP has been in continuous development since a first land use map dividing the State into 75 catchments was completed in 1999. Since that time, the map data has been extended and improved to include land use and vegetation mapping. EOS has been a critical

component of this further development of the land use map.

The economic benefit created covers a wide range of areas. A key recent development was the approval by the Queensland Spatial Council to include EOS data in QLUMP as foundation spatial data. This is critical for the further development of a number of attributes but is especially vital to the ongoing development of the cadastre.

#### 4.2.6 State Wide Land Cover and Trees Study (SLATS)

All States and Territories operate specific land cover monitoring programs to different degrees. The Queensland Government SLATS program is one of the earlier programs developed by a State Government that illustrates the importance of monitoring programs that draw on EOS.

SLATS monitors Queensland's forests and woodlands to assess vegetation extent and clearing activities in support of the Vegetation Management Act 1999 (VMA) and regional planning initiatives. The VMA was introduced in 2000 to regulate the clearing of native vegetation in order to conserve

remnant vegetation, prevent land degradation and loss of biodiversity, maintain ecological processes and reduce greenhouse gas emissions. The Queensland Government monitors compliance with the vegetation management framework through analysis of SLATS data and other information.

Landsat imagery can be used to reliably map areas of woody vegetation change of one hectare or greater. However, the image resolution may limit its suitability

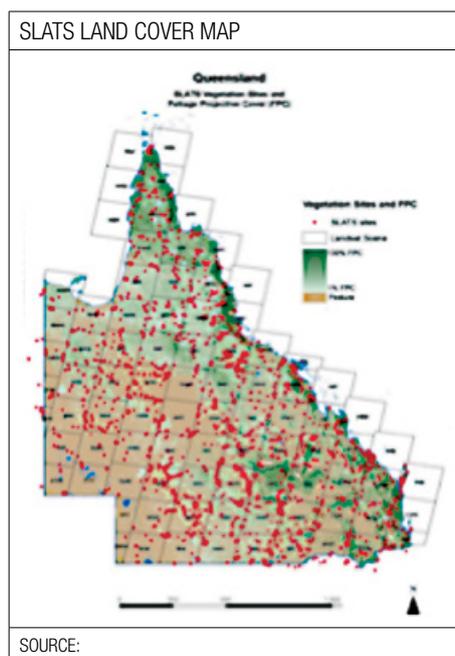
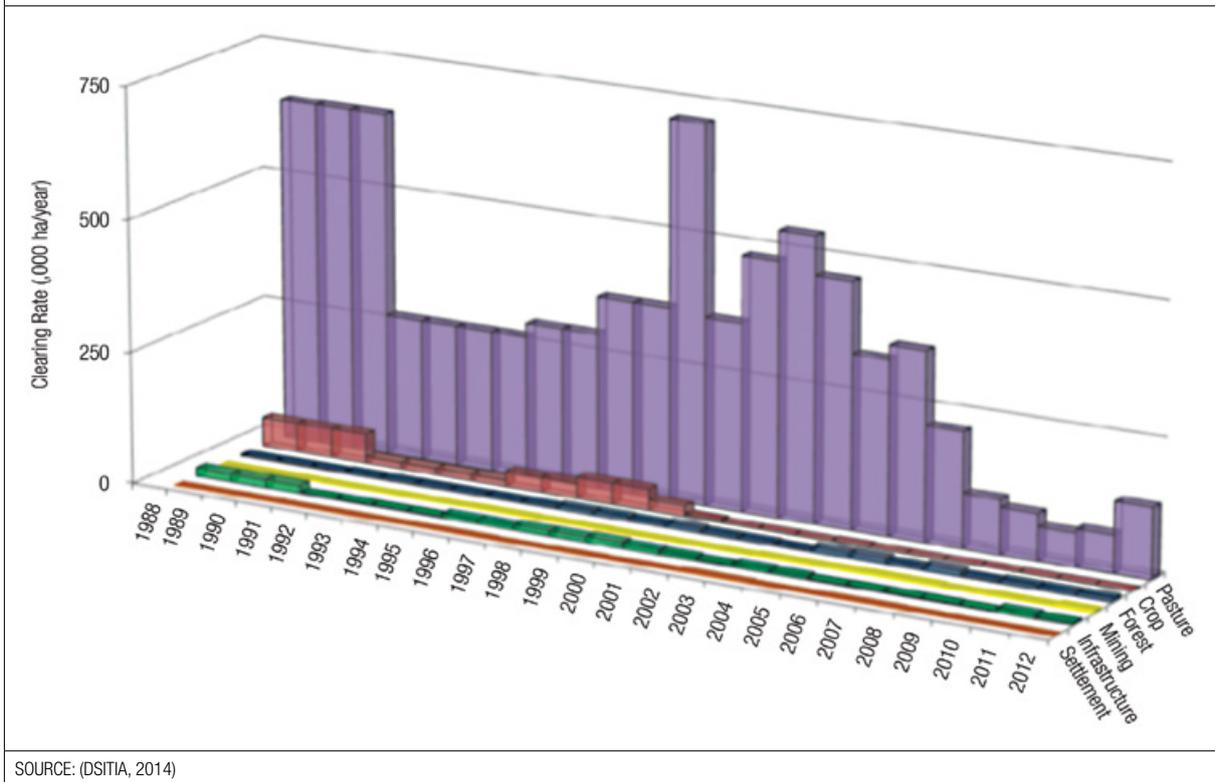


FIGURE 4.4 – EXAMPLE OF OUTPUT FROM SLATS



SOURCE: (DSITIA, 2014)

for mapping narrow vegetation corridors. SLATS mapping is not intended to be a substitute for high-resolution studies of areas such as riparian vegetation or small patches of remnant bushland. These areas would conventionally be studied by using high-resolution satellite imagery or aerial photography. An example of output from the SLATS program is shown in Figure 4.4.

Queensland Government officials have reported that the use of these data has significantly improved the implementation of government policy with respect to maintaining minimum ground cover levels, and has enabled it to be achieved at significantly lower cost than alternative methods.

#### 4.2.7 Application of ACLUMP and QLUMP data

All Australian governments draw on the collaborative land cover mapping programs for monitoring and compliance purposes. The Queensland Government has moved further than other jurisdictions towards providing data to land users to assist

their land management. Graziers, for example, are required to maintain sustainable farm management practices that include minimum ground cover levels. The government is developing tools to provide graziers with information on ground cover levels and general soil conditions sourced from remote sensing data. Such feedback is generally in its infancy in Australia but as agriculture becomes more data intensive it can be expected that such products will promulgated more widely across Australia.

Such developments will extend the reach of products produced from remote sensing beyond monitoring to providing farmers and other land users with data to manage their land use in a manner consistent with policy objectives. This will also ultimately facilitate the long-term sustainability of enterprises that are dependent on land. This is discussed further in Chapters 5, 6 and 7.

#### 4.2.8 Spatial Hub

The NRM Spatial Hub is an example of the development of tools for industries such as live-stock enterprises utilising data provided by remote sensing from EOS. The Hub is a central element of the 15-year blueprint of the Australian Rangelands Initiative.<sup>11</sup> The purpose of The Hub is to provide land managers with systems, tools, data and skills needed to improve access to property-scale information and knowledge. These capabilities will underpin better management decisions and measurable improvements in landscape condition and productivity.

Stage 1 of The Hub commenced in April 2014 with support from the National Landcare Programme, Meat and Livestock Australia and other project partners. The Hub uses online geospatial mapping technologies and time series satellite remote sensing of ground cover to enable the sheep and beef meat industries to use and compare their own data with government data in a consistent and interactive way.

The initiative aims to demonstrate the value of integrating time series remote sensing of ground cover into land condition monitoring and total grazing pressure management. Through an online interface, land managers across Australia's rangelands will be able to access and understand this data to make better, more informed decisions.

An initial project under this initiative has been the development of an On-line Property Planning and Information System (OPPIS). OPPIS will provide graziers, land managers and regional bodies with the data and mapping tools to allow the consistent development of extensive digital property plans, infrastructure maps and plans of on-ground work across the Rangelands.

The use and application of OPPIS is discussed further in Chapter 5.

#### 4.3 Future EOS applications

ACIL Allen's consultations with stakeholders suggest that a major area of growth is likely to be in vegetation mapping by the mining industry for regulatory compliance. Governments also use it for compliance monitoring.

Australia's large land area means that remote sensing is a logical option for cost effective mapping of land cover change. Medium resolution data such as Landsat terrestrial mapping, MODIS and AVHRR has been used extensively for mapping programs by governments. Commercial imagery such as available from SPOT, ALOS, Digital Globe and Airbus has also been used for mapping agricultural land use, forestry and peri urban environments at higher resolution.

Programs such as the ACLUMP national ground cover monitoring program, catchment scale mapping by State Governments and dynamic land cover mapping by Geoscience Australia (in partnership with ABARES) will continue to provide new insights into land cover change. Commercial products using high-resolution imagery and SAR products are growing in use for the management of land cover and land use in agriculture, mining and property services.

Competing demands for land use between agriculture, mining and urban development can be expected to continue the growth in demand for mapping products. The extension of higher resolution mapping into agricultural enterprise management, biosecurity management, mining and property management can be expected to be important drivers of this growth.

<sup>11</sup> The Australian Rangeland Initiative is an initiative of the Australian Rangelands Alliance with the support of the CRC for Spatial Information. It is a blueprint basis for the long-term investment by Government, industry, communities and producers in these natural resources. The National Rangeland NRM Alliance (made up of the 14 rangeland-based Natural Resource Management (NRM) bodies), together with industry, agencies and communities, have compiled this document.

There is potential for growth in use of EOS by local government in areas such as monitoring the removal of trees in urban areas and monitoring land cover in peri-urban areas for fire risk mitigation.

The property industry is beginning to use satellite imagery to provide up-to-date details of property characteristics, including vegetation, buildings, soil erosion and weed infestation, as part of valuation, insurance and mortgage approvals.

A review of land cover mapping requirements undertaken by ACLUMP partners in 2011 identified priorities in land cover and land use change reporting. These priorities were:

- tracking hotspots changes including
  - land cover change in peri-urban areas
  - loss of agricultural land, productive land resources and biodiversity
  - transitions in irrigated agriculture, forestry and carbon farming
- forecasting land cover change
  - increased climate variability
  - natural disasters including biosecurity, fire, flood and severe weather.

To this list ACIL Allen would add growing demand by the agricultural, mining and property industries for higher resolution mapping data to support management of land cover changes and land use planning for operational and commercial purposes.

These drivers of demand are likely to lead to growing demand for mapping data derived from EOS. It is difficult to see how such demands could be met with denial of access to such services.

#### 4.4 Case study – NSW Native Vegetation Monitoring Program (NVMP)

In 2007, NSW committed \$24 million to enhance its capacity to undertake vegetation change monitoring and compliance using high-resolution satellite imagery. As a result, the four-year Vegetation Change Monitoring Program was established. The high-level goal of this program was to support NSW's commitment to monitoring and reporting statewide woody vegetation changes with a focus on compliance activities related to the Native Vegetation Act 2003 (NSW) (NVA).

The program was instituted to address a number of deficiencies including the lack of a system to monitor changes to native vegetation accurately and the absence of a formal risk assessment to serve as a basis for prioritising monitoring efforts.

The activities and outputs of the program impacts on the wellbeing of the community by:

- reducing the amount of illegal clearing of native vegetation in NSW, which is valued by society due to associated improvements in biodiversity status, reduced erosion and improved water quality
- reducing the costs of achieving zero net loss in native vegetation in NSW
- improving the management of natural resources on private land in NSW
- improving the understanding and management of waterways in NSW.

Other benefits generated include an increased knowledge of natural resources and the potential for future refinement of native vegetation management options under the NVA.

In the absence of the NVMP the past and future policy and compliance activities would:

- rely on compliance solely based on public reporting
- involve periodic mapping through aerial means
- base education and incentive programs on priorities informed by anecdotal evidence and public reporting.

In addition, there would also be no benefits from the statewide mapping outputs for natural resource management actions undertaken by the NSW Government.

The operational implementation of the NVMP required the establishment of an in-house capability to map statewide woody vegetation extent annually and map consequent changes.

To establish the desired vegetative mapping capacity, a custom-designed computing facility was established and personnel were recruited. The scientific strategy for the NVMP was to adapt to NSW the State wide Land cover and Trees Study (SLATS) developed in Queensland.

#### 4.4.1 Economic impact

The CRC for Spatial Information undertook a cost-benefit analysis of NVMP. The benefits of the NVMP that were quantified in the cost-benefit analysis were:

- The avoidance of illegal clearing that would be undertaken in the absence of the NVMP (assessed through a per hectare value placed on areas not cleared, estimated at approximately 9,500 hectares, of \$760 per hectare)
- the annual benefit of the NV Act in reducing illegal clearing was estimated at \$7.169 million, of which 75 per cent (that is, \$5.377 million) is attributable to the NVMP

- the decrease in compliance effort associated with implementation of the NVA (assessed by estimating the additional costs needed to offset the impact of no comprehensive monitoring)
- the annual benefit from reduced compliance effort as a result of the NVMP was estimated at \$680,000 per year
- the improved effectiveness and efficiency of interface activities in natural resource management. (assessed by assigning an efficiency factor to current total expenditure on Catchment Management Authorities' activities that relate to landscape management of 2 per cent)
- this benefit was valued at \$1.32 million per annum between 2008 and 2010, and at \$1.82 million per annum between 2011 and 2022.

The benefits of the program arising from reduced illegal clearing and cost efficient provision of appropriate compliance were estimated at \$84 million over 15 years.

The costs of the program over 15 years were estimated to be in the order of \$36 million. Thirty-seven percent of these costs were sunk, that is, they had supported basic research and include capital expenditures that had been expended.

The annual operational costs associated with the program in the future were expected to reduce over time to \$2.0 million per year due to significant reductions in costs of obtaining the satellite imagery because of competitive pressures and purchase for the whole of government.

The discounted cost of the NVMP over 15 years was estimated to be approximately \$28 million (using a 5 per cent discount rate). It was assumed that the NVMP has a significant role in avoiding illegal clearing over the 15 years of the Program.

The Benefit-Cost Ratio of the NVMP was found to be 3.0 using a 5 per cent discount rate and the Net Present Value was estimated at \$56 million. This would be equivalent to a benefit of around \$5 million per year if the net benefits were the same in each year.

The CRC-SI study concluded that the NVMP provides effective monitoring based on a high probability of detection that is communicated to landholders across the State. It also enables the targeting of the NV enforcement strategy as ‘hotspots’ of potential clearing change over time. Moreover, the NVMP is expected to continue deliver benefits in the future as the incentives that drive illegal clearing will be present over the next decade.

#### 4.4.2 Impact in 2015

##### Counterfactual – without EOS scenario

The counterfactual would have been that without the EOS-supported NVMP, more extensive illegal land clearing would have occurred. It was estimated that this would have amounted to 9,500 hectares of illegal land clearing each year. Greater effort in monitoring compliance with the NV Act would have been expended and the NRM efficiency benefits enabled by the NVMP would have been foregone.

##### Evaluation scenario – with EOS scenario

The evaluation case is the situation, as it exists in 2015.

##### Assessment

The economic evaluation commissioned by CRC-SI showed that the benefits to NSW were equivalent to \$5 million per year over the 15-year period. Hence, the value in 2015 would be \$5 million for NSW.

ACIL Allen understands that several other states (such as Queensland, Victoria and Western Australia) have developed and implemented

programs that are similar to the NVMP, where EOS is deployed in native vegetation mapping and monitoring.

Recent state-level data on native vegetation clearance appears to be unavailable in the public domain. ABS data from 2001 suggests that the ratio of the total area of native vegetation in the rest of Australia relative to NSW was approximately 8.75:1. The area of woody vegetation cleared each year in the rest of Australia was approximately 6.95 times that of NSW.

Applying the first ratio to the compliance effort benefits of the NVMP and the second ratio to the benefits from reduced native vegetation clearing and to the benefits from NRM activities,, ACIL Allen estimates that approximately \$39.2 million of benefits would accrue to the rest of Australia each year if the other states and territories used EOS for native vegetation mapping and monitoring in a similar way to NSW and enjoyed similar types of benefits.

Assuming, conservatively, that 60 per cent of these benefits have been realised and that program costs are approximately one-third of program benefits in the rest of Australia (as they are in NSW), the total net benefit of the NSW NVMP program and other programs of its ilk to the whole of Australia is estimated to be approximately \$20.7 million in 2015.

#### 4.4.3 Economic impact by 2025

##### Counterfactual – the without EOS scenario

The counterfactual would be the current situation remaining in place with no increase in use or application.

##### Evaluation case – with EOS scenario

The evaluation case would be continuation of the program in NSW, with similar programs implemented in all other states and territories.

## Assessment

In 2025, it is assumed that all other states and territories will be using EOS as extensively and effectively as NSW in native vegetation mapping and monitoring. The total net benefit to the whole of Australia in 2025 is estimated to be approximately 39.2 million in 2015 dollars.

### 4.5 Case study – land use planning

#### 4.5.1 EOS as an enabler of the cadastre

A cadastre, using a cadastral survey or cadastral map, is a comprehensive register of the real estate or real property's metes-and-bounds of a country. The metes-and-bounds system uses physical features of the local geography, along with directions and distances, to define and describe the boundaries of a parcel of land.

The cadastral systems of Australia underpin stable and reliable registration of land based property rights. They serve as the foundation for effective land tenure transactions and in securing the legal status of property boundaries.

In 2014, The ANZLIC committee on Surveying and Mapping (ISCM) released a vision for the cadastre for 2034. In this vision statement the ISCM stated:

*“At the heart of our mission is consumer expectations and the opportunities afforded through integrated social, economic and land-related information. The emphasis is toward achieving a cadastral system that enables the community to readily and confidently identify the location and broader interests that relate to land and real property. This includes enhancing the usability and visualisation of cadastral information by embracing 3 and 4 dimensional capabilities. A key element of this strategy is to ensure the longevity of our cadastral systems. This requires a strong commitment to improving the management and sharing of cadastral information and the dedication to preserve this valuable resource for future generations.” (ICSM, 2015).*

## KEY FINDING 6 – VALUE IN NSW FOR MONITORING OF ILLEGAL CLEARING

### 2015

The economic value of EOS in the NSW NVMP program and similar programs in several other states is assessed to be approximately \$20.7 million in 2015.

### 2025

The economic value of EOS in the NSW NVMP program and similar programs in all other states and territories is assessed to be approximately \$39.2 million by 2025.

The cadastre is more than just a plan or map of existing land parcels. The registers of ownership, easement rights, restrictions and other responsibilities are integral parts of a spatial database where other data is increasingly being linked to the spatial reference that the ‘Mapbase’ of land parcels provides. The development of Geographic Information Systems and 3D mapping systems offers the potential for more powerful applications to help social and town planners, engineers and architects develop more liveable and sustainable cities, urban landscapes and better manage flood and other risks associated with the built environment.

The cadastre of the future will need to support a range of new technologies including 3D and 4D mapping and visualisation capabilities, as well as support new approaches to urban and metropolitan planning, the digital economy and smart cities.

EOS data is becoming a key enabling technology of the cadastre. The Queensland Spatial Industry Council recently endorsed the adoption of EOS as foundation spatial data for this purpose.

#### 4.5.2 Economic importance of the cadastre

EOS data are enabling technologies for land use planning and maintenance of the cadastre. This makes it very difficult to assess their final value to the economy as they support and improve the productivity and output of other activities. Examining the economic significance of the activities undertaken by the users of these services helps place the value in perspective.

To quote the ICSM vision report for the cadastre:

“The cadastral system, in combination with the land registration system, is a powerful economic lever. It assembles, manages and shares information that defines and reinforces property rights. In turn, these property rights translate into economic development, social stability and physical well-being.

At the end of 2014, there were \$1.4 trillion in housing loans secured against land titles. At the same time the total value of all real property held in title in Australia was estimated as \$5.2 trillion.

Given that the size of the Australian economy is \$1.6 trillion per annum (as at November 2014), the value of a sustainable cadastral system is self-evident. The cadastral and land registration systems allow people, businesses and governments to leverage and manage this huge national asset base.” (QLUMP, 2015)

The property industry and the banks are major beneficiaries of improved cadastre services.

The value added by these industries in 2014 was:

- property industry
  - \$32.108 billion or 2 per cent of GDP
- finance industry
  - \$87.792 billion or 6 per cent of GDP

Government is also a major beneficiary as shown above. The value added by regulation and public administration was \$51.732 billion or 3 per cent of GDP.

It is not possible to identify precisely what percentage of the value added for the finance sector

or government had benefited from these services. However, it is clear from the above discussion that it is important across a wide range of activities of government in Queensland and this is understood, from discussions with stakeholders, to also apply in other states and territories.

The links to the property sector are more easily identified. Property developers and real estate agents are highly dependent on accurate property data. This value will increase, as more data is geocoded and linked to individual properties. We have therefore focused on the property sector to develop an indication of value.

THE CADASTRE WILL BE AVAILABLE ON MULTIPLE DEVICES



SOURCE: (ICSM, 2015)

NEW APPROACHES TO CITY PLANNING BUILD ON A DIGITAL CADASTRE



SOURCE: (ICSM, 2015)

### 4.5.3 Economic impact in 2015

Counterfactual – without EOS scenario

The counterfactual would be the case where the cadastre and land cover and land use mapping data were based solely on conventional surveying methods.

Evaluation case – with EOS scenario

The use of EOS has been increasing in the development of the cadastre and related land cover and land use models. However, its adoption as a key input into the development of land use data and the cadastre has only become critical in the past five years.

Assessment

From our discussions with the property industry it has been learned that the foundation data on which property boundaries, land use and land values are based is delivering productivity improvements which, when scaled up to an industry wide value, amount to around 0.2 per cent of the industry's value added or around \$64.4 million.

The direct employment impacts of this increase are 384 FTE.

### 4.5.4 Economic impact in 2025

Counterfactual – the without EOS scenario

The counterfactual would be the case where there is no further development of foundation data in land use data or the cadastre.

Evaluation case – with EOS scenario

For the evaluation case it has been assumed that the vision of the ICSM is achieved. This includes development of a fully integrated land use database and cadastre in the foundation dataset. This would allow full development of the new and emerging 3D and 4D capacities in design and land use planning, which would benefit the property industry as well as many other sectors of the economy.

## KEY FINDING 7 – BENEFITS IN LAND USE PLANNING – THE CADASTRE

### 2015

The benefit from the use of EOS in land use data and the cadastre for the property industry is estimated to be \$64.4 million in 2015.

Direct employment impacts are estimated to be 384 FTE.

### 2025

The benefit from the use of EOS in land use data and the cadastre for the property industry is estimated to rise to \$128.8 million in 2025.

Direct employment impacts are estimated to be 768 FTE.

Assessment

The merging of the new technologies for spatial planning and precise positioning systems implies significant productivity improvement for the property industry. We estimate that the productivity impact could more than double and have assumed an additional productivity impact of 0.2 per cent. This would mean that the economic benefit from these applications could grow to \$128.8 million.

The direct employment impacts of this increase are estimated to be 768 FTE.

This is considered a very conservative estimate.

## 4.6 Summary of EOS benefits for landscape monitoring

Two examples of the application of EOS in relation to land use monitoring landscape change and land use were studied for this case study:

- vegetation mapping and monitoring for government regulatory purposes
- land use mapping and the cadastre.

Sector	Category	2015 \$ million	2025 \$ million
Government	Vegetation monitoring to regulate land clearing activities in NSW and other jurisdictions	20.7	31.1
Property	Land use mapping and the cadastre	64.4	128.8
		<b>85.1</b>	<b>159.9</b>

SOURCE: ACIL ALLEN

The findings are summarised in Table 4.1.

The combined benefits of EOS across the two case studies are estimated to be approximately \$85.1 million in 2015. These are expected to rise to \$159.9 million by 2025.

The employment impacts in the property sector are estimated to be 384 FTE in 2015 and 768 FTE in 2025.

## 5 AGRICULTURE

### 5.1 Introduction

The supply of food is dependent on trends in the natural environment, including weather and climate, freshwater supplies, soil moisture and other variables. Conversely, agriculture can have a major impact on the environment. Farms and pastures, unless sustainably managed, have the potential to cause desertification, chemical pollution and water shortages. Likewise, fishing can deplete fish stocks and damage coastal ecosystems. It is important that these risks be monitored and managed.

EOS has the potential to help farmers, fishers and policymakers maximise productivity while preserving ecosystems and biodiversity. EOS can support the sustainable management of agriculture by disseminating weather forecasts, early warnings of storms and other extreme events, water pollution, long-term forecasts of likely climate change impacts, and information on water supplies.

These and other data are being integrated so that they can be used in models for simulating and predicting agricultural trends. Related activities include mapping the changing distribution of croplands around the world, advancing the accuracy of measurements of biomass (the total amount of living material in a given habitat or population), reporting agricultural statistics in a more timely manner, and improving forecasts of shortfalls in crop production and food supplies.<sup>12</sup>

### 5.2 Current EOS applications

EOS is currently applied to agriculture at three geographic levels:

- National monitoring
- Regional monitoring
- Enterprise level and paddock level monitoring

#### 5.2.1 National monitoring

A broad outline of national land cover monitoring was outlined previously in Chapter 4. Remote sensing using data from EOS has been a key source of data underpinning the Australian Collaborative Land Mapping Program. Information on land cover change is essential for making decisions on agricultural production potential, drought responses, water management and biosecurity, and for resolving conflicting pressures on agricultural land cover and demands from mining and urban development. It is also used by some marketing companies (such as Cargill) to estimate crop yields in Australia and abroad to assist in developing annual marketing strategies.

#### 5.2.2 Regional monitoring

State Governments also use EOS data for more detailed monitoring of agricultural activity, with the Western Australian and Queensland Governments having a particularly strong role in this area. The monitoring is also part of regulatory compliance.

Catchment level monitoring is generally the province of State and Territory Governments. As discussed in Chapter 4, Catchment level monitoring is important for policy and regulation of land clearing, biosecurity and water resources management.

<sup>12</sup> [https://www.Earthobservations.org/geoss\\_ag.shtml](https://www.Earthobservations.org/geoss_ag.shtml).

### 5.2.3 Enterprise and paddock level monitoring

Enterprise and paddock level monitoring using EOS has been implemented on a relatively small scale to date. Studies and evidence suggest that significant productivity improvements have been achieved. Remote sensing via EOS is one input into precision agricultural practices that is gaining increasing acceptance in Australia.

Landgate in Western Australia operates a service to agriculture known as Pastures from Space. This service along with relevant software provides paddock scale data on pasture growth rates (PGR) and food on offer. This is used by farmers to estimate stocking rates and predict productivity trends. It operates in Southern Australia and is being developed to supply data in the Kimberley's in Western Australia. Landgate is developing products that will enable biomass analysis for weed detection and germination.

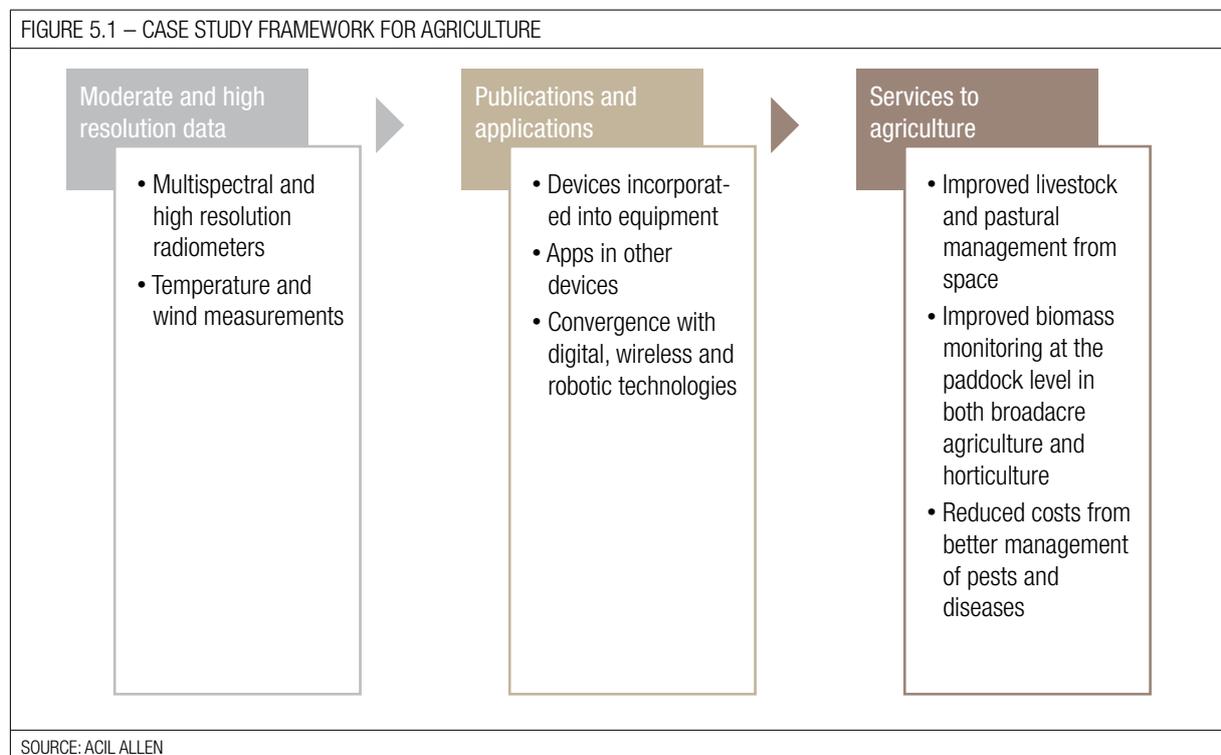
Enterprise and paddock level monitoring is also used elsewhere in Australia in broad acre

agriculture and horticulture for biomass estimates, productivity monitoring, and monitoring of pests and diseases. It is used by the banana, sugar cane, mango and macadamia industries for local yield monitoring and pest monitoring.

The Spatial NRM Hub being developed by the CRC for Spatial Information is developing an On-line Property Planning and Information System (OPPIS) that aims to provide farmers, land managers and regional bodies with data and mapping tools to support digital property plans and infrastructure maps.

The supply chain for EOS data in both broad acre agriculture and horticulture is represented in Figure 5.1.

The data that are useful for these purposes are from multispectral and high resolution radiometers. These are used for crop and soil condition and moisture monitoring, and for wind and temperature measurements. The data are generally



provided by service providers (for example, via email attachments) but increasingly are expected to be accessible directly by farmers through apps on portable devices such as smartphones and tablets. The main outcomes are improved crop and live-stock management through better planning and use of fertiliser, and potentially in the future, improved management of pests and diseases.

### 5.3 Future EOS applications

Higher frequency passes and higher resolution are expected to provide more useful data on soil and crop moisture and soil erosion. The latter is of interest to government regulators and program managers, in addition to farmers.

The use of EOS data is likely to expand in horticulture, such as in the management of weeds, pests and disease. Higher resolution multispectral imagery is already integrated into farmer data pools, analytics and devices to be used on farm. Airbus Industries provide a service (Spot Farm Star) which is being used in irrigated cotton, rice and sugar production to monitor crop vigour and the operation of irrigation systems. Monitoring from the WorldView-2 and WorldView-3 satellites is being used to monitor pests and diseases in horticulture including avocados, macadamias, mangos and bananas in Queensland. These kinds of services are expected to grow as the adoption of precision farming becomes more ubiquitous.

Development of paddock level monitoring systems using high-resolution imagery and developments

such as the Spatial NRM hub have the potential to improve management practices in most agricultural enterprises over the longer term.

Greater use of the data to assist in developing market projections by growers and marketers of agricultural products is also a strong prospect for future applications of EOS data.

### 5.4 Case study – broad acre cropping

#### 5.4.1 Application of satellite imagery enabled precision farming to broad acre cropping

Precision agriculture is a farming management concept based on observing, measuring and responding to inter- and intra-field variability in crops.

Precision agriculture aims to optimise field-level management with regard to crop science (by matching farming practices more closely to crop

needs), environmental protection (by reducing environmental risks and the footprint of farming) and economics (by boosting competitiveness through more efficient practices such as improved management of fertiliser usage and other inputs).

Precision agriculture management practices can significantly reduce the amount of nutrient and other crop inputs used while boosting yields. Farmers obtain a return on their investment by saving on phytosanitary and fertiliser costs while minimising environmental risks. This is achieved through the application of the right amount



of inputs in the right place at the right time that benefits crops, soils and groundwater. Precision agriculture is enabled by technologies such as GPS enabled machinery, crop yield monitors, variable rate seeders and sprayers, real time vehicle mounted sensors, and multi- and hyper-spectral aerial and satellite imagery).

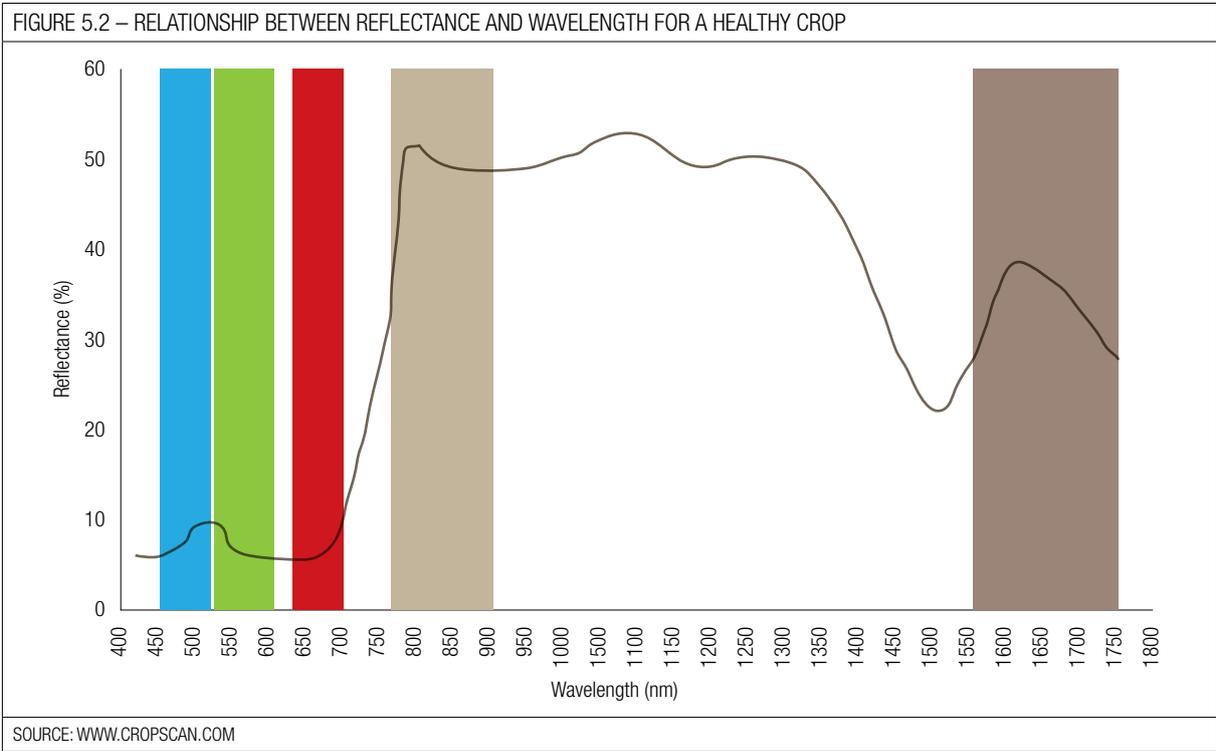
Satellite imagery plays an important role in the application of precision agriculture to broad acre cropping (oilseeds, cereals and pulses) and horticulture. It captures the light reflecting from crops/plants through a scanner. “Bands” are certain wavelengths of light which are captured by the scanner, and are kept as separate files until combined at a later date, in either the form of true colour images (composites), or indices such as the Normalised Difference Vegetation Index (NDVI) (Precision Agriculture, 2015).

Figure 5.2 illustrates the reflectance values (blue line) of a healthy crop. On the healthy crop, there is low blue and red reflectance and a slight

jump in the green band – the reason why healthy crops appear green. The first grey colour band (between 720-900 nm) is the Near Infrared (NIR) light, which is beyond the visible spectrum. NIR is critical for measuring the health, vigour and biomass of crops remotely. The point at which the blue line jumps rapidly between the red and NIR bands is called the “red-edge”.

After capturing of the imagery, the imagery is processed to create vegetation indices, and these are clipped to the paddock or farm boundary, to bring out differences in crop growth. This is then delivered to the farmer electronically. After harvest, the yield data (or other spatial data) can be compared with the imagery using sophisticated GIS tools. Trial information can be easily extracted to examine the response of the crop to certain treatments.

The pace of adoption of precision farming in broad acre crops is growing rapidly in many countries including Australia. Use of autosteer, yield maps,



yield monitors and variable rate fertiliser application has grown rapidly in recent years. Adoption levels in 2012 in cropping and horticulture are estimated to be:

- autosteer ~80 per cent
- yield maps ~30 per cent
- yield monitors ~60 per cent
- variable rate fertiliser technology ~20 per cent (see Appendix B.7).

These developments have created the opportunity for further advancements in crop monitoring and management using EOS data. Adoption at the time of writing this report is reported to be at around 6 per cent (Neale, July 2015).

#### 5.4.2 Economic impact in 2015

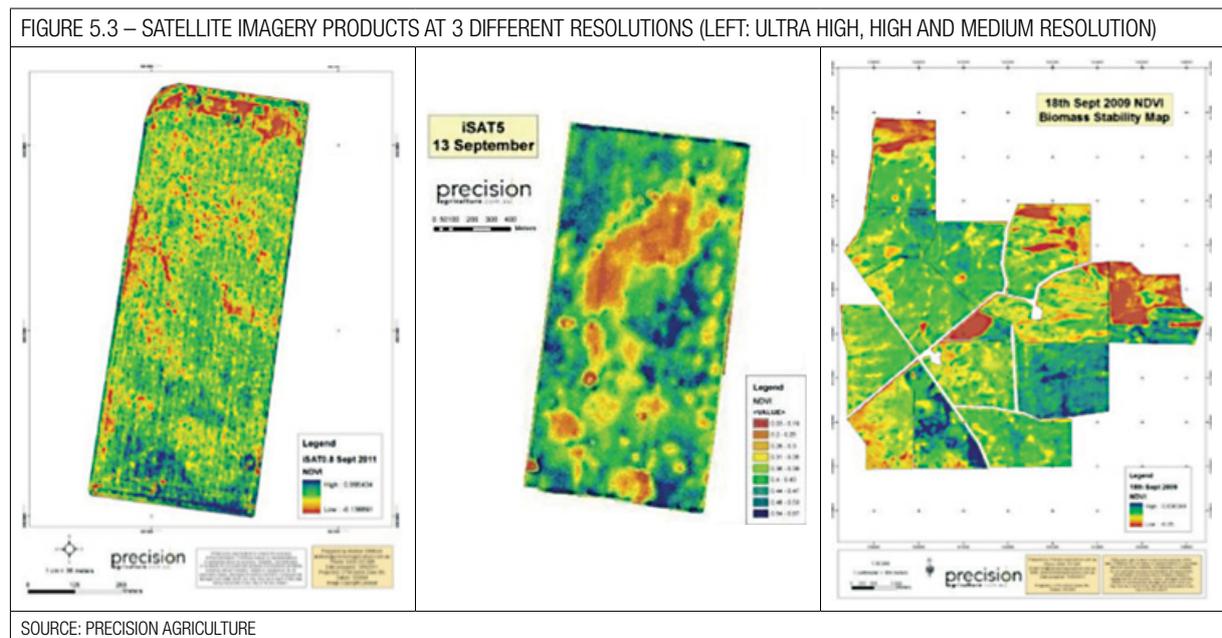
##### Counterfactual

- All farmers in Australia rely on precision agriculture methods without the use of EOS data.

##### Evaluation case

- Precision agriculture enabled by remote sensing from EOS is applied in 6 per cent of grain growers in Australia to guide zone definition for fertiliser and to monitor inter- and intra-field variability in crops to enhance overall yields while lowering input cost.

A range of satellite imagery is available to farmers who wish to adopt precision farming practices. One company that provides EOS data and services to cropping enterprises in Queensland offers three satellite imagery products at different resolutions (see Figure 5.3). The first is a 0.8 metre by 0.8 metre image product which provides a highly detailed look at micro differences occurring in the field, and is also well suited to evaluating trials. The second has a pixel size of 5 m x 5 m and is useful for zoning and in-crop applications of crop protectants, nutrients and desiccation, where appropriate. The third is a medium resolution image product of 30 metres by 30 metres. While it is fairly coarse for precision agriculture, its cost effectiveness enables a whole farm or catchment to be captured relatively inexpensively. Its primary use is for examining long-term trends over the property or catchment.



	Total area	Adoption	Area of adoption		Total benefit
	Thousands of ha		Thousands of ha	\$/ha	\$ million
2015 – wheat	12,979.00	6%	778.74	17.55	13.7
2015 – coarse grains	5,199.00	6%	311.94	12.85	4.0
Total	18,178.00		1,090.68		17.7
2025 – wheat	12,979.00	75%	9,734.25	17.55	170.8
2025 – coarse grains	5,199.00	75%	3,899.25	12.85	50.1
Total	18,178.00		13,633.50		220.9

SOURCE: ACIL ALLEN, SEE APPENDIX B.7.1

Consultation with an industry operator (and subsequently confirmed with other experts in the field) suggested that precision agriculture enabled by remote sensing can potentially increase yield on average by up to 0.50 tonnes per hectare in low productivity areas, by 0.31 tonnes per hectare in medium productivity areas and increase yield by 0.18 tonnes per acre in high productivity areas. The characteristics of cropping enterprises varies significantly across Australia.

There are few recent studies of the value of precision agriculture across the Australian grain growing regions and no studies of the value of the contribution from EOS. Past studies of the economics of precision agriculture are discussed in Appendix B.7.1. Most of the past studies were done prior to 2008 and focus on the cost savings possible from precision agriculture rather than the increased yield. None of these studies fully reflects the state of the technology today.

One study estimated the value of precision farming in crops to deliver 10 to 15 per cent savings in operating costs and yield increases from 10 per cent to 30 per cent (Schofield, 2007). Other reports citing specific case studies reported returns to Variable Rate Technologies ranging between \$1.5 per hectare to \$32 per hectare (adjusted to current grains prices).

ACIL Allen considers that it would be appropriate to include the impacts of both cost savings and

yield increased in assessing benefits that might be attributed to precision agriculture and to the use of EOS in this task.

Drawing on the average yield increases cited above, ACIL Allen estimated that the net benefit of the use of EOS and the Normalised Difference Vegetation Index (NDVI) with Variable Rate Technology (VRT) was around \$17.55 per hectare for wheat and \$12.95 per hectare for coarse grains (see Table B.11 in Appendix B.7.1).

While the adoption rate for use of EOS is currently very low (at approximately 800,000 to 1 million hectares a year, or around 6 per cent of the total cropping areas in Australia of 18.2 million hectares), the adoption of EOS in precision agriculture is expected to increase over the next decade, particularly with large-scale commercial farms leading the way. Advice to ACIL Allen suggested that this could reach 75 per cent by 2025.

The impact of the use of EOS in precision agriculture is summarised in Table 5.2

The table shows that the net benefit from the use of EOS in precision agriculture is estimated to be \$17 million in 2015. The employment impacts are estimated to be 402 FTE in 2015.

Full details of these calculations are provided in Appendices B.7 and B.10.

### 5.4.3 Economic impact in 2025

Counterfactual – without EOS scenario

- The existing low level of adoption of precision agriculture enabled by remote sensing persists to 2025.

Evaluation case – with EOS scenario

- The adoption rate of EOS in precision agriculture throughout Australia grows from 6 per cent in 2015 to around 75 per cent by 2025.

Precision agriculture is gaining increasing acceptance in broad acre agriculture and horticulture in Australia. EOS provide the underlying data to fully realise its potential. The development of farming machinery and technology that uses precise positioning information combined with other data and digitised imagery are fundamentally changing the ways in which farm businesses are run and managed. The implications of these developments are the subject of research currently being conducted by the Australian Farm Institute in conjunction with the Cotton Research and Development Corporation, Dairy Australia and Grain Growers Limited (Australian Farm Institute, 2015).

Using similar logic as applied above for the year 2015, the net benefit from the use of EOS as part of precision agriculture has been estimated to be \$221 million (Table 5.1 above). Employment impacts are estimated to be 3,583 by 2025. Details of these calculations are provided at Appendices B.7 and B.10.

## 5.5 Case study – Rangelands and livestock

### 5.5.1 Pastures from Space

In many parts of Australia, pasture utilisation by sheep and cattle during the growing season has historically tended to be low relative to total pasture production. In many years, total pasture

## KEY FINDING 8 – VALUE OF EOS IN PRECISION AGRICULTURE

### 2015

The value of EOS in enabling precision agriculture to be applied to broad acre cropping is estimated at approximately \$17 million per year.

Employment impacts are estimated to be 402 FTE.

### 2025

The value of EOS in precision agriculture related to broad acre cropping across Australia might reach \$221 million per year.

Employment impacts are estimated to be 3,583 FTE.

consumption can be as low as 20 to 30 per cent. That is, producers forego potential production due to their inability to make informed decisions on the management of their feed resources.

In southern Australia, the environment is characterised by high winter/spring rainfall and summer/autumn drought. Pasture that is not utilised before the end of the growing season dries up, senesces and is available with a greatly reduced nutritive value.

The Pastures from Space program provides estimates of pasture production during the growing season by means of remote sensing. Satellite data is used to accurately and quantitatively estimate Pasture Biomass or Feed on Offer (FOO), or combined with climate and soil data is used to produce Pasture Growth Rate (PGR) estimates.

Estimation of PGR and FOO using remote sensing provides temporal and spatial information on feed resources, which allows producers to more effectively manage their enterprise and potentially raise the productivity and profitability of their businesses. An objective measure of the spatial variation of pasture production might also highlight

opportunities to improve the environmental management of the landscape. Electronic delivery of the information (email or web based) enables near real time decisions to be made.

The technology has been widely trialled by Western Australian farmers, where PGR information is broadcast on ABC Radio and signposted in regional areas. PGR estimates for Shires in the Southern agricultural or Mediterranean regions of Australia are now being developed and trialled nationally.

Pastures from Space was implemented in 2003 and the number of subscribers have generally been in the hundreds, although this has recently fallen slightly. Landgate is developing a new, improved version of the program. While current uptake is below 1 per cent of enterprises that would benefit from the service, Landgate WA is working towards achieving an adoption rate exceeding 10 per cent in 2-3 years' time, with the longer-term target adoption rate of 20 per cent within the decade. In future, the service is expected to be extended from the Southern agricultural and Mediterranean regions of Australia to the rangelands and savannahs of Northern Australia.

### 5.5.2 The NRM Spatial hub

The development of the NRM Spatial Hub (the Hub) was introduced in Chapter 4. It is a central element of a 15-year blueprint of the Australian Rangelands initiative. The aim of the Hub is to provide land managers with the tools, data and systems needed to improve access to property-scale information, with the aim of supporting better management decisions and measurable improvements in landscape condition and productivity (NRM Spatial Hub Rangeland Alliance, 2015). The Hub is intended to provide:

- an online farm planning and information system
- coordinated information delivery, support and training services
- paddock to national scale productivity and environmental monitoring.

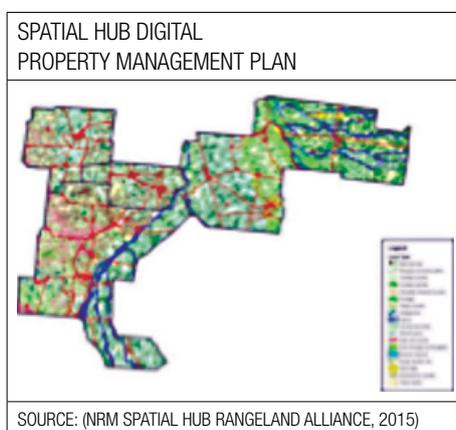
Data for property infrastructure mapping in the hub is drawn from the DigitalGlobe satellite imagery service down to 0.5 m resolution, as well as services from ESRI and Bing. Medium resolution data from Landsat is also used to undertake paddock scale monitoring of ground cover for almost 30 years of imagery.

As noted previously in Section 4.2.8, an initial development under this initiative has been an On-line Property Planning and Information System (OPPIS). OPPIS provides graziers, land managers and regional bodies with the data and mapping tools to allow the consistent development of extensive digital property plans, infrastructure maps and plans of on-ground work across the Rangelands.

Users gain secure on-line access to spatial data over their land, such as high resolution and innovative time series satellite imagery products, as well as tools to analyse land condition, water access and plan infrastructure. They also have the ability to capture supporting information in the field, using

handheld devices such as GPS units and smart phones.

Customised and easy to use mapping, reporting and analysis tools allow land managers to analyse the condition of their properties over time, and better understand how well their current infrastructure such as fences and water points effect



pasture utilisation and long-term safe carrying capacity. It also provides tools to assist with strategic decisions such as grazing development plans aimed at achieving productivity and sustainability.

Development of services under the Spatial NRM Hub is still in its early days. There has been no economic assessment of the trial use of the Hub services. However, demonstration trials of OPPIS in Queensland have yielded promising results. The potential reported benefits from these services include:

- significant savings in time and resources to map water infrastructure on cattle properties
- improvements in documenting and managing an assets register
- critical for both managing assets and documenting assets for financial institutions
- benchmarking performance against other comparable farm enterprises
- improved management of fire risk
- improved productivity for pastoral enterprises from better location of infrastructure such as watering points.

Initial evidence suggests that paddock scale monitoring can be acquired at a cost of around 10 cents per square kilometre. This is estimated to be a ten-fold increase in mapping productivity compared to current airborne data collection. The service also provides a time series of paddock conditions that provides a baseline for comparison, as well as a synoptic view of conditions. This would not be possible without EOS.

### 5.5.3 Economic impact in 2015

Estimates of economic impact are based on developments in the Pastures from Space program and future development of OPPIS under the NRM Spatial Hub initiative. The estimated impact are discussed below.

For estimating the impact in 2015, the following has been assumed:

Counterfactual – without EOS scenario

- The Pastures from Space program does not exist.

Evaluation case – with EOS scenario

- Uptake of the Pastures from Space program is its current level of less than 1 per cent. The NRM Hub is not yet operational.

Costs

The costs to users of Pastures from Space are set on a commercial basis and include:

- \$542 initial set-up fee
- Annual subscription fees of \$154 for up to 1,000 hectares and \$400 for between 1,000 and 4,000 hectares for a weekly data feed.

Benefits

In 2003, in-depth case studies were undertaken with six producers in major sheep producing areas in Western Australia to quantify the monetary benefits accrued from the Pastures from Space information (Gherardi, Anderson, Sneddon, Oldham, & Mata, 2004). In all cases, the use of remote sensed PGR improved the profitability of their sheep enterprise. The increase in gross margin ranged from AUD\$23 to AUD\$332 per winter grazed hectare. The increased profit resulted from better utilisation of pasture through more effective feed budgeting and the introduction of new management techniques in to the farming system.

The six producers recognised remote sensing as a valuable tool when applied to decisions about the use of other management techniques such as lot feeding of wethers, increasing stocking rates and conserving fodder in the spring. The information on PGR was also found to improve producers' confidence in decision making and helped reduce stress levels. Elevated stress levels are known to lead to poor decision making.

In another study, economic analysis demonstrated an increase in gross margin per winter grazed hectare of \$53 from \$314 to \$367 resulting from an increase in stocking rate from 12 to 16 DSE.<sup>13</sup> The study was undertaken at a property of 510 arable hectares at Arthur River, approximately 180 km southeast of Perth. Approximately 60 per cent of the arable area was planted with crops. Satellite-based information on pasture growth rate (PGR) enabled a movement from set stocking to rotational grazing and a consequent increase in stocking rates. Weekly average PGR and 7-day forecast PGR information facilitated major stocking rate, grazing systems and pasture management decisions on the farm.

Assuming an average increase in gross margin of \$60 per hectare, an average farm size of 4,000 hectares and adoption of Pastures from Space by 100 such farms, the net benefits of the program is estimated to be approximately \$24 million per annum.

#### Economic impact in 2025

For estimating the impact in 2025 the following has been assumed:

#### Counterfactual – without EOS scenario

- Uptake of the Pastures from Space program in 2025 remains at a very low level of less than 1 per cent.

### KEY FINDING 9 – VALUE OF EOS TO AGRICULTURE VIA THE PASTURES IN SPACE PROGRAM

#### 2015

The value of EOS to agriculture through the Pastures in Space program is estimated at approximately \$24 million per year.

#### 2025

The value of EOS to agriculture through the Pastures in Space program augmented by technologies developed through the Spatial Hub is estimated at approximately \$480 million per year.

#### Evaluation case – with EOS scenario

- Uptake of the Pastures from Space and the OPPIS program with the Spatial Hub increases the use and application of remote sensing for pastoral activities to 30 per cent by 2025.

As noted above, while current uptake of the Pastures from Space program is below 1 per cent of enterprises that would benefit from the service, the Landgate WA objective is to achieve an adoption rate of 20 per cent within the decade. Assuming that the average increase in gross margin will continue to be \$60 per hectare, the net benefits of the program could be \$480 million per annum by 2025 (see Appendix B.7 for calculations).

#### 5.5.4 Biosecurity

Biosecurity is concerned with management of risks to the economy, the environment and the community from pests and diseases entering, establishing or spreading in the Australian landscape (Hafi, A; Addai, D; Zhang, K; Gray, E, 2015). Maintaining a high level of biosecurity is critical for Australian agricultural industries. An incursion of a pest or

	Cost of FMD event	Probability without biosecurity	Average annual cost without biosecurity	Probability with biosecurity	Average annual cost with biosecurity	Net reduction in average annual cost FMD
	\$ billion		\$ billion		\$ billion	\$ billion
Large scale outbreak	52.21	0.16	8.35	0.01	0.52	7.83
Small scale outbreak in Victoria	6.00	0.16	0.96	0.01	0.06	0.90
Small scale outbreak in QLD	5.64	0.16	0.90	0.01	0.06	0.85

SOURCE: (BUETRE, ET AL., 2013) (HAFI, A; ADDAI, D; ZHANG, K; GRAY, E, 2015)

disease would affect returns in a number ways. There can be significant costs arising from lost production and eradication. However, the impact on Australia’s trade can be extremely high if trading partners ban the importation of affected commodities.

Australian governments and industry have established formal arrangements for cooperation of programs to limit the likelihood of incursions, prepare for incursions and eradicate pest or disease should one occur.

The value of biosecurity activities can be measured in many different ways. A common approach is to estimate the value of the costs avoided from incursions of pests and diseases from mitigation activities. These costs include:

- direct production losses (for example, reductions in the productivity of crops and livestock and output quality)
- additional expenditures on control measures and damage mitigation (for example, additional chemical inputs)
- export market losses (for example, because of trade bans or the loss of price premiums as products are diverted to lower value markets where the pest, disease or weed is endemic).

Hafi et al (2015) in a report published by ABAREs, reported that without biosecurity mitigation activities (Hafi, A; Addai, D; Zhang, K; Gray, E, 2015):

- annual profits of beef, dairy and sheep enterprises in Australia would be 8 to 12 per cent lower
- annual profits of pig enterprises would be 15 per cent lower
- annual profits of cropping enterprises would be 7 per cent lower.

The report concluded that Australia’s biosecurity system improved annual profits of a sample of broad acre farms by \$12,000 to \$17,000 because it reduces the risk of FMD, Karnal bunt and Mexican feather grass outbreaks.

It is difficult to scale these findings up to a national level because of the non-uniform nature of the farming enterprises examined, among other reasons. For the purposes of making a lower bound estimate of the value of biosecurity measures in Australia, ACIL Allen drew on another study prepared by ABARE estimating the costs of an outbreak of Foot and Mouth Disease (FMD) in Australia (Buetre, et al., 2013).

The study estimated the direct production losses, the eradication costs and the impact of trade sanctions that would arise from large and small outbreaks of FMD. The findings are summarised in Table 5.2. The table also provides estimates of

the probability of an outbreak of FMD with and without biosecurity measures from the previously cited ABARE report (Hafi, A; Addai, D; Zhang, K; Gray, E, 2015).

While the calculations are general estimates for specific states, they provide an indication of the value of biosecurity measures against FMD. Taking a conservative approach, the calculation suggests that a lower bound estimate of the average annual value of biosecurity would be around \$850 million.

Expected net benefits in 2015

For estimating the impact in 2015, the following has been assumed:

Counterfactual – without EOS scenario

- The ACLUMP and State/Territory mapping programs using EOS do not exist. Mapping is based on traditional surveying measures and accuracy varies at the local level.

Evaluation case – with EOS scenario

- The existing situation applies with the ACLUMP program.

In the Evaluation case, remote sensing from EOS provide the underlying mapping layer on which biosecurity measures rely:

- The Western Australian Government reported that the mapping provided under ACLUMP was used to plan for FMD and Newcastle disease preparedness exercises.
- The Northern Territory Government reported that mapping provided under ACLUMP had supported pest and disease response planning for horticulture in the Territory.
- The Plague Locust Commission relies on accurate land cover mapping for the deployment of eradication action on an annual basis.

## KEY FINDING 10 – VALUE OF EOS TO AGRICULTURE FROM BIOSECURITY MEASURES

### 2015

The value of EOS to agriculture from biosecurity measures is around \$42 million in 2015.

### 2025

The value of EOS to agriculture from biosecurity measures would be approximately \$54 million by 2025.

There is no one estimate of the marginal value of mapping provided by EOS remote sensing to the effectiveness of biosecurity measures. However, broad scale mapping is critical to biosecurity preparedness and to eradication programs.

Based on our consultations with governments and industry, we have assigned a marginal value of a 5 per cent contribution to the value of biosecurity measures. This is based on the impact of broad scale availability of mapping data and historical time series on which preparedness plans are developed and on which response actions are based.

On this basis, we have estimated that the average annual value of the marginal contribution of remote sensing from EOS would be around \$42 million (see Appendix B.7).

Expected net benefits in 2025

For estimating the impact in 2025, the following has been assumed:

Counterfactual

- There is no further development of the ACLUMP program and no further development of high resolution remote sensing.

Sector	Category	2015	2025
		\$ billion	\$ billion
Cropping	Increasing broad acre cropping yields	17.7	220.9
Pastoral	Improving pasture utilisation by sheep and cattle	24.0	480.0
Biosecurity	Biosecurity measures	43.0	53.8
		84.7	754.7

SOURCE: ACIL ALLEN

#### Evaluation scenario

- There is further development of the ACLUMP, the Spatial NRM Hub and the use of higher resolution sensors for monitoring of plant condition and plant disease.

Consultations with governments and industry indicate significant potential for the use of remote sensing from EOS for biosecurity preparedness and for response plans. More consistent mapping coverage at the national, catchment and the paddock level is expected to improve response planning and eradication measures.

The emergence of higher resolution imagery, multispectral services and higher frequency image capture is expected to improve the performance of biosecurity measures. Consultation with stakeholders did not provide a single estimate of the improvement. However, higher resolution multispectral imagery, with more frequent repeat cycles, combined with wide coverage down to the paddock level could be expected to increase the value of remote sensing from EOS to the package of technologies and measures that form part of national and regional biosecurity measures.

Our consultations suggest that this could increase the marginal contribution of EOS by at least 25 per cent, which would lead to a value of \$53.8 million in 2025.

## 5.6 Summary of benefits for agriculture

Three examples of the application of EOS in agriculture were studied in this chapter:

- precision farming to broad acre cropping
- livestock and pastoral enterprises
- biosecurity

The findings are summarised in Table 5.3

The combined benefits of EOS to agriculture across the three case studies are estimated to be approximately \$67 million in 2015. By 2025, based on the assumptions discussed above, the combined benefits could plausibly be in excess of \$534 million per annum.

The employment impacts have been estimated using ABS employment statistics and the aggregate proportional impact on value added. The employment impacts were estimated to be:

- 318 FTEs in 2015
- 2,535 FTEs by 2025.

## 6 WATER

### 6.1 Introduction

Increasing pressure on freshwater resources is a major concern to Australia. Water is needed for irrigation (farmers, graziers), forestry, industrial users, environmental flows for the country's river systems, and for human consumption. With increasing population and economic growth, these pressures will continue to increase over the coming decades, making it more important to have accurate information about the sources and availability of water, as well as the consumption of water (e.g., monitoring the amount that is pumped from groundwater sources).

EOS plays a critical role in this process. It introduces objective measures that can be tracked over time, and amongst other applications enables monitoring for compliance and reporting purposes. EOS data can be used for a range of water related applications, such as catchment management, ground water monitoring, and water resource assessments.

### 6.2 Current EOS applications

Specific applications of EOS in relation to water are discussed below.

#### 6.2.1 Catchment management

Water managers and planners have been using data from satellite sensors with the right spectral range (for example MODIS, Landsat, SPOT, WorldView-2 and WorldView-3) to support catchment level monitoring and forecasting, to estimate parameters such as evapotranspiration, calibrate catchment models, estimate interception from forests and assess the impacts of land cover change on water availability. Use of EOS data helps reduce the costs of data acquisition.

The Sydney Catchment Authority uses data from satellites such as those listed above to model natural and man-made processes over large areas

and to a high degree of accuracy. For example, satellite data are used to model fire fuel loads, land cover, cyanobacteria growth in dams, or pasture cover variability. This information is used to better target catchment interventions.

EOS data are also being used for projecting future water availability using archival material and for estimating soil moisture and runoff for future events.

#### 6.2.2 Ground water modelling

The University of Adelaide has used data from the MODIS and Landsat to monitor spring flows in the Great Artesian Basin (GAB). Over a decade of data from these satellites was analysed by Geosciences Australia and NASA to provide vegetation indices. The University of Adelaide then calibrated that information against the volume of water flowing from springs in the GAB. The results of the research formed the basis for a major report to the National Water Commission.

#### 6.2.3 Water resource assessments (WRAs)

CSIRO has a long history of scientific research aimed at understanding and better managing Australia's water resources. CSIRO's water resource assessments began in 2006, when the then Prime Minister, John Howard, called on CSIRO to conduct the Murray-Darling Basin Sustainable Yields (MDBSY) Project at a time when Australia's food bowl was in the grip of the millennium drought. The project was an independent, scientific and transparent study of current and future water supply in the Murray-Darling Basin and ultimately underpinned the creation of the Murray-Darling Basin Plan.

The tools, methodologies and capabilities developed in the course of the MDBSY project and a related project, the South-Eastern Australian

Climate Initiative, were then adapted and applied to sustainable yields projects in three other areas of Australia (northern Australia, south-west Western Australia and Tasmania). The techniques and experience gained, were subsequently extended and applied to the Great Artesian Basin, and the Flinders River and Gilbert River catchments in north Queensland.

Because of the cumulative capabilities built up through these projects, Australia has systematically developed and applied a nationally consistent framework for assessing water resources and water availability under changing climatic conditions to serve as a basis for responsible water resource management.

#### 6.2.4 National water reporting

Under the *Water Act (2007)*, the Bureau of Meteorology (BOM) has responsibility for water accounting and coordinates the processes by which data is gathered, analysed and measured across Australia. This feeds into the Bureau's work in reporting and forecasting water resources availability and other services.

The Bureau is responsible for the annual National Water Account (see <http://www.bom.gov.au/water/nwa/>). Currently MODIS, AMSR-2, satellite derived NDVI are all used in the accounting process.

#### 6.2.5 Australian Hydrological Geospatial Fabric (Geofabric)

The BOM have developed the Geofabric, which is a GIS based topologically connected model of hydrological features. The model is being iteratively updated with improved map features and a 1-second Digital Elevation Model sourced from SAR data.

Geofabric provides the critical framework for modelling of Australia's surface and groundwater hydrology. It is provided free from the BOM web portal and is incorporated into commercial products (notably within ARC GIS).

The application of these models to water resource management, prediction and planning will form a platform for economic analysis of the application of improved hydrological modelling for catchment management at the regional level and irrigation planning at the enterprise level.

By detailing the spatial dimensions of these hydro features and how they are connected, Geofabric enables the user to see how water is stored, transported and used through the landscape.

Geofabric comprises six product datasets:

- **Hydrology Reporting Regions** define drainage divisions and river regions across Australia, for consistent reporting by governments and other organisations.
- **Hydrology Reporting Catchments** are the building blocks of reporting regions, providing increased detail for smaller rivers, along with a simplified stream network.
- **Surface Catchments** define the base level of catchments for stream segments, sinks and coastal draining areas. Universities, governments and consultants use these to identify contributing catchment areas.
- **Surface Network** provides a detailed fully connected and directed stream network. You can trace streamflow paths and link them to Surface Catchments.
- **Surface Cartography** enables visualisation of surface water features such as dams, canals and bridges. This context is useful for water managers and emergency services, e.g. to anticipate how downstream communities may be affected by floods.

- **Groundwater Cartography** shows groundwater resources and their features—such as aquifer boundaries, salinity, and the rocks and sediments at different levels below the surface.

Geofabric is akin to a digital street directory of Australia’s important water features. The layers of data depict maps of how Australia’s national water system is connected at various levels of detail. Users can discover, visualise and model hydrological features anywhere in Australia at the appropriate scale depending on their requirements.

Geofabric is suitable for a wide range of water information applications. For example, streams can be traced upstream or downstream to identify drainage networks, catchment areas, and other features of interest such as monitoring points and water storages. These features are used by natural resource managers and the Bureau for water accounting, assessment, modelling and forecasting.

Users of the Geofabric include:

- internal users within BOM (Land and Water Resource Assessment, flood forecasting and warning)
- Insurance companies
- fisheries (to analyse migratory paths of fishes and to monitor environmental contamination downstream from a spill)
- NSW Water
- Queensland Environment Heritage Protection

- Department of Environment (using it for mapping the Ramsar wetlands).

Potential future enhancements of Geofabric include incorporating higher resolution data and offering a web processing service to allow users to examine the topological connectivity between two points.

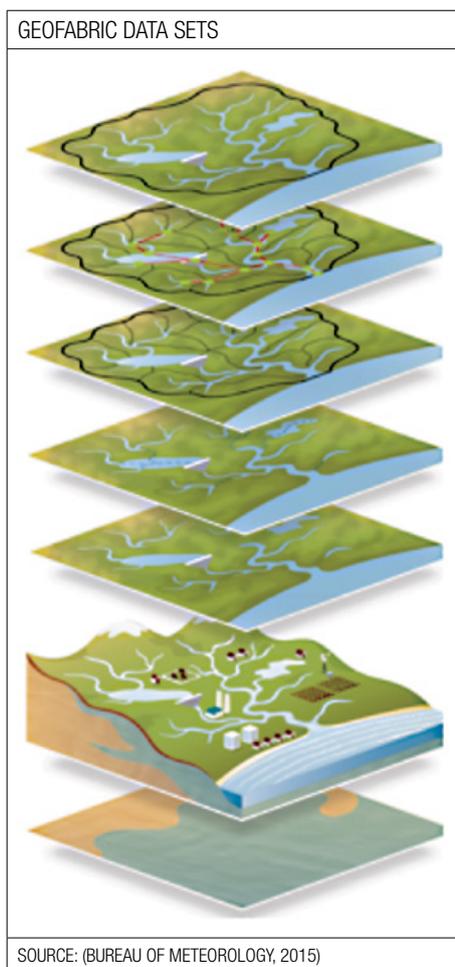
The use and application of such datasets creates a capability by resource managers to better plan and manage water resources supplies.

### 6.2.6 Irrigation

Remote sensing from EOS has been applied in many areas for yield optimisation in horticulture in monitoring water usage in crops, improving crop water use efficiencies as well as for planning for water release for irrigation. This was documented by the United States Geological Survey for global applications, as well as for trials in Victoria (USGS, 2014).

The USGS report fore-shadows significant potential for improvement in water use per crop and increased water use efficiency in irrigation in future years.

In Europe, Airbus Industries offers a service, “Farm Star”, to assist irrigation enterprises schedule water applications and monitor the operation of irrigation systems. This applies in the cotton, rice and sugar industries. The data enables enterprise managers to develop indices for relative variation in vigour of each crop as a component of precision farming.



It is used in irrigated agriculture to assess blockages in irrigation systems thereby improving management and lowering costs in irrigation.

It is also being used for:

- planning water releases for irrigation
- modelling future areas under cropping
- monitoring water usage in irrigated crops.

### 6.3 Future EOS applications

The use of EOS to undertake water resource assessments as part of overall catchment management and water resource planning can be expected to increase as catchment models are enhanced and as the need to manage competing demands for consumptive use expands.

Water NSW sees future applications in forecasting water demand for irrigation supply planning purposes.

Earth observations has the potential to provide spatially and temporally comprehensive information on a limited set of water quality variables, derived from reflectance information in the visible, near infrared and thermal infrared wavelength regions.

Optical remote sensing measures solar radiation reflected from the Earth's surface across the optical portions of the electromagnetic spectrum (visible, near and shortwave infrared wavelength regions). Because different aquatic materials such as suspended matter, chlorophyll pigments in phytoplankton, and bottom sediment interact differently with photons at different wavelengths, it is possible to detect the composition of water column constituents and, if visible, the substratum.

Indeed, using an understanding of the interaction of different wavelengths of light with different

materials (spectroscopy) is a fundamental method of many environmental measurements and traditional water quality monitoring techniques. By performing these measurements from spacecraft or aircraft, synoptic measurements are possible.

Earth observations can be used to establish environmental baselines as well as for understanding temporal changes. Environmental change detection can show temporal change (days to decades) and spatial change (0.4 m to 1 km spatial resolution) at local to global scales. It can be used for analysing processes such as hydrodynamics, eutrophication, carbon flows, and changes in biodiversity. For example, low spatial, high temporal resolution earth observation sensors can provide national level reporting and monitoring of water bodies, medium spatial and temporal resolution sensors can provide regional, state and river basin reporting, while high spatial resolution sensors are suitable for detailed reporting based on regional and local water management agency needs (Dekker and Hester 2012).

Earth observations has the potential for retrospective processing of archival images going back several decades.

### 6.4 Case study – Water NSW

Water NSW is responsible for developing infrastructure solutions for improved water supply and reliability, protecting water quality in its designated catchments, catchment protection in the Greater Sydney drinking water catchments, asset management, and flood operations and mitigation.

The Spatial Science work unit provides support for Water NSW's functions.

#### 6.4.1 Current EOS applications

EOS is used to monitor the condition of Sydney's drinking water catchment. It is used to examine vegetation conditions and disturbance (e.g. bushfires) and pasture conditions, monitor land cover changes and identify potential sources of pollution.

The application of EOS can be both short term, such as assessing the risk of run off from an area affected by bushfire, and longer term, such as examining longer-term changes in catchments (e.g. changes to grazing areas and what farmers might need to do to reduce risks of run-off events).

Water NSW uses satellite imagery from Landsat, Spot, Modis, World View 2 and 3 (Digital Globe products) and Pleiades. However, the first three are the main sources of data. Thermal (short wave infrared) and visual imagery are the main types of data accessed.

EOS data are used to inform the development of a healthy catchment strategy, which is in turn used to inform a wide range of users (government departments, local governments, graziers, regulators, etc.). Information such as fire fuel loads, severity of bush fires, etc. is also provided to other groups on request.

EOS data enables a reduction in the risk of water quality issues emerging through better planning and targeted actions.

#### 6.4.2 Potential future uses of EOS

One potential future project is mapping irrigated cropping across NSW. This will be used in forecasting models and be used to help manage water supplies.

The project will enable the organisation to better track water use by examining water use by irrigators, soil moisture content and the use of water by plants (evaporation), etc. The objective is to track water use and identify water deficits.

This will in turn help plan and inform water use, and help ensure that the correct amount of water is used on crops that allows the plants to grow and be healthy. Irrigation customers will have better information on their future water needs.

The project would also be able to identify possible water misuse, for example irrigators using water when none has been allocated.

The project is very likely to be approved and begin to be implemented by 2020 and then progressively rolled out up to 2025. This may be a service that is provided (possibly for a fee) to users.

Water NSW believes that the project would not be feasible without EOS as the costs would be prohibitive. The greatest risk to the project is the availability of good (fit-for-purpose) satellite imagery at a reasonable cost. If Landsat were unavailable, this would be a major problem as Digital Globe data is too fine a resolution and costs would be prohibitive. Conversely, Modis resolution is too coarse for the purposes of this project.

#### 6.4.3 Current benefits and costs of EOS

Water NSW believes that EOS is highly cost-effective. For example, Water NSW is required to report on land cover changes in Sydney's Drinking water catchment every four years as an Operating Licence requirement. Without EOS data, extensive field work would be required. Currently this reporting costs about \$30,000 with EOS data; without EOS the costs would be close to \$150,000.

Water NSW also believes that decision-making would be much more risky without EOS data. For example, the Pollution Source Risk Assessment Tool (PSAT) provides a decision-making tool for 4.7 million dollars of catchment intervention works as part of the Targeting High Risk Pollution Sources program in Water NSW's 2014-2015 Healthy Catchments Program. EOS provides critical input datasets into PSAT.

In addition, EOS enables Water NSW to meet its legislative, regulatory and service standard requirements at lower cost. It estimates that such costs would increase from \$100,000 to \$500,000 per annum in the absence of EOS.

The equipment purchased in relation to the use of EOS cost Water NSW approximately \$155,000 over 10 years. Over this period, research and demonstration costs were over \$1 million, while training costs were approximately \$30,000. Labour costs were approximately \$80,000 per year, while data costs were \$30,000 per year.

The annual total benefits of EOS to Water NSW is estimated to be  $(\$150,000 - \$30,000) + (\$500,000 - \$100,000) = \$520,000$ .

The average annual cost of using EOS for Water NSW is estimated to be  $(\$155,000 + \$1,000,000 + \$30,000 + \$80,000 + \$30,000) / 10 = \$129,500$ .

The average annual net benefit of EOS to Water NSW is therefore approximately  $\$520,000 - \$129,500 = \$390,500$ .

In 2012-13, NSW consumed 8,713,105 ML of water, which was 44.1 per cent of the Australian total (of 19,748,882 ML). Using this proportion, ACIL Allen estimates that the Australia-wide benefit of EOS to water authorities is currently approximately \$885,000 per year, assuming that Water NSW's peer organisations in other states and territories use and benefit from EOS in the same way.

#### 6.4.4 Future developments

It is highly likely that new and better monitoring products will become available as higher resolution sensors are adopted. These provide the opportunity for closer monitoring of catchments, vegetation types and land cover. These developments have been reported previously in Chapter 4.

### 6.5 Case study – CSIRO Water Resource Assessments

In the period 2006 to 2013, CSIRO undertook six water resources assessments focusing on different parts of regional Australia, as well as the South Eastern Australian Climate Initiative.

## KEY FINDING 11 – VALUE OF EOS TO WATER NSW

### 2015

The value of EOS to Water NSW and its peer organisations in other states and territories in meeting their Operating Licence, legislative, regulatory and service standard requirements is estimated to be approximately \$885,000 a year.

### 2025

The annual value of EOS to Water NSW and its peer organisations in other states and territories in 2025 is expected to be at least equal to its value in 2015, most likely higher.

Each of these projects has seen techniques and methodologies originally applied to the Murray-Darling Basin Sustainable Yields Project, the first of CSIRO's water resource assessments, adapted for regional conditions and varying levels of data availability. The other Sustainable Yields projects were undertaken in Northern Australia, Tasmania, south-west Western Australia, the Great Artesian Basin, and the Flinders and Gilbert water catchments.

CSIRO's activities included:

- fieldwork to collect data, establish the value, costs and risks of irrigated agricultural production or other water developments, and benchmarking of new production methods.
- region-scale geochemical and geophysical surveys to map salinity risks and connectivity, and surface and groundwater
- mapping land and soil agricultural suitability and production risks (such as salinity and floods) across agricultural, horticultural and pastoral systems

- topographic mapping and automated terrain analysis to identify and evaluate water storage and development options
- hydrodynamic and river modelling to assess the extent, magnitude and duration of floods, land suitability, and connectivity between surface water and groundwater
- assessments of potential environmental impacts under a range of climate and development scenarios and identify Indigenous water values
- socio-economic cost–benefit analyses, including demands placed on key resources under a range of development scenarios

Activity	Detail / example
Integration of pre-existing data and models to provide a consistent picture over time of water resources	This involved: <ul style="list-style-type: none"> <li>• the collection of existing models for different water sources in the region</li> <li>• critical assessment of the models, harmonisation of time periods and units across the models</li> <li>• integration with newly developed CSIRO models for each WRA and the SEACI.</li> </ul>
Characterising and quantifying climate and hydrologic variability	This involved: <ul style="list-style-type: none"> <li>• analysing hydro climate variability over annual, decadal and longer time scales;</li> <li>• long-term trends in climate and streamflow series, and;</li> <li>• large-scale ocean–atmosphere drivers of regional climate and changes to these drivers.</li> </ul>
Estimating climate change impacts on water	This involved: <ul style="list-style-type: none"> <li>• assessing and weighting global and regional climate models;</li> <li>• climate–water modelling to predict future water availability and river flow characteristics;</li> <li>• providing recharge estimates over large land areas and water systems.</li> </ul>
Hydrological modelling	This involved: <ul style="list-style-type: none"> <li>• attributing past and future changes in water availability to changes in climate inputs and changes in dominant hydrological processes;</li> <li>• quantifying biosphere influence on water availability through catchment vegetation;</li> <li>• modelling of individual catchment-scale hydrological processes (land cover change, high and low flows, surface water – groundwater interactions, and floodplain processes);</li> <li>• estimating changes in water balance components under future scenarios of land cover change;</li> <li>• developing a floodplain inundation model to predict the size, depth and volume of floodplain inundation.</li> </ul>
Developing measurement and modelling techniques to assess surface-groundwater interactions	This involved: <ul style="list-style-type: none"> <li>• comparing methods of estimating groundwater contributions to surface water flows and developing new methods where necessary;</li> <li>• developing modelling methodologies;</li> <li>• developing field-based approaches to determine the state of connectivity in losing rivers.</li> </ul>
Tailoring water resource assessments to water planning needs	This involved: <ul style="list-style-type: none"> <li>• communicating water availability projections to important stakeholders;</li> <li>• developing risk-based methods that can better utilise climate-water prediction to consider alternative water planning and adaptation options;</li> <li>• working with catchment, state and Australian Government agencies to incorporate climate-water prediction in basin and regional water sharing plans and climate adaptation options.</li> </ul>
Developing techniques to estimate and quantify uncertainty and probability in water resource models	This involved: <ul style="list-style-type: none"> <li>• providing a methodology to account for uncertainty in forecasts of groundwater flows;</li> <li>• exploring different options to deal with uncertainty in hypothetical future water allocations;</li> <li>• developing a range of benchmark techniques and methodology for recognising and estimating uncertainty in water supply forecasts.</li> </ul>

SOURCE: ACIL ALLEN; CSIRO

- information and data distribution through web-based information products, reports and regular community-based information sessions.

Table 6.1 provides further information on activities undertaken by CSIRO in relation to the Sustainable Yields assessments.

EOS was critical to many of the tasks listed above. For example, EOS was used for catchment characterisation, water resource modelling and irrigation projection, and for estimating future water requirements based on estimates of land under cropping.

The main (medium and low-resolution optical) data streams were from Landsat and MODIS, with spatial resolutions from 250 m down to 25 m.

EOS was also used to produce soil moisture maps of the top 5 cm of soil, using weekly passive and active microwave data streams from ASCAT.

#### 6.5.1 Benefits and costs

For estimating the impact in 2015, the following has been assumed:

##### Counterfactual

- CSIRO's WRAs and Sustainable Yields projects are less effective because they do not have the benefit of access to EOS technology.

##### Evaluation scenario

- The effectiveness of CSIRO's WRAs and Sustainable Yields projects is enhanced through the adoption and application of satellite imagery.

CSIRO's Murray-Darling Basin Sustainable Yields (MDBSY) project has delivered substantial value through its influence on the imposition of sustainable diversion limits (SDLs) in the Murray-Darling Basin. A CSIRO study found that the additional Basin-wide value of enhanced habitat ecosystem services (arising from floodplain vegetation, water-bird breeding, native fish and the Coorong, Lower

Lakes, and Murray Mouth) is worth between AU\$3 billion and AU\$8 billion in present value 2010 dollar terms, under a scenario of recovering 2,800 GL/year of water for the Murray-Darling Basin relative to the baseline scenario. ACIL Allen's analysis suggested that between 10 to 20 per cent of these impacts could be attributed to CSIRO's MDBSY project. In turn, 70 per cent of the research outputs of the project could be attributable to CSIRO. The benefits attributable to CSIRO therefore range from \$210 million (that is, 10% x \$3 billion x 70%) to \$1,120 million (that is, 20% x \$8 billion x 70%), with a mid-point of \$600-700 million.

As a lower estimate, CSIRO's WRAs are estimated to have delivered approximately \$685-795 million in economic and environmental benefits in present value terms. This is based upon

- the mid-point estimate of benefits delivered by SDLs in the Murray-Darling Basin, that are attributable to CSIRO's MDBSY (\$600-700 million), and
- a mid-point estimate of benefits delivered by Tasmania's Tranche 1 and 2 irrigation projects that are attributable to CSIRO's Tasmania Sustainable Yields project (i.e. the mid-point between \$60 million and \$120 million in benefits, which is \$85-\$95 million).

CSIRO research costs associated with the WRAs were \$54.2 million. Other costs include \$15-61 million in lost agricultural production as a result of MDBSY influence on the imposition of SDLs. (However, this is a short- to medium-term cost that will dissipate over time due to positive economic influence of increased water supply security and increased incentive to improve the water efficiency of agricultural production.)

TABLE 6.2 — EOS BENEFITS OF CSIRO WATER RESOURCE ASSESSMENTS AND SUSTAINABLE YIELDS PROJECTS		
	Low estimate	High estimate
<b>Murray-Darling Sustainable Yields project</b>		
Value of enhanced habitat ecosystem services	\$3 billion	\$8 billion
Attribution of benefits to CSIRO project	10%	20%
Internal attribution	70%	70%
Value of benefits attributable to CSIRO	\$210 million	\$1,120 million
Central estimate of value of benefits attributable to CSIRO	\$600 – 700 million	
<b>Tasmania Sustainable Yields project</b>		
Value of benefits attributable to CSIRO	\$60 million	\$120 million
Central estimate of value of benefits attributable to CSIRO	\$85 – 95 million	
<b>Total benefits</b>	<b>\$685 million</b>	<b>\$795 million</b>
CSIRO research costs	\$54.2 million	\$54.2 million
<b>Net benefits</b>	<b>\$630.8 million</b>	
Proportion of net benefits attributable to EOS	20%	
<b>Net benefits attributable to EOS</b>	<b>\$126 million</b>	
<b>Average net benefits per year attributable to EOS (2006 to 2015)</b>	<b>\$14 million</b>	
SOURCE: CSIRO AND ACIL ALLEN CONSULTING		

The net benefits of the CSIRO WRAs are therefore estimated to be at least \$685 million - \$54.2 million = \$630.8 million. If 20 per cent of this is attributed to the role played by EOS, then the net benefit of EOS to the WRAs is estimated to be approximately \$126 million or an average of \$14 million a year between 2006 and 2015.

The net benefit calculations are summarised in Table 6.2

The annual value of EOS to CSIRO in water resource assessments in 2025 is expected to be at least equal to its value in 2015, most likely higher. For the purposes of this report, we have assumed that it remains at \$14 million per annum.

## 6.6 Valuation of water savings enabled by EOS

By enabling better modelling of water usage/needs by irrigators, EOS can facilitate the efficient use of water and reduce unnecessary releases from water storages for irrigators. This is just one of multiple ways in which EOS can reduce surface and ground-water use.

A mooted project for mapping irrigated cropping across NSW is expected to lead to better modelling of current and future water usage/needs by irrigators. This will increase the efficient use of water and reduce ‘redundant’ releases from water storages for irrigators. Water is often released up to 20 days before it arrives to an irrigator – if it rains in the meantime, the irrigator may not use that water allocation and it continues to flow downstream. Better water usage and allocations will give NSW greater water security, especially for drinking water and agriculture. The research and implementation costs of the project are expected to be approximately \$1 million. Labour and data costs are expected to be \$150,000 per year and \$100,000 per year, respectively. Research for this report identified similar activities under consideration in other states.

A previous study by ACIL Tasman found that the value added of water used by industry could range from around \$1,000 per ML for agriculture to over \$50,000 per ML for minerals extraction and energy generation.<sup>14</sup> A pair of Productivity Commission reports released in 2010—one on

## KEY FINDING 12 – VALUE OF EOS IN CSIRO’S WATER RESOURCE ASSESSMENTS

### 2015

The value of EOS in enhancing the effectiveness of CSIRO’s Water Resource Assessments and Sustainable Yields projects is estimated to be \$14 million by 2015.

### 2025

The annual value of EOS to CSIRO in water resource assessments in 2025 is expected to be at least equal to its value in 2015, most likely higher. For the purposes of this report, we have assumed that it remains at \$14 million.

market mechanisms for recovering water in the Murray Darling Basin and the other on urban water pricing—estimated prevailing prices for water in urban and regional catchments to range from \$100 to \$500 per ML.<sup>15, 16</sup> A 2013 report by Deloitte Access Economics, estimated the economic value of groundwater to be \$200 per ML for irrigated agriculture, \$2,750 per ML for mining and \$2,000 per ML for manufacturing and other industries.<sup>17</sup>

According to the ABS, total water use in Australia in 2012-13 was 82,297 GL, while water consumption in that year was 19,749 GL (of which 17,898 GL was used by industry and 1,851 GL by households).<sup>18</sup> Water use includes water self-extracted by the electricity supply industry

## KEY FINDING 13 – VALUE OF EOS IN ENABLING WATER SAVINGS

### 2015

The value of EOS in reducing aggregate water consumption across Australia is estimated to be \$40 million a year.

### 2025

The value of EOS in reducing aggregate water consumption across Australia is estimated to be \$80 million a year.

for hydro-electricity generation, which is a non-consumptive use.

Using a conservative estimate of the value of water at \$200 per ML, if EOS currently enables a 1 per cent reduction in aggregate water consumption across Australia, the benefits would be approximately \$39.5 million per annum in 2015.

With expected technological advances in EOS and more ubiquitous use of EOS in agriculture and other industries, it is reasonable to expect EOS to facilitate a much higher level of saving. There is no published data or reports on such potential savings. Based on our consultations, however, it is considered reasonable to conclude that the level of water use efficiency savings by such monitoring activities could double to a 2 per cent reduction in aggregate water consumption across Australia from the 2012-13 level by 2025. If this were to eventuate, the benefits in 2025 would be approximately \$80 million by 2025 dollars.

14 ACIL Tasman (2010), *The Economic Value of Earth Observation from Space: A review of the value to Australia of Earth observation from space*.

15 Productivity Commission (2010), *Market Mechanisms for Recovering Water in the Murray Darling Basin*.

16 Productivity Commission (2010), *Developing a Partial Equilibrium Model of an Urban Water System*.

17 Deloitte Access Economics (2013), *Economic Value of Groundwater in Australia*.

18 ABS (2014), publication no. 4610.0 *Water Account, Australia, 2012-13*.

Organisation	Category	2015 \$ million	2025 \$ million
Water NSW and similar organisations in other jurisdictions	Monitoring water catchment condition, land cover changes and pollution sources	0.9	0.9
CSIRO	Enhancing habitat ecosystem services through sustainable diversion limits	14.0	14.0
Various industries	Enhancing efficiency in water use, including in irrigated agriculture	39.5	80.0
<b>Total</b>		<b>54.4</b>	<b>94.9</b>
SOURCE: ACIL ALLEN			

## 6.7 Summary of EOS benefits for water

Three examples of the application of EOS in relation to water were studied for this case study:

- use of EOS by Water NSW
- CSIRO water resource assessments
- the value of water use efficiency savings.

The findings are summarised in Table 6.3.

The combined benefits of EOS in relation to water across the three examples are estimated to be approximately \$54.4 million in 2015. These are expected to increase to \$94.9 million by 2025,

## 7 NATURAL HAZARDS AND INSURANCE

### 7.1 Introduction

Imagery from satellites is crucial for managing disaster events where impacts can occur across very large areas. In many cases, the disaster event may lead to serious disruptions in normal earthbound communications and severely limit the ability to obtain timely information by means other than satellites.

The Australian Academy of Science (2008) noted that emergency services authorities at the Commonwealth, state and local government level all utilise EOS information in the four phases of disaster management: planning; preparedness; response; and recovery (AAC, ATSE, 2008).

In the response and recovery stages, timeliness is critical as disaster events often disrupt communication and transportation services, hampering relief efforts. Information is required not only in major population centres, but also at various scales over all of Australia and its surrounding waters. This information is often provided by satellite imagery.

Emergency management services organisations are particularly important users of EOS data. Better and earlier forecasts of extreme weather events (including heat waves) help them to plan more timely responses to events that can reduce the amount of damage to property and the incidence of personal injury or death. EOS can help manage and mitigate the impact of disasters such as extreme weather (cyclones, storms, heat waves), bush fires, flooding and volcanic eruptions.

### 7.2 Current EOS applications

Specific current applications of EOS in relation to natural hazards and insurance are discussed below.

#### BOX 7.1 – INDUSTRY DATA GLOBE

The ICA Data Globe project coordinates insurance company access to an extensive database of natural hazard information, including flood, earthquake, bushfire, and storm surge and cyclone exposures at an individual property level. The data stored on the Data Globe are sourced from governments (including local governments).

Data collected by the ICA is available to participating stakeholders in common GIS formats and can be visualised in a web browser at resolutions that allow identification of individual addresses.

Although providing hazard data to insurers is an important step to assist with accurate risk calculation, the tool also helps to identify where hazard mapping is missing, or where mitigation efforts to reduce existing hazards may deliver an insurance affordability outcome for local residents.

The Data Globe contains information such as:

- the location of earthquakes, bushfires, cyclone tracks
- digital elevation models for determining flood risk
- information on the location of individual properties.

SOURCE: [HTTP://WWW.INSURANCECOUNCIL.COM.AU/AFFORDABILITY](http://www.insurancecouncil.com.au/affordability),  
ACCESSED 30 JANUARY 2015.

### 7.2.1 Insurance

The insurance industry also uses EOS data to help it understand and estimate future average annual damage, which it uses to set premiums. It also uses EOS data to help manage claims. The Insurance Council of Australia (ICA) operates an Industry Data Globe (GIS based) that provides information to insurers for these purposes (see Box 7.1).

The data made available help to improve the assessment of risk by insurance companies and reduce costs by targeting insurance to different risk profiles. It also helps to reduce false claims, thus reducing the overall demand on insurance reserves, which in turn helps lower insurance premiums.

All the data on the Data Globe is provided by governments. For example, the Queensland Government has a memorandum of understanding (MOU) with the ICA under which the Department of Natural Resources and Mining (DNRM) provides ICA (at no cost) with:

- access to all State Government-held elevation data (DEMs)
- all subsequent elevation data acquired as part of its forward program
- ongoing access to flood mapping developed in the State.

Under the MOU, the DNRM and ICA will also work together to identify areas of the State lacking detailed elevation data and flood mapping information.<sup>19</sup>

### 7.2.2 National Flood Information Data Base (NFID)

In 2008, as part of a project to increase the availability of flood insurance for the Australian community, the general insurance industry developed an address-level flood exposure database using

existing government flood mapping. The NFID, is funded and managed by the insurance industry. It combines all available government flood-mapping data into a format that is practical for underwriting of flooding risks at address level, rather than at postcode or lower resolutions.

Where a local or state government has provided flood mapping of an appropriate standard, The NFID provides participating insurers with estimations for the depth of flooding (if any) at each individual address for the one-in-20 year, one-in-50 year, one-in-100 year and Probable Maximum Flood (PMF) events. This allows an underwriter to consider what premium may be applicable, given the nature of the building at that location.

As a result of flood data becoming available, access to flood insurance has increased from 3 per cent of household policies in 2006 to 93 per cent of policies sold today. Where no flood mapping is available, insurers will generally adopt a very conservative approach to setting premiums.

### 7.2.3 Property Resilience Exposure Program (PREP)

The natural disasters that Australia has experienced since 2010 have caused billions of dollars of damage. These events have highlighted the importance of having communities and properties that are durable and resilient to extreme weather.

Constructing permanent physical mitigation infrastructure to protect at-risk towns and cities, where it is feasible, and policies to help improve community resilience, are essential if communities that are regularly affected by extreme weather are to survive and prosper.

The Insurance Council of Australia's Property Resilience Exposure Program (PREP) provides local government and the insurance industry with more

<sup>19</sup> ICA Media release, *Insurers and Queensland Government work together to address insurance affordability*, 16 October 2013.

robust information on the resilience of housing stock. PREP seeks to improve the alignment between the data and hazard mapping relied upon by insurers to price risk. It also enables councils and shires to understand the relationship between hazard exposure, building vulnerability and risk premiums, while also providing information to assist in the design of government mitigation programs by identifying possible insurance affordability benefits that might result from different mitigation options.

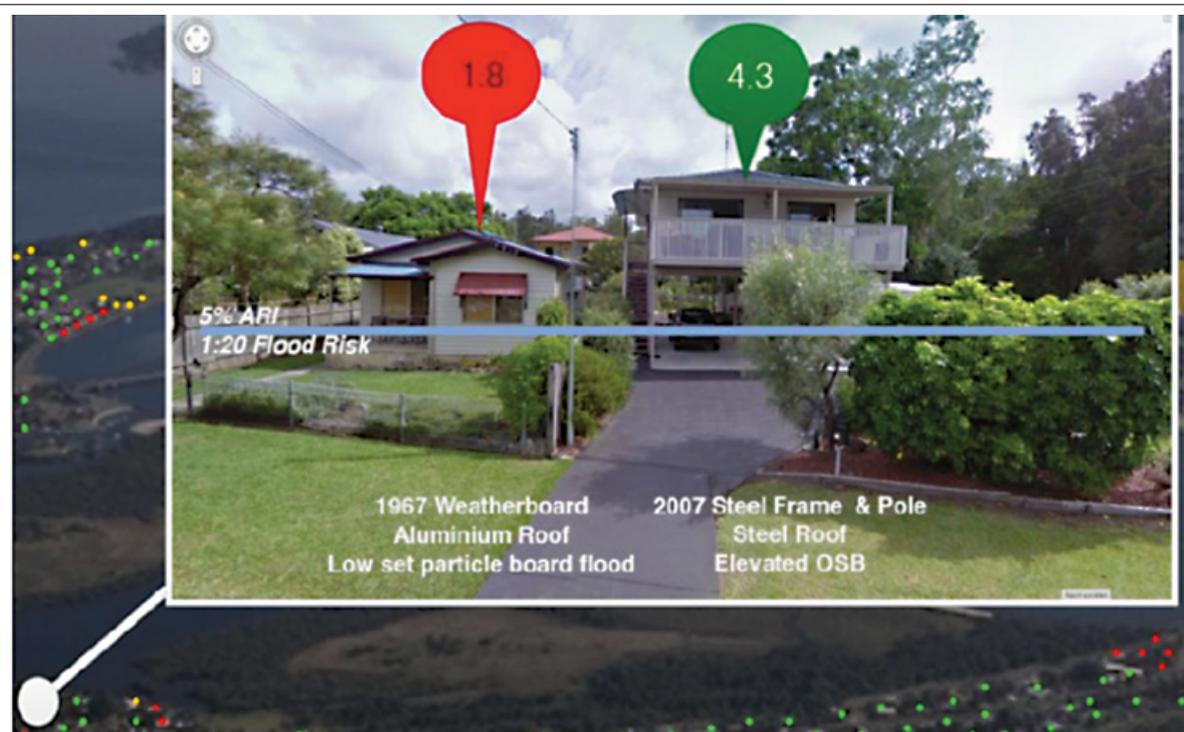
PREP has four modules:

- Module 1 – Existing hazard mapping provided by a participating local government that meets a minimum standard.
- Module 2 – Building survey data for all addresses provided by a participating local government, that insurers can use to recognise the resilience many properties already have by virtue of existing development controls.

- Module 3 – A resilience heat map provided by the PREP process for participating local governments. PREP will identify areas where properties are at risk (through poor design and building controls), and identify those that may require high-priority mitigation and intervention to reduce the potential impact of the hazard on that community.
- Module 4 – Best-available hazard data and building information for underwriters. This improves their capacity to price risk at an individual address level, and to acknowledge the full benefit that local development controls and mitigation may have delivered in reducing property owners’ vulnerability to extreme weather.

Figure 7.1 illustrates how PREP can help measure the ability, at address level, for buildings to resist an extreme weather event (such as a flood) based upon their design, construction and materials used.

FIGURE 7.1 – ILLUSTRATION OF HOW PREP COMPARES FLOOD RISK



SOURCE: [HTTP://WWW.INSURANCECOUNCIL.COM.AU/AFFORDABILITY](http://www.insurancecouncil.com.au/affordability), ACCESSED 30 JANUARY 2015.

#### 7.2.4 Extreme weather

Early warnings of extreme weather events are important to many industries in Australia. For example, the transport sector is concerned about the impact on their ability to transport goods around the country, while the agriculture sector relies on this sort of information to help them manage risks to their crops or livestock. Early warnings are also crucial to the resources sector, which may lose millions of dollars in production if they are unable plan for such events (this is discussed further in the Weather Forecasting Case Study).

Geoscience Australia's Community Safety Branch uses land cover maps derived from satellite images and data on elevation (available in GA as well) to produce wind multipliers. These take into account local effects such as terrain, shielding and topography of the land to predict local wind speeds based on regional wind speeds. The calculations use the Australian Wind Loading Standard AS/NZS 1170.2:2011. Understanding local wind speeds is important in managing potential hazards and reducing risks.

#### 7.2.5 Heat waves

The extended periods of high temperatures associated with heat waves tend to increase death rates among the elderly and persons suffering from illness. Better forecasts about heat waves would enable governments to better plan for such events and reduce the impact on the at-risk population.

A study into protecting human health during extreme heat events was published in November 2011.<sup>20</sup> It found that while 173 people died in the Black Saturday fires in Victoria in 2009, more than 370 people died from the extreme heat in Victoria in the same week as the Black Saturday fires.

The report found that deaths are likely to increase with population growth, ageing and climate change. It found that:

*By 2050, an extreme heat event in Melbourne alone could typically kill over one thousand people in a few days if we don't improve the way we forecast, prepare for and manage these events.*

#### 7.2.6 Bush fires

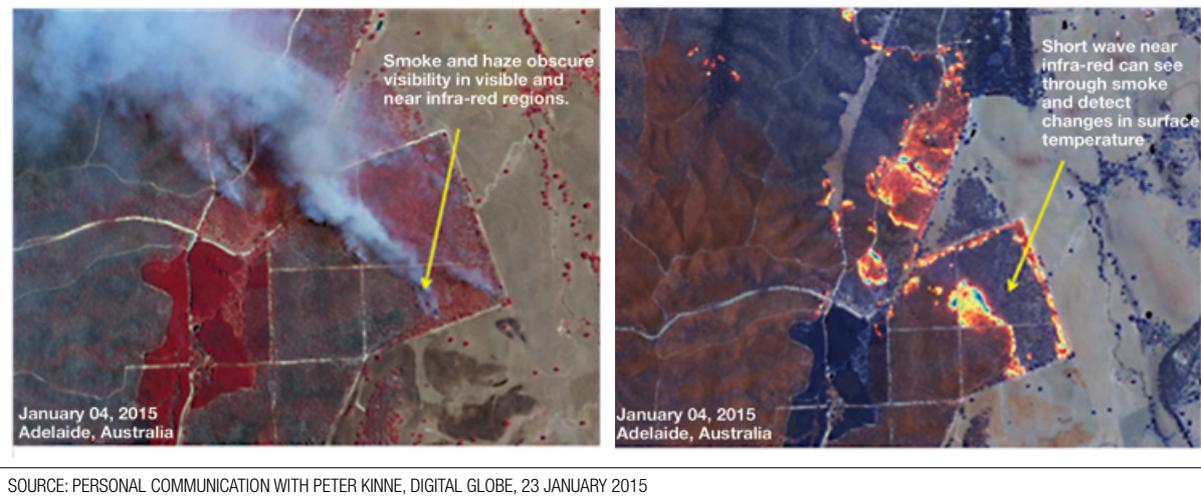
The Bureau of Meteorology uses EOS data for grassland curing (dying) mapping. They can produce near-real-time maps of grassland fuel state. These are used operationally by fire agencies in some states to plan bushfire management, assess fire risk levels and declare fire bans, and by the Bureau of Meteorology as an input to Fire Danger Indices.

Fine-grained information on wind speed is also important for better risk assessment and risk management associated with bushfires. The current resolution of land cover data used by Geosciences Australia is 250 metres. The resolution of the digital elevation model (DEM) is about 30 metres. They hope in the near future to have a land cover product with 25 metre resolution. The higher resolution EOS data is expected to greatly improve the accuracy of the wind multiplier information both in terms of location and on the ground wind strength.

Geoscience Australia operates the Sentinel hotspots service. This is a national bushfire monitoring system that provides timely information about hotspots to emergency service managers across Australia. The mapping system allows users to identify fire locations with a potential risk to communities and property. The service uses data from the NOAA 18 and 19 satellites.

<sup>20</sup> *Protecting human health and safety during severe and extreme heat events – A national framework*, PWC, November 2011.

FIGURE 7.2 – COMPARISON OF A NORMAL AND SWIR IMAGE



The data provided through the Sentinel program enables the edge of a fire to be tracked. The higher the frequency of the satellite pass the better the information is from the perspective of tracking the fire movement.

During the bushfires in South Australia in early January 2015, Digital Globe was able to advise the SA Government about which buildings had been damaged or destroyed within 24 hours, well before the area was safe for emergency personnel to access. This allowed the government to begin to assist affected persons much earlier than would otherwise have been the case.

The Defence Science and Technology Organisation (DSTO), in collaboration with the Australian Geospatial-Intelligence Organisation (AGO), was instrumental in initiating the collection of sophisticated satellite imagery during the same bushfire. A DSTO researcher was familiar with the Short Wave Infrared (SWIR) sensor capability on the WorldView-3 satellite (owned and operated by US company, Digital Globe), including its ability to ‘look through’ the smoke and haze created by wildfires (see Figure 7.2).

Upon hearing reports of heavy smoke inhibiting the emergency response, DSTO was quick to identify the potential value of this technology to the South Australian Country Fire Service (CFS).

The imagery, licensed by Defence from Digital Globe, was delivered directly to the CFS headquarters where it was used to assist in mapping the impacted area and active fire fronts. It was also used to help identify unaffected properties, assist the CFS’s fire suppression efforts and provide clear and accurate information to the public about the fire’s size and extent.

#### 7.2.7 Flooding

Earth observations, particularly digital elevation measurements, are important inputs for activities such as flood plain mapping, flood zoning and better planning of developments in the flood plain. In remote areas, using data from satellites is more cost effective than airborne photography. Satellites can also provide digital elevation data to support flood mitigation planning at the catchment level.

Satellite optical imagery can be used to provide more regular monitoring of water movements during and following major storm events when the ability of aircraft to provide aerial photographs may be compromised.

Geoscience Australia operates the National Flood Risk Information Portal (NFRIP) and the Water Observations from Space Portal.

Following the devastating floods across eastern Australia in 2011, the Australian Government initiated the Natural Disaster Insurance Review. This review highlighted the lack of consistency across the country in the way flood risk information was collected and made available to users. The review also recognised the need for consumers to be aware of the natural disaster risks they may face, as well as the benefits of making flood risk information more readily accessible.

The National Flood Risk Information Project has the potential to transform how future flood risk information is produced and distributed. Through the development of guidelines and standards, NFRIP can improve the quality of new flood studies, and improved access to flood information will benefit many sectors.<sup>21</sup>

Flood studies, models and maps are critical inputs to land cover planning and emergency management, as well the design of infrastructure such as buildings, roads and bridges. Flood information is also a fundamental requirement to ensure appropriate assessment of flood risk, and the subsequent pricing of flood insurance.

Water Observations from Space is a web service displaying historical surface water observations derived from satellite imagery for all of Australia from 1987 to the present day. The service aims to allow better understanding of where water is usually present, where it is seldom observed, and where inundation of the surface has been occasionally observed by satellite. The service displays the detected surface water from the Australia-wide Landsat 5 and Landsat 7 satellite imagery archive.

Airbus Industries indicated that their radar satellites can also map flood events at higher frequency.

#### 7.2.8 Emergency response intelligence capability (ERIC)

In the aftermath of a natural disaster, the Department of Human Services manages two business needs: continued and safe operation of ‘business as usual’ in affected areas, and administration/delivery of extra support for citizens directly affected. These business needs are met through the regular preparation of Situation Reports that provide the information needed to support decision making by executive managers.

A partnership between the Department and CSIRO has developed a software tool called ERIC (Emergency Response Intelligence Capability) to help the Department to better plan its responses to natural disasters. The ERIC software automatically collects information about an event from multiple authoritative electronic sources (such as Sentinel hotspots data) and integrates this with demographic information from the Australian Bureau of Statistics and aggregate customer data from the Department into a single national picture.

ERIC allows the Department of Human Services to perform the intelligence gathering and collation tasks faster and more comprehensively than previously, allowing more time for situation analysis.

ERIC was successfully tested during two major bushfires in Tasmania and NSW during the bushfire, cyclone and flood disaster season of October 2012 to March 2013.

<sup>21</sup> <http://www.ga.gov.au/scientific-topics/hazards/flood/nfrip>, Accessed on 27 August 2015

### 7.3 Future EOS benefits

It is understood that a nationally coordinated emergency mapping facility has been developed that will bring Australia in line with international norms for emergency management. Policy makers anticipate that this kind of information could help reduce natural disaster payment fraud, increase the effectiveness of response and recovery efforts, and lower the costs associated with disasters.

Many of the applications in emergency management will benefit from greater frequency of satellite passes and higher resolution data. The benefits would be timelier forecasts and more accurate tracking of emergency events.

Greater precision in forecasting and climate modelling will come from increased frequency of data that can be provided by Himawari 8, for example.

### 7.4 Assessment of current and future benefits

The costs of natural disasters throughout Australian history are substantial. Between 2000 and 2012 alone, the insured losses (borne by insurers) totalled \$16.1 billion, an average of over \$1.2 billion per year.

Insured losses represent only a proportion of the total economic costs of natural disasters. Total economic costs incorporate broader social losses related to uninsured property and infrastructure, emergency response, and intangible costs such as death, injury, relocation and stress.

Research conducted by the Bureau of Transport Economics (BTE) in 2001 attempted to estimate the total economic costs borne by Australians due to natural disasters.

Using data from disaster events which occurred between 1967 and 1999, and restricting the analysis to cases where the total estimated cost exceeded

\$10 million, it was found that total economic costs were between two and five times greater than insured costs alone for most natural disasters (BTE, 2001).

Using Insurance Council of Australia data on the incidence of past natural disasters in Australia (ICA, 2013), Deloitte Access Economics developed forecasts of the likely future costs of natural disasters. The methodology for these forecasts is explained in Box 7.2.

The forecasts presented capture three separate measures of expense: insured costs, total economic costs, and costs incurred by governments. Insured costs represent the payouts made by insurance companies in response to eligible policy claims. To these costs are added broader social costs that would not otherwise have been incurred had a disaster not taken place. The final additional costs relate to the likely financial obligations of local, state and federal Governments.

In 2011, the total economic costs of natural disasters in Australia was estimated to average around \$6.3 billion per year. In real terms, this total was forecast by Deloitte Access Economics to grow by 3.5 per cent annually. This is primarily due to the likely impact of further population growth, concentrated infrastructure density, and the effect of internal migration to particularly vulnerable regions. With this growth rate, the annual total economic cost of natural disasters in Australia is expected to double by 2030 and reach \$23 billion in real terms by 2050 (see Figure 7.3).

EOS can reduce the economic cost of natural disasters in several ways:

- It reduces the probability of a disaster from occurring by improving mitigation strategies (for example, by enabling better management of vegetation in fire-prone areas to reduce fire risks)

## BOX 7.2 – DELOITTE ACCESS ECONOMICS' METHODOLOGY FOR FORECASTING FUTURE COST OF NATURAL DISASTERS IN AUSTRALIA

Deloitte Access Economics' forecast of the future cost of natural disasters were based on the historical frequency and severity of natural disasters in Australia. The process applied to generate the forecasts of insured losses can be summarised in the following steps:

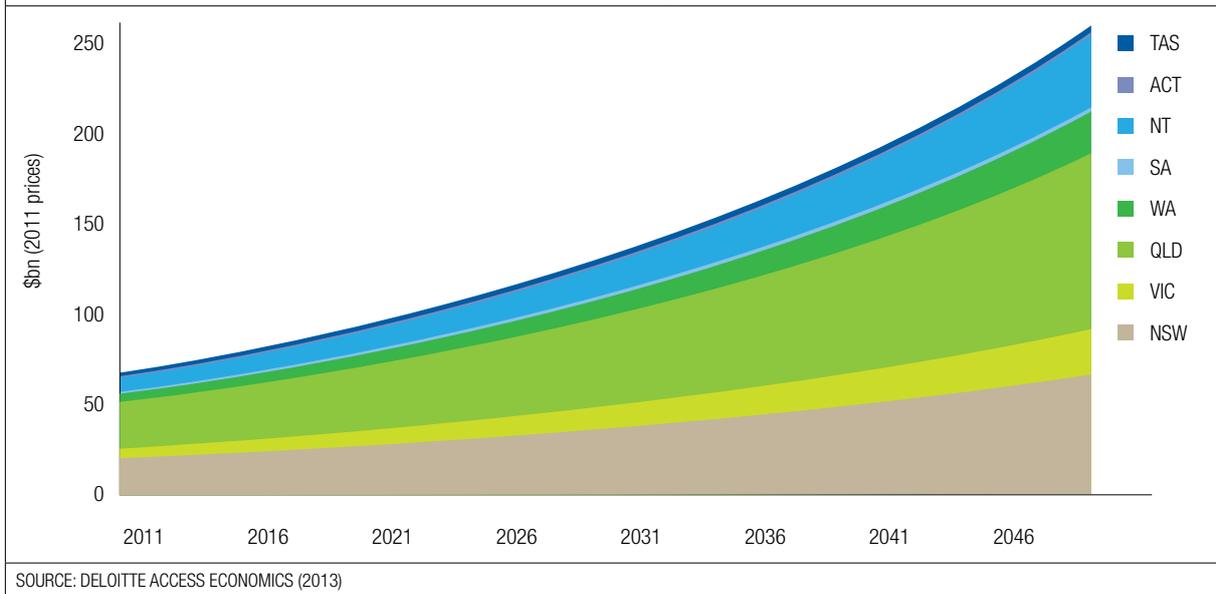
1. Data on natural disaster events was gathered from the Insurance Council of Australia's database of natural disasters (ICA, 2013).
2. For each state, the historical data was first used to identify the distribution of the number of natural disaster events each year.
3. For the forecast period, the number of natural disaster events per year was simulated from this historical distribution. This gave a total number of events to be simulated for each state for each year of the forecast period.
4. Each natural disaster event was then simulated using a bootstrapping procedure. This involved randomly selecting a historical event from the ICA database and incorporating some additional random variation in severity of the event to represent tail risk not captured in historical data.
5. The bootstrapping procedure was carried out 1000 times to provide a reliable estimate of both the distribution of natural disaster costs that could be expected, as well as the average annual natural disaster cost in each state.
6. The resulting simulated costs were then indexed to account for growth in the number of households and increases in the value of housing stock. This index was constructed from the Australian Bureau of Statistics (ABS) population growth forecasts (ABS catalogue number 3236.0), as well as extrapolating trends in ABS data on housing value (ABS catalogue number 4102.0). It was assumed that growth rates for the value of housing in each state converged in the long run towards the national average.

To obtain predictions of total economic costs, the multipliers for different natural disaster types reported by the Bureau of Transport Economics (2001) were applied to the insured loss data. To ensure the relevance of these multipliers, they were checked against Deloitte access Economics' estimates of the relationship between insured costs and total economic costs.

In order to forecast the costs to government, the effects of historical disaster costs on the level of Natural Disaster Relief and Recovery Arrangements (NDRRA) expenditure was analysed. It was found that each dollar of insured natural disaster costs generally led to around 32c of Australian Government expenditure in the year following the natural disaster, 22c in the next year and 13c in the third year. The use of the funding rules set out in the NDRRA determination allowed for total government costs to be estimated and to be apportioned between the Australian Government and the states.

SOURCE: (DELOITTE ACCESS ECONOMICS, 2013)

FIGURE 7.3 – FORECAST TOTAL ECONOMIC COST OF NATURAL DISASTERS, 2011 TO 2050



- It reduces the impact of natural disasters on humans and livestock (for example, by facilitating re-location from flood-prone areas that are more clearly identified through better quantification of flood risks)
- It can, in some cases, improve the response of emergency crews during a disaster and its immediate aftermath, thereby potentially reducing the number of deaths and injuries as well as the extent of damage to property.

#### 7.4.1 Benefits in 2015

For estimating the impact of EOS on natural hazards and insurance in 2015, the following have been assumed:

##### Counterfactual – without EOS scenario

- EOS is unavailable to reduce the probability of natural disasters in Australia, moderate their impacts or improve the responses to them.

##### Evaluation case – with EOS scenario

- EOS reduces the probability of natural disasters, moderates their impact and/or improves the responses to them so that the economic costs of natural disasters in Australia are reduced by 2 per cent.

In its 2010 report, ACIL Allen examined a sample of natural disaster cost estimates to estimate a high-level average annual damage cost of natural disasters of \$2 billion per annum. This estimate focused mainly on the cost of fires and flooding. Of this amount, 5 per cent was attributed to the value of EOS in mitigating the cost of natural disasters.

The Deloitte Access Economics report is a more contemporary estimate based on modelling of a wider range of events. The estimates in this report suggest that the total economic costs of natural disasters in Australia in 2015 would be \$7.1 billion. Because this estimate is based on a wider range of natural disaster events, it is considered appropriate to reduce the contribution from EOS to 3 per cent in recognition of the fact that the responsiveness of costs of fires and floods to EOS supported systems is likely to be higher than for a wider range of events.

On this basis, the economic impact of EOS in mitigating the cost of natural disasters in 2015 would be \$213 million (see Appendix B.9).

7.4.2 Benefits in 2025

For estimating the impact of EOS on natural hazards and insurance in 2025, the following have been assumed:

Counterfactual

- From 2015 onwards, there are no further advances that would enable a further reduction in the economic costs of natural disasters in Australia.

Evaluation case

- Advances in EOS between 2015 and 2025 further reduce the probability of natural disasters and their impacts while further improving the responses to them.

Deloitte Access Economics’ modelling indicated that the total economic costs of natural disasters in Australia in 2025 would be approximately \$9.9 billion.

In the decade to 2025, ACIL Allen expects that technological advancements in EOS will enable it to have an even greater ability to ameliorate the impacts of natural disasters in each of the three ways identified above. It has therefore been estimated that the contribution of EOS to amelioration of costs of natural disasters would have risen from 3 per cent to 5 per cent.

**KEY FINDING 14 – VALUE OF EOS TO REDUCING THE ECONOMIC COSTS OF NATURAL DISASTERS**

**2015**

The value of EOS in reducing the economic costs of natural disasters in Australia is estimated to be approximately \$213 million in 2015.

**2025**

The value of EOS in reducing the economic costs of natural disasters in Australia is estimated to be approximately \$495 million in 2025.

Under these assumptions, the value of EOS for this purpose would have risen to \$494 million (see Appendix B.9).

7.5 Summary of EOS benefits for natural disaster management

The findings for the case study in natural disaster management are summarised in Table 7.1.

TABLE 7.1 – SUMMARY FOR CASE STUDY IN NATURAL DISASTERS			
Various industries, government and the community	Category	2015 \$ million	2025 \$million
Natural disasters	Insured costs plus social costs	213.0	4950
<b>Sub total</b>		<b>213.0</b>	<b>495.0</b>
SOURCE: ACIL ALLEN			

## 8 ONSHORE MINING

### 8.1 Introduction

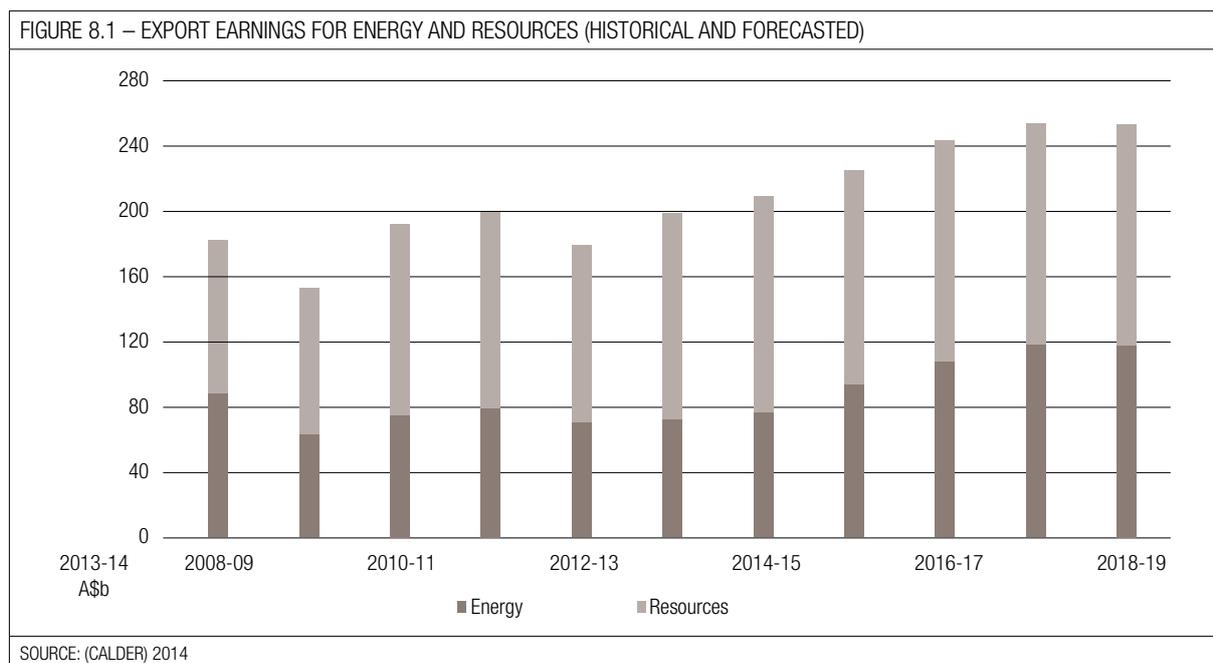
The Australian mining industry is one of Australia's most important industry sectors, contributing around 8 per cent to Australia's GDP, with an industry value add of 125 billion in 2013-14.

The industry employed around 108,000 FTEs in 2013-14. The mining industry also stimulates economic activity in other areas of the economy including design and construction, manufacturing and services. Investment by the mining industry has been an important driver of overall economic growth for the Australian economy.

The recent downturn in the outlook for commodity prices has moderated expectations of mining activity and output over the near term. The Reserve Bank and other commentators have pointed out that the Australian mining industry is in transition from an investment phase to a production phase. While this is likely to have a substantial impact on the Australian economy, it does not imply a decline. The Bank's Head of Economic Analysis, Alexandra Heath, noted at a recent conference:

*“The dramatic increase in Australia’s capacity to export commodities, along with similar responses from other resource producers around the globe, has increased global supply relative to global demand to the point where prices for these commodities have fallen. Supply will continue to respond to, and affect, commodity prices, and while the growth of Chinese demand is slowing, many of the long-term drivers of the original increase in demand for commodities from China are still in play. The Chinese economy is continuing to evolve in ways that will support demand for resources, and the sheer size of the economy suggests that these demand forces will, over the medium to long term, remain strong.”* (Heath, 2014)

The mining industry can expect continued but perhaps more modest growth in the next decade (see Figure 8.1).



EOS services are used in the mining industry for a number of purposes. As mines move into the production phase there is likely to be ongoing demand for EOS for mine site monitoring, stock-pile management and environmental and land cover monitoring to meet regulatory requirements.

## 8.2 Current EOS applications

### 8.2.1 Exploration

EOS is used in minerals exploration as an aid to identifying potential mineral deposits. The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) is an imaging instrument on NASA's Terra satellite. Geoscience data available from ASTER's 14 spectral bands is specifically designed to detect key minerals groups including di-octahedral "Al-OH" clays (e.g. kaolins, white micas and smectites), tri-octahedral minerals (e.g. chlorite, amphibole, talc and serpentine), silicates (quartz and garnets), carbonates and iron oxides.

The Australian ASTER Initiative that is led by CSIRO's Western Australian Centre of Excellence for 3D Mineral Mapping, is a collaborative project between state, national and international agencies. The ASTER Geoscience Maps are a web-accessible, continent-scale product from the ASTER Global Mapping data archive.

According to industry representatives consulted for this project, the ASTER Map has become the default base map for exploration. It is an important tool to assist with target generation by exploration geologists and has become one of the layers of information on which they depend. The ASTOR map is of particular interest to small to medium sized companies. These companies are often the most active in greenfields exploration onshore.

### 8.2.2 Monitoring by mining companies

The societal and environmental impacts of mining attract significant interest from society; perhaps

more now than in the past. Mining companies are under increasing pressure to minimise the environmental impacts of their operations including land cover change, waste rock and tailing disposal, dust and noise, and water use and re-use.

One of the challenges facing the mining industry is to develop objective, reliable, affordable and reproducible methods to identify, understand, observe, characterise, measure and map the impacts of their mining operations and to monitor them over time. Remote sensing from EOS plays an important role in producing this information.

From the late 1980s and in the 1990s, several programs began to foster the use of EOS applied to environmental concerns. The Superfund program in the US (a federal government program led by the Environmental Protection Agency (EPA) and the United States Geological Survey (USGS) to clean up the nation's uncontrolled hazardous waste sites) demonstrated the capabilities of EOS methods, in particular Hyperspectral AVIRIS Imaging in mapping hazardous wastes. Meanwhile, the development of the Hy-Map sensor in Australia and the involvement of CSIRO fostered the use of imaging spectroscopy in this domain.

In Europe, the PECOMINES project using conventional satellite sensors and the FP5 MINEO project using HyMap hyperspectral images were cornerstone projects focusing on mining related environmental concerns. However, neither of these projects made an integrated use of all available earth observation tools and techniques, and they lacked integration of satellite, airborne and in situ monitoring technologies.

The use of the remote sensing approach in the investigation of environmental impacts caused by mining to address issues like acid mine drainage (AMD), watershed pollution, subsidence and ecological footprint is replacing older methods such as aerial photography and ground-based

monitoring. Until recently, satellite imagery lacked the spatial, temporal and radiometric resolution to compete, especially at small scale and in the quantification of target materials. However, new satellite systems offer opportunities for data collection both in the optical part of the electromagnetic spectrum and in the microwave wavelength region. Falling instrumentation costs is lowering costs per square kilometre and stimulating the development of suitable models for data analysis, time series analysis and data assimilation techniques as well as the development of quality measures and quality standards.

In Europe, the EO-Miners initiative is enabling mining companies and regulatory authorities to monitor the sustainability of mining and mining-related activities. A dialogue among mining companies, regulatory bodies and other stakeholders, conducted in the Czech Republic, Kyrgyzstan and South Africa, identified 11 environmental and socio-economic indicators affecting mining communities and the natural habitat near mining operations. Integrating these indicators into EOS tools is helping governments develop policies that are more effective and regulations around mining activities that balance commercial objectives, environmental management, and the interests of the local community. Sound environmental management of mining activities can avoid high remediation costs, thereby preserving public and private capital.

Supported through the European Commission's FP7 Programme (EC-FP7), the multi-sector EO-Miners consortium includes the German Aerospace Center (DLR), government geological agencies from the Czech Republic, France, Slovenia, South Africa and United Kingdom; mining companies from the Czech Republic, Kyrgyzstan and United Kingdom; and research organisations and universities from France, Germany, Israel and Kyrgyzstan.

## 8.3 Case study – monitoring mining and coal seam gas operations

### 8.3.1 Meeting regulatory reporting requirements of Government

All mining projects are required to report changes to land cover, environmental impacts and remediation as part of the operating licence. This can include changes to vegetation coverage, evidence of subsidence and sustainability reporting. Land cover reporting can vary from providing a general description of vegetation coverage to identifying specific types of vegetation. Evidence of reinstatement after mining operations is also required by environmental agencies as part of the reporting cycle.

### 8.3.2 Planning and liaison with government

Mining operations involve significant consultations in the course of planning and executing operations. For example, in remote areas mines often share road maintenance costs with local government. This requires maintenance of detailed records of road use and maintenance activities. Satellite imagery is used for evidence-based planning and consultation in these cases.

Mining operators must also monitor the proximity to waterways to ensure that their activities do not pollute or contaminate surface and ground water resources. Satellite imagery is used to map waterways and monitor operations in close proximity to waterways.

### 8.3.3 Financial assurance

Mining operations must manage the financial risks associated with potential environmental damage. The penalties and potential legal costs resulting from environmental damage can be significant. In extreme cases, it could affect a company's financial position and its access to future production licences.

Mining companies insure against the risk of environmental damage. Their insurance costs can be minimised through careful management of environmental damage risks.

#### 8.3.4 Data requirements

Mining companies generally gather information from more than one source. They tend to use EOS, airborne surveys and increasingly unmanned aerial vehicles (UAVs) to capture data. EOS, however, has a cost advantage where periodic surveys are required to monitor landscape changes over time. The most common requirement is for multiband spectral – red, green, blue (RGB) and near infrared. Near infrared is sensitive to different types of vegetation but sometimes the mapping is too coarse and must be reinforced by other data including aerial surveys and UAVs. Aerial surveys compete with EOS but they have the disadvantage of the need for scheduling and are not as flexible as EOS. UAVs are generally only used where detailed data is required.

A typical aerial survey costs around \$8,000 to \$10,000 per area based on around an hour's flying time. Costs of aerial surveys have fallen in recent months with the downturn in mining construction activity in Queensland in particular.

The cost of a satellite contract is around \$200,000<sup>22</sup> per year. With the advantage of wide coverage and flexible survey times, EOS is reported to be more competitive than aerial surveys for ongoing monitoring. Regulatory authorities generally require annual reporting which leads mining companies to source EOS data either 6-monthly or annually.

#### 8.3.5 Economic impact in 2015

Estimating the economic value of the contribution of EOS to maintaining a licence to operate is challenging. There is no readily available data on the likely size of the market and some of this data is commercial in confidence. It would also be difficult to estimate the cost of alternative approaches to doing the same job. To quote one respondent from a mining company, EOS has become so embedded in parts of exploration and mining activities that it is hard to conceive of doing their job without it.

<sup>22</sup> Personal communication with mining companies and providers.

#### Counterfactual – without EOS scenario

For practical purposes, the case without EOS would most likely result in higher monitoring costs for mining companies in terms of land and aerial surveys, higher labour costs and less efficient development of mining in general, with longer time required to plan and gain approvals. One company reported that it would need to hire one additional staff member for reporting purposes and engage in more aerial and land surveys.

#### Evaluation case – with EOS scenario

This is the current situation where the use of EOS is increasing as new mining and coal seam gas projects are developed across the nation. Demand is likely to increase as projects move from the development to production stage and the monitoring and reporting tasks increase.

#### Assessment

For evaluating a net benefit, we have assumed that the impact of the counterfactual case would be derived from:

- higher monitoring costs
- a slower rate of development of mining and petroleum projects as a result of risk averse regulation
- less effective management of vegetation and mining impacts.

Based on our consultations we have estimated mining industry expenditure on EOS to be in the order of \$5 million per year. This represents 0.003 per cent of total operating costs of \$177 billion for the mining industry in Australia (ABS, 2015).

Based on discussion with selected companies, we have estimated that the cost of monitoring would at least double to \$10 million if there were no access to EOS for the purpose of land cover and related monitoring.

It is also likely that there would be less effective environmental management and, as a result, a lower output from the mining industry in general. However, due to the difficulty of assessing this impact we have not included it in this assessment.

### 8.3.6 Economic impact in 2025

#### Counterfactual

In the counterfactual, it is assumed that the current situation continues until 2025.

#### Evaluation case

The evaluation case would represent further adoption of EOS technologies across the mining industry and new applications.

#### Assessment

It is considered reasonable to assume that the demand for EOS services by the mining industry will continue to grow as the production phase is rolled out. This will be one source of growth. The other source of growth in the demand for EOS services will be new technologies and applications in the use of EOS data. Discussion with the EOS industry indicated that it is already possible to use EOS to monitor aspects of mine operations, including recording details of ore stockpiles and the perimeters of mine operations and roads and infrastructure, landslips and subsidence.

Launch of low orbit multiple satellites is also likely to provide high resolution, high frequency EOS data. There is little information on how the mining industry might use this data but it offers potential for closer monitoring of mining projects.

## KEY FINDING 15 – ECONOMIC IMPACT OF THE USE OF EOS BY MINING COMPANIES FOR LANDSCAPE MONITORING

### 2015

The value of EOS to mining companies for monitoring environmental and landscape change is estimated to be \$5.0 million in 2015.

### 2025

The value of EOS to mining companies for monitoring environmental and landscape change is estimated to increase to \$6.7 million by 2025.

EOS competes with aerial surveys for this purpose and it is not clear how the two technologies will compete as new technologies are introduced.

On the present outlook for technological development, ACIL Allen considers that it is likely that EOS, aerial surveys and UAVs will continue to compete for monitoring tasks but EOS will continue to be competitive for ground cover and mine monitoring where regular data are required and archival data are important.

In ACIL Allen's view, it would be reasonable to assume that the market for EOS services will grow at a rate of around 3 per cent per annum, which takes into account the slowdown in mining construction activity but continued growth in demand from production activities.

This implies that the value will have grown by a further 34 per cent to \$6.7 million by 2025.

## 8.4 Summary of EOS benefits for onshore mining

The findings for the case study in onshore mining are summarised in Table 8.1.

Sector	Category	2015 \$ million	2025 \$ million
Onshore mining	Reduction in landscape monitoring costs	5.0	6.7
Sub total		5.0	6.7

SOURCE: ACIL ALLEN

## 9 FINDINGS

### 9.1 Summary of benefits

The total direct economic benefits identified in the case studies are:

- \$496 million in 2015
- \$1,694 million by 2025.

In addition, social/environmental benefits are estimated to be:

- \$861 million in 2015
- \$1329 million by 2025.

A full summary of the benefits is provided in Appendix A.

Case study	Application	Impact	Nature of benefit	2015 \$million	2025 \$million	Potential employment impacts 2015	Potential employment impacts 2025
Weather forecasting	Aviation	Reductions in delays on domestic flights/ reductions in diversions/reduced costs of volcanic ash incidents	Economic	50.8	63.3	770	833
	Agriculture	Increased output in broad acres agriculture	Economic	25.0	135.8	478	2581
Ocean observation	Environmental monitoring	Sustainable management of the GBRMP ecosystem	Social/ environmental	825.0	1,275.0	7593	10,146
	Petroleum and shipping	Offshore oil operations and oil spill monitoring	Economic	13.3	29.7	11	26
Landscape and land cover monitoring	Government	Vegetation monitoring to regulate land clearing activities in NSW and other jurisdictions	Social/ environmental	20.7	39.2		
	Property	Land cover mapping and the cadastre	Economic	64.4	128.8	384	768
Agriculture	Crops, pastoral and biosecurity	Increased gross margin in crops and livestock, more effective biosecurity measures	Economic	67.0	534.0	402	3,583
Water management	Water sector	Improved water resource management and water use efficiency	Economic	39.5	80.0		
	Water resources	Enhancing habitat ecosystem services through sustainable diversion limits	Social/ environmental	14.9	14.9		
Natural disasters	Insured costs plus social costs		Economic	213.0	495.0		
Mining	Licence to operate	Vegetation and mine monitoring	Economic	5.0	6.7		
Total economic				495.7	1,694.0	9,293	15,997
Total social and environmental.				860.6	860.6	1,329.1	
NOTE: THIS PROJECT SCOPE DID NOT INCLUDE ECONOMY-WIDE MODELLING OF THE DIRECT ECONOMIC EFFECTS ON GDP AND INCOMES. THE TOTALS, THEREFORE, ARE DIRECT EFFECTS AND NOT OUTCOMES FOR THE ECONOMY AS A WHOLE.							
SOURCE: ACIL ALLEN							

The results by case studies are shown in Table 9.1. The table shows that many of the benefits from the case studies arise in important industry sectors including agriculture, aviation, tourism and recreation, petroleum, water, property, insurance and mining.

These are case studies of specific applications and do not reflect the potential value across all applications.

The table shows the largest benefits identified in the case studies was for agriculture in 2025 of \$534 million and natural disasters of \$495 million. Other interesting results are the benefits from the use of EOS in weather forecasting and ocean observation. The case studies for these areas focused on specific applications. The benefits identified would be higher if we had considered their application more widely.

The GBRMP case study also identified significant environmental value benefits rising from \$825 million in 2015 to \$1,275 million by 2025. This case study did not include the direct economic impact on industries dependent on the GBRMP.

Industries that depend directly on the GBRMP such as tourism, recreation and commercial fishing, contribute \$5.7 billion to GDP. Industries adjacent to the GBRMP, including mining and agriculture, account for around \$40 billion in value add and depend on sustainable management of their impacts on reef ecosystem in order to continue operations at current levels. The mining industry component of this group, for example, employed around 166,000 people in 2013. An estimate of the impact on employment in this group is included in the above estimates.

A comprehensive estimate of the impact on economic growth and employment would require economy-wide modelling of impacts of productivity improvement across the sectors examined. This was beyond the scope of this report.

It was estimated that the direct impact of the use of EOS services had resulted in employment in the sectors examined being around 9,293 higher in 2015 than it would otherwise have been. It was estimated that this figure would increase to 15,997 by 2025 as a result of the use of EOS in these sectors.

## 9.2 Impact of a denial of service

There are two aspects to consideration of a denial of service:

- no access to public EOS services provided by other governments—partial denial of service
- no access to any EOS, both government and private—complete denial of service

A partial denial of service would create serious problems for many government services including weather forecasting, ocean observation and landscape monitoring. It would limit the effectiveness of these services with increasing consequences for many sectors in the Australian economy as well as for governments concerned with environmental monitoring. Government agencies concerned with emergency arrangements would not have access to satellite data available through the Space Charter (see Section 3.2.1). There could be some source shifting to commercial services if governments elected to fund further access; however, this would require short-term budget appropriation and some delays in switching services.

A complete denial of service would imply that Australia did not have access to either public or commercial remote sensing satellites. The idea that such a situation could occur in the next ten years is hard to conceive given the diverse sources of satellite services that are becoming available through various governments and the private sector. The potential introduction of smaller low orbit satellites, as foreshadowed by some companies, is further evidence that such a situation is extremely unlikely.

Having said that, if a complete denial of service were to occur, the economic and social impact would be far higher than the values that have been calculated in this report. A complete denial of service would cause a serious disruption to most of the applications examined and the industry sectors dependent on them.

Lack of EOS data would have serious consequences for meteorological modelling and weather forecasts. It would seriously disrupt ocean monitoring and it would affect comprehensive land cover monitoring by both governments and industries such as mining. A loss of productivity would arise through narrower coverage and higher costs.

For this reason, the cost of a complete denial of service is likely to exceed by some margin the values of EOS services that have been discussed in this report.

Government agencies from other nations supply many of the EOS services on which Australian governments and industry rely. There are mechanisms and intergovernmental agreements in place that establish these supply arrangements. It would be important to ensure that these mechanisms are sufficiently robust to protect the EOS supply chain on which Australian governments and industry rely.

9.3 Comparison with the 2010 report  
ACIL Tasman examined the value of EOS in 2010 from a broad examination of its use from three perspectives (ACIL Tasman, 2010):

- the direct contribution of the EOS sector to GDP
- the productivity impact on other sectors
- other benefits accruing to society from the use of EOS not captured in GDP figures.

This report took a more focused approach examining 17 specific case studies to assess the current and prospective value of EOS services in specific applications. While this focus was more targeted it provides the opportunity to reassess the broader assessment made in the 2010 report. The following comments examine the earlier reports findings in the light of the current findings in this report.

### 9.3.1 Direct contribution to GDP

The direct contribution to GDP is the value added from all EOS activities across government and industry. The 2010 report noted that over 90 government programs used EOS data in one way or another. Surveyors, farmers, miners, insurers, fishers, engineers, and other commercial users were identified as increasingly using EOS to pursue their business objectives.

Looking along the supply chain from image suppliers, data processors to application developers, the 2010 report estimated the direct value added for government and businesses, and concluded that the total value add associated with the EOS sector would be of the order of \$1.4 billion (Table 9.2).

On reviewing these figures, ACIL Allen believes that the government contribution would now be closer to 1.5 billion, considering the rapid increase in the use of EOS by state governments and the impetus from the Foundation Spatial Data Framework initiative of ANZLIC.

TABLE 9.2 – THE EOS SECTOR'S DIRECT CONTRIBUTION TO GDP IN 2008-09 FROM 2010 REPORT	
Source of value added (= contribution to GDP)	2008-09 estimate
Government – identified during consultancy	\$800 million to \$2 billion
Imagery resellers	< \$10 million
'Plausible' range	\$0.9 billion to \$2 billion
ACIL Tasman estimate (mid-point)	\$1.4 billion
Note: This included a broad estimate of the contribution from Commonwealth and State Governments and from Defence and National Security.	
SOURCE: (ACIL TASMAN, 2010)	

We also consider the industry figure would be larger in 2015. The scope of this project did not extend to surveying all industry participants including image providers, processors, value adders and service providers. However, our targeted surveys and consultations suggested that the Australian revenues for image providers would now be around \$10 million and the revenues for, processors, value adders and service providers would be of the order of \$200 million to \$300 million. By comparison, the 2010 report estimated that the revenues of value adders were between \$30 million and \$40 million.

This suggests that the direct contribution to GDP would now exceed \$1.4 billion and possibly be around \$1.8 billion in 2015. With the growth in open geospatial data, the accelerating uptake by governments, and the foreshadowed improvements in resolution and frequency, it would be reasonable to assume that the value add from the EOS sector will continue to grow over the next ten years. Our estimate is that it could grow to \$2.5 billion by 2025.

### 9.3.2 Productivity benefits

The second step in the 2010 project was to derive an estimate of the productivity impact that the EOS sector was delivering to other sectors of the economy. Accordingly, the 2010 work involved asking stakeholders to estimate the component of the value of spatial information calculated in ACIL Tasman's 2008 report on the value of spatial information generally (ACIL Tasman, 2009) that could be attributed to EOS. The consensus was around 15 per cent. This gave an estimate of 15 per cent of \$12.6 billion = \$1.9 billion.

The case studies undertaken for this report identified a total of \$478 million of direct economic benefits to a number of sectors of the economy in 2015. This drew on a small sample of direct benefits and our view is that these benefits would represent less than a quarter of the total benefits that would accrue if we had undertaken a much

larger sample of case studies. We therefore consider it reasonable to conclude that the figure for productivity benefits would now be of the order of \$2.0 billion.

We also note that by 2025 the estimate of productivity benefits for this study would increase by around \$1 billion. This is a lower bound estimate given that it is derived from the selected case studies. This suggests that the productivity benefit from EOS would be of the order of \$3 billion by 2025.

### 9.3.3 Social and environmental values

GDP estimates do not include benefits that might accrue when addressing overarching national challenges such as sustainable resource and environmental management. The 2010 report analysed three areas and estimated their contribution in economic terms:

- response to climate change: \$300 million per year
- natural resource management: \$500 million per year
- emergency response benefits: \$200 million per year.

These were estimates of orders of magnitude rather than precise estimates. Taken together the scale of these benefits was estimated to be in the region of \$1.0 billion per year.

This report focuses on sector specific case studies and only examines two areas of environmental value. It estimated that the value of EOS for environmental monitoring derived from these case studies was \$860 million in 2015 rising to \$1,329 by 2025. The insights from these two case studies suggest that the value for natural resource management would now exceed \$500 million per year by a significant margin.

This report estimated of the value of EOS in reducing the emergencies was \$213 million in 2015 rising to \$495 million by 2025. The estimate focused on insured costs, total economic costs, and costs incurred by governments and not on social costs to the community.

We did not examine the impact of EOS on climate change in this study but have no reason to believe that the original estimate would still be valid if a little conservative given the advances in the use of EOS in meteorological and ocean monitoring since that time.

On balance we consider that an order of magnitude of \$1.5 billion would be an appropriate estimate for 2015 based on the social benefits associated with improved environmental and natural resource management and reduced social costs associated with management or the consequences of climate change.

As remote sensing from EOS is extended and higher resolution satellites become available for land cover monitoring the value of EOS for natural resources and environmental management could reasonably be expected to grow to around 2 billion by 2025.

9.3.4 Summary of comments on the 2010 results  
 Comments on the 2010 results in the light of the findings of the case studies are summarised in Table 9.3. The key feature of this table is the significant

rise in the productivity impact between 2015 and 2025. Over 90 per cent of this is attributable to use of EOS enabled services in weather forecasting, agriculture, property services and natural disasters management.

These estimates should be regarded as of orders of magnitude underpinned by the findings of the 17 case studies in this report.

### 9.4 Implications

The findings in this report are based on 17 specific case studies. Extending the findings of the case studies to economy-wide impacts should be treated with care. However, from the case studies and consultations undertaken for this report, ACIL Allen considers that that the impact of EOS on the Australian economy and society has increased materially over the assessment made in 2010.

Most importantly, the value of the contribution of EOS is expected to increase over the next decade as higher resolution and more frequent data become available and as the applications and products that build on the data increase.

### 9.5 Caveat

There are two important caveats to the findings of this report.

The case studies examined in this report provide estimates of the direct effects of the use of EOS in specific applications. They do not represent the

	2010 estimate \$ billion	2015 \$ billion	2025 \$ billion
Contribution to GDP			
Direct value added by EOS industry	1.4	1.8	2.5
Productivity impact of EOS for other sectors	1.9	2.0	3.0
Social and environmental benefits			
Natural resource management, ecosystems	1.0	1.5	2.0
NOTE: THE FIGURES IN THIS TABLE ARE ORDERS OF MAGNITUDE ESTIMATES INFORMED BY THE 17 CASE STUDIES UNDERTAKEN IN THIS REPORT.			
SOURCE: ACIL ALLAN			

final impact for the economy as a whole because they do not take into account resource constraints or shifts in the economy that would arise as a result of these direct productivity effects. To do this would require additional modelling of the wider impacts through techniques such as input-output multipliers or Computable General Equilibrium modelling. Such modelling was beyond the scope of this report.

Most of the estimates of benefits were drawn from surveys and consultations with users. In the majority of cases, commercial users were not able to divulge benefit and cost figures for commercial reasons. It was therefore necessary for ACIL Allen to make its own estimates based on industry research. Where feasible, these estimates were checked back with the survey respondents to confirm that the results were reasonable.

## GLOSSARY OF TERMS

ACLUMP	Australian Coordinated Land Use Mapping Program
AIRMET	Aerodrome Weather Information Service
ALOS	Advanced land observing satellite
AMOSC	Australian Marine Oil Spill Centre
ANZLIC	Australian and New Zealand Land Information Council
ASCAT	Advanced scatterometer
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
AVHRR	Advanced very high resolution radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
DEM	Digital Elevation Model
DNV	Det Norske Veritas
DSE	Dry Sheep Equivalent
ERIC	Emergency Response Intelligence Capability
FTE	Full time employee
GNSS	Global Navigational Satellite System
ICA	Insurance Council of Australia
ISCM	Intergovernmental Committee on Surveying and Mapping
MODIS	Moderate resolution imaging spectroradiometer
NDRRA	National Disaster Relief and Recovery Arrangements
NDVI	National Differential Vegetation Index
NFIDB	National Flood Insurance Data Base
NFRIP	National Flood Risk Information Portal
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
NRT SWH	Near Real Time significant wave height
OPPIS	On line Property Planning and Information System
PGR	Paddock growth rate
PREP	Property Resilience Exposure Program
PREP	Property Resilience Exposure Program
RGB	Red, green, blue imagery
SAR	Synthetic Aperture Radar
SIGMET	Significant Meteorology Information
SOI	Southern Oscillation Index
SWIR	Short wave infrared
VAAC	Volcanic Ash Advisory Centre
VIRR	Multispectral Visible and Infrared Scan Radiometer
VRT	Variable Rate Technologies
VTS	Vessel Tracking Services
WRA	Water Resource Assessment

## A. ECONOMIC METHODS

### A.1 The nature of value

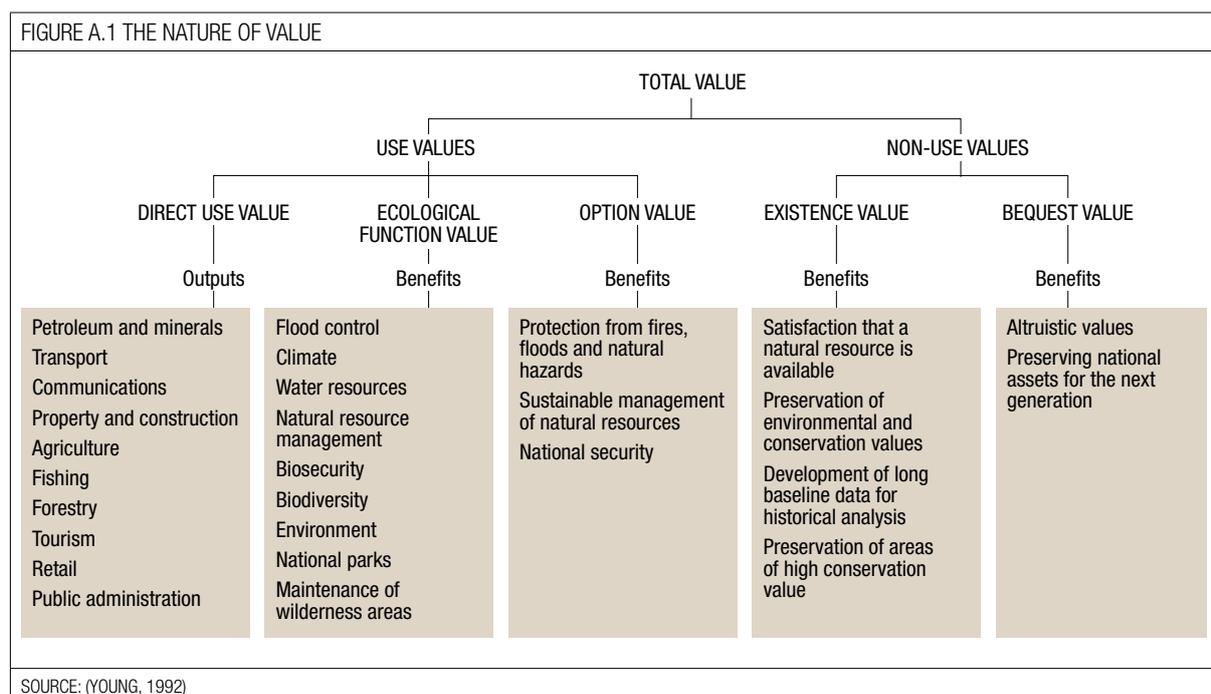
A starting point in estimating a value for provision of geospatial data is to clarify what is meant by the term “value”. Fundamental geospatial data is an intermediate good and an enabler of other activities through value added services. To understand its value, we need to explore the value that suppliers and users draw from the data.

The answer to this question depends on the viewpoint of the person asking the question. For a government EOS data custodian, it could be as narrow as the financial benefit (for example, realised future savings) less the cost of the investment in acquiring the data. For a policy maker, it could be as wide as the expected benefits that would accrue to society as a whole from the use of the data less its costs.

A framework for considering different concepts of value is provided in Figure A.1. In this figure, value is divided into use values and non-use values. Use values are those goods and services that people consume. Use values comprise direct use values (such as the value of goods and services), ecological values (such as biodiversity or sustainable rivers and streams) and option values (such insurance against the costs of natural disasters).

Non-use values include existence value (for example, valuing the existence of a coral reef but never diving on it) and bequest value (preserving the value of assets for later generations). While non-use values are conceptual, they are important to many in society and potentially become policy issues for this reason.

In theory, total socioeconomic value is the sum of the use and non-use values.



## A.2 Economic concepts of value

There are several approaches to estimating economic value. Two have been used in this report. They are discussed below.

### A.2.1 Welfare analysis

Welfare analysis is an economic concept that describes the societal value of a good or a service. In an efficient market, the economic welfare of society is measured by consumer and producer surplus. The conceptual base for consumer and producer surplus is the supply and demand or market model depicted in Figure A.2.

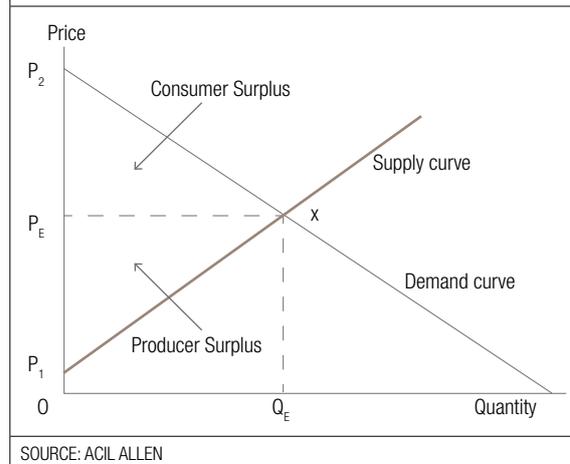
Consumer surplus is the difference between what consumers would be willing to pay for a good or a service and what consumers have to pay. In Figure A.2 it is the area between the demand curve and the price line ( $P_2XPE$ ).

Producer surplus is the difference between the revenue received by producers for a good or service and the cost of producing it. In practical terms, it is the net revenue (before tax) that is earned by producers. In Figure A.2 it is the area between the price line and the supply curve ( $P_1XPE$ ).

If the diagram represents the quantity of goods or services demanded and supplied in a year, the sum of the consumer and producer surplus represents the annual value to society of the product or service.

An issue with welfare analysis arises when attempting to value intangible benefits such as a clean environment and basic ecological functions. Economists often draw on willingness to pay surveys to estimate the demand curve and consumer surplus. An application in one of the case studies draws on a report that employs this concept.

FIGURE A.2 STANDARD CONCEPTS OF PRODUCER AND CONSUMER SURPLUS



SOURCE: ACIL ALLEN

### A.2.2 Productivity and value added analysis

An alternative approach to welfare analysis is to examine the productivity gain arising from the use of a good or service, measured in terms of gross value added.

Gross value added of an industry represents the total revenue generated less the cost of inputs incurred. In practice, it reflects the returns to capital (profits) accruing to service providers and salaries and wages paid to those working for them. Gross value added makes up the bulk of Gross Domestic Product (GDP).<sup>23</sup> GDP is an important national economic indicator for economists and policy makers.

Information and data from EOS are generally intermediate goods. They enable other sectors to perform their tasks more efficiently, thereby improving their productivity. A way of measuring the economic value of EOS is to estimate its impact on the productivity (and consequently the gross value added) of sectors that utilise this information. This approach has been used for the majority of the case studies in this report.

<sup>23</sup> GDP comprises the sum of gross value added plus taxes less subsidies.

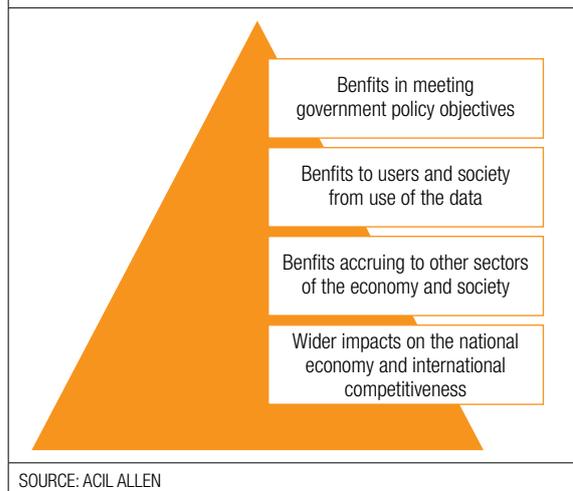
### A.3 The beneficiaries

One aspect of the use of EOS services is that the beneficiaries can be found in many different sectors of the economy. They include:

- Commonwealth and state/territory government departments
- Local governments
- Regulators
- Non-government organisations
- Universities and research institutions
- Defence organisations
- Emergency management organisations
- Agriculture businesses
- Mining and petroleum businesses
- Insurance industry businesses
- Water sector businesses and organisations
- Energy sector businesses and organisations
- Finance sector businesses
- Environmental groups.

The benefits can arise in many contexts as illustrated in Figure 9.1. They can include meeting government policy and regulatory objectives, benefits to the users of the data, benefits accruing to other sectors of society and wider impacts on national economic and international competitiveness.

FIGURE 9.1 – BENEFITS ACROSS SOCIETY



The case studies in this report mainly focus on benefits arising from meeting government objectives or accruing to users and other sectors. Wider impacts on the national economy have not been assessed.

## B. CASE STUDY CALCULATIONS

### B.1 Weather forecasting and agriculture

#### B.1.1 2015

For the purposes of estimating the value of information from EOS, farming enterprises were segmented into ‘wheat and other grains’ and ‘mixed livestock and crops’ and ‘wheat and other crops’.

The evaluation case and the counterfactual are discussed below.

#### Counterfactual – without EOS scenario

This has been assumed to be the situation that would have arisen without the benefit of data from EOS in the forecasting process. While such circumstances may be hard to conceptualise, it would be a state where meteorologists depended on terrestrial observations augmented by data from such sources as weather balloons, reports from ocean-going vessels, and aircraft. Interpolation of point-based observations across Australia is almost impossible without satellite-based adjustments. It would be impossible to run a predictive climate model such as the POAMA effectively. Without EOS, the skill levels (accuracy of forecasts) would be very low; approaching zero.<sup>24</sup>

#### Mixed livestock and crops

A conservative assumption of a skill level of 10 per cent has been assumed for the counterfactual, which is one of the lowest points on the skill chart in Table 2.1. This corresponds to an economic value of \$0.20 per hectare. The adoption rate in the counterfactual is assumed to be 30 per cent based on desktop research and consultations with stakeholders discussed in Sections 2.4.1 to 2.4.3 of the report.

#### Wheat and other crops

Following a similar argument, it has been assumed that the value of weather forecasts without EOS is limited.

#### Evaluation case – the EOS scenario

The evaluation case has been defined as the current situation with data from existing sensors and dynamic modelling. The latter was introduced in the BOM in 2013 and is under continual development. It is unlikely that the full benefits of dynamic modelling would have been achieved by 2015.

#### Mixed livestock and crops

ACIL Allen has applied the relationship between forecasting skill and improvement economic value, summarised in Figure 2.2 in Section 2.4.2 in the body of the report, to estimate the likely value of improved weather forecasts.

Crean (2014) estimated that the level of skill in mixed farming in western NSW would have been around 20 per cent in 2013. There is insufficient information to assess a likely skill score in 2015 but the improvements in climate modelling would have caused it to increase over 2013. For the purpose of modelling, we have estimated that forecasting skill level would have increased to 30 per cent (with an economic value of \$2.62 per hectare).

#### Wheat and other crops

Interviews with wheat and grain growers in WA and farm consultants indicated the value of improved weather forecasts could deliver up to 15 per cent of gross margin. In 2013-14, gross margins in wheat and other cropping enterprises across Australia ranged from \$96 per ha in Victoria to \$216 per ha in South Australia. This would imply an improvement in gross margin from better weather forecasts of between \$14 per hectare and \$42 per hectare. Achieving these results would depend on the skill of the farmers and the extent to which they are using precision farming. The uptake of precision farming in Australia is accelerating but is still in the early to middle stages of adoption.

<sup>24</sup> Personal communication, Professor S Phinn, University of Queensland, October 2015.

For the purpose of this report, we have assumed that the value of EOS supported weather forecasts is around \$5 per hectare for 2015, which is approximately 3 per cent of the current average gross margin. This is a conservative estimate.

### B.1.2 Estimated economic impacts in 2015

#### Mixed livestock and crops

The net increase in economic value for mixed farming has been calculated as follows:

Increase in economic value

$$\begin{aligned} &= \text{Value in evaluation case} - \text{value in counterfactual} \\ &= \$2.62 - \$0.20 = \$2.42 \text{ per hectare} \end{aligned}$$

Converting the economic value per hectare into an Australian-wide number is difficult. The representative farm in the Crean paper was based on a mixed farming enterprise in central west NSW. This region is typical of mixed farming systems in south-eastern Australia. Average rainfall is 700 mm in the eastern part and 700 mm in the West. Rainfall variability has an important influence on agricultural production. Farms in the central west have adopted mixed dryland farming systems. Winter cereals accounted for just over 80 per cent of the total crop area. Wheat comprised just over 70 per cent of the winter cereal area with non-cereal crops including canola, field peas and lupins making up the remainder. Livestock activities have been typically based around wool production, supported by a mixture of native and improved pasture species (Crean, Parton, Mullen, & Jones, 2013).

This model of mixed farming would not necessarily represent mixed farms elsewhere in Australia. However, there is no data available that would permit a more detailed analysis. There are data on the areas of cropping and mixed farming along with representative financial data by State developed from farm surveys conducted by the Australian

Bureau of Agricultural and Resource Economics and Science (ABARES).<sup>25</sup> These data and the net increase in gross margin quoted above have been used to scale up the results from the findings of the Crean paper for NSW, Victoria, South Australia, Queensland and Western Australia.

Based on interviews with researchers, consultants and farmers we assumed an adoption level of 30 per cent. This is considered a conservative estimate given the increasing uptake of controlled traffic farming and precision farming generally.

#### Wheat and other crops

The ABARES crop report cited above also contained data on area planted for wheat and other crops for certain Australian states. These data were drawn from the crop report produced by ABARES. This report includes production of barley, canola, chickpeas, faba beans, field peas, lentils, linseed, lupins, oats, safflower, triticale and wheat. Some of the production would also include grazing activities.

Data on the area of wheat and other crops harvested in 2013-14 was combined with a conservative assessment of \$5 per hectare to estimate the value of EOS for NSW, Victoria, South Australia, Queensland and Western Australia.

Increase in economic value

$$\begin{aligned} &= \text{Value in evaluation case} - \text{value in counterfactual} \\ &= \$5.00 \text{ per hectare} \end{aligned}$$

Based on interviews with researchers, consultants and farmers we assumed an adoption level of 30 per cent. This is considered to be a conservative estimate given the increasing uptake of controlled traffic farming and precision farming generally.

The results of ACIL Allen's benefit valuation exercise are shown in Table B.2. They provide a broad indication only of the potential value in

<sup>25</sup> ABARES - Broadacre-industry-by state.xls.

	Units	NSW	Victoria	QLD	WA	SA	Total
Cropping and livestock	ha	1,907,984	787,978	382,106	2,097,190	1,360,969	6,536,227
Improvement in gross margin	\$/ha	2.42	2.42	2.42	2.42	2.42	2.42
Level of adoption	%	30%	30%	30%	30%	30%	30%
Increase in gross margin	\$	1,385,197	572,072	277,409	1,522,560	988,063	4,745,301
Wheat and other crops	ha	2,906,017	2,240,016	690,053	5,621,522	2,070,366	13,527,974
Improvement in gross margin	\$/ha	5.00	5.00	5.00	5.00	5.00	6.00
Level of adoption	%	30%	30%	30%	30%	30%	130%
Increase in gross margin	\$	4,359,026	3,360,025	1,035,079	8,432,282	3,105,549	20,291,961
Total increase in gross margin		5,744,223	3,932,096	1,312,488	9,954,842	4,093,612	25,037,262

SOURCE: ACIL ALLEN, (CREAN, J; PARTON, K; MULLEN, J; HAYMAN, P, 2014), ABARES - BROADACRE-INDUSTRY-BY STATE.XLS

2015. However, in the absence of more precise data they are considered a reasonable indicator of the potential additional value that could accrue for the purposes of this report.

### B.1.3 Estimated economic Impacts in 2025

For projecting future benefits, the counterfactual and the evaluation case were defined as follows:

#### Counterfactual – without EOS scenario

This assumes that weather forecasts are not enabled by EOS but that some development of alternative methods occurs. This might include greater use of airborne and ocean monitoring. It would not be possible, however, for interpolation of point-based observations across Australia or in Australia's marine zone.

The skill score would increase slightly, perhaps to around 20 per cent equivalent to an increase in gross margin to \$.96 per hectare.

#### Evaluation case – the EOS scenario

##### Mixed livestock and crops

For the EOS case it is assumed that newer satellites such as Himawari 8 and 9 will significantly improve the accuracy and frequency of remote sensing and would also support improvements in

dynamic meteorological modelling to the extent that the skill score increases to 50 per cent (with an economic value of \$7.13 per hectare) and the adoption rate increases to 80 per cent (see Table B.2). This is considered reasonable given the expected improvement in accuracy and the demonstration effect especially with younger farmers coming into the production cycle. This assessment has also been based on consultations with researchers and with selected farmers.

##### Wheat and other crops

For wheat and crops it is considered reasonable to assume that the adoption of improved short-term and seasonal forecasts leads to an improvement in gross margin from the 3 per cent assumed in 2015 to 5 per cent for 2025, equivalent to \$9 per hectare increase over the without EOS case.

### B.1.4 Evaluation

Mixed livestock and crops

Increase in economic value

$$= \text{Value in evaluation case} - \text{value in counterfactual} \\ = \$7.13/\text{ha} - \$0.96/\text{ha} = \$6.17/\text{ha}$$

It has been assumed that adoption for mixed livestock and crops would be around 80 per cent.

Wheat and other crops

Increase in economic value

$$= \text{Value in evaluation case} - \text{value in counterfactual} \\ = \$9.00 \text{ per hectare}$$

It is also assumed that adoption increases to 85 per cent in line with increased adoption of precision agriculture across Australia by 2025.

## B.2 Weather forecasting and aviation

The estimate of a cost of a diversion was based on diversion of a domestic and an international flight from Sydney to Brisbane. This would involve diverting a plane bound for Sydney to Brisbane first and then flying from Brisbane to Sydney. This is used as a representative diversion for domestic and international flights to Australia. Diversions to Melbourne would cost slightly less and diversions

in South Australia and Western Australia would cost more given the longer distances to travel.

A Boeing 737-800 was used as a representative aircraft for domestic routes and a Boeing 777 was used as a representative international aircraft. Fuel consumption parameters were obtained from the Boeing website and cross checked with IATA documents and industry consultations.

The details of the assumptions and the calculations for the cost of diversions are summarised in Table B.3.

## B.3 Volcanic ash calculations

The estimates of the frequency of volcanic ash events are based on a report by Gulfani (2010), which reported on the number of volcanic ash incidents since 1953 (Gulfanti, Casadevall, & Budding, 2010).

The calculation of the average annual damage costs was based on press reports of estimates by Macquarie Equities and the Tourism and Transport forum at the time.

Macquarie Equities placed the cost of disruptions to airlines from the eruption of the Puyehue

	Units	NSW	Victoria	QLD	WA	SA	Total
Cropping and livestock	ha	1,907,984	787,978	382,106	2,097,190	1,360,969	6,536,227
Improvement in gross margin	\$/ha	6.17	6.17	6.17	6.17	6.17	6.17
Level of adoption	%	80%	80%	80%	80%	80%	80%
Total value added		9,417,811	3,889,457	1,886,077	10,351,728	6,717,743	32,262,816
Wheat and other crops	ha	2,906,017	2,240,016	690,053	5,621,522	2,070,366	13,527,974
Improvement in gross margin	\$/ha	9.00	9.00	9.00	9.00	9.00	9.00
Level of adoption	%	85%	85%	85%	85%	85%	85%
Total value added		22,231,033	17,136,125	5,278,904	43,004,639	15,838,300	103,489,002
Total value		31,648,844	21,025,583	7,164,981	53,356,367	22,556,043	135,751,818

SOURCE: ACIL ALLEN, (CREAN, J; PARTON, K; MULLEN, J; HAYMAN, P, 2014), ABARES - BROADACRE-INDUSTRY-BY STATE.XLS

Item	Units		
Representative aircraft		B777-300ER	B737-800
Fuel/100 km/seat	litres per 100 seat km	3	3
Seats		350	160
Load factor	%	75%	75%
Fuel price	\$/litre	1.25	1.25
Distance one way	km	728	728
Additional landing fees	\$	5,000	5,000
Fuel cost of diversion	\$/diversion	19,110	8,736
Total fuel plus landing fees per diversion	\$/diversion	24,110	13,736
Passenger time	Hours per diversion per passenger	8	4
Total passenger time lost	Hours per diversion	2,100	480
Percentage of productive time	%	0.5	0.5
Opportunity cost of employee	\$/hour	43	43
Passenger opportunity cost per diversion		45,150	10,320
Fuel, landing and passenger costs of one diversion		69,260	24,056

SOURCE: ACIL ALLEN

Volcano in Chile in 2011 at \$21 million for Qantas and \$11 million for Virgin Australia (Taylor & Perry, 22 June 2011). The tourism industry was also reported to be impacted at an estimated cost of \$15 million during the two-week period (Daley, June 2011). The total cost of the Chilean event, a conservative estimate of the cost of the eruption in Australia, would therefore be estimated to be in the order of \$42 million.

The average number of major events globally from 1953 to 2015 was 0.47. Assuming that the figure for Australia might be around half that number and using the above estimate of the cost of a major event, it has been estimated that the potential average annual damage cost of major volcanic ash events would be of the order of \$19.6 million. Using an estimate of the potential impact of volcanic ash warnings of around 25 per cent the impact of EOS enabled volcanic ash warnings is estimated to be \$2.46 million. These calculations are shown in Table B.4.

	Encounters	Major incidents
Number of volcanic ash events	132	29
Number of years from 1953 to 2015	62	62
Average number of events	2.13	0.47
Estimated cost of major event		\$42million
Average annual damage cost		\$19.6million
Estimate for Australia		\$9.8million
Proportionate Impact of VACC		25%
Impact of EOS		\$2.46 million

SOURCE: (GULFANTI, CASADEVALL, & BUDDING, 2010)

## B.4 Great Barrier Reef case study

Table B.5 shows the value added and employment statistics for mining and energy industries operating adjacent to the Great Barrier Reef.

Table B.6 summarises the estimation of employment impacts in GBR dependent and GBR related industries.

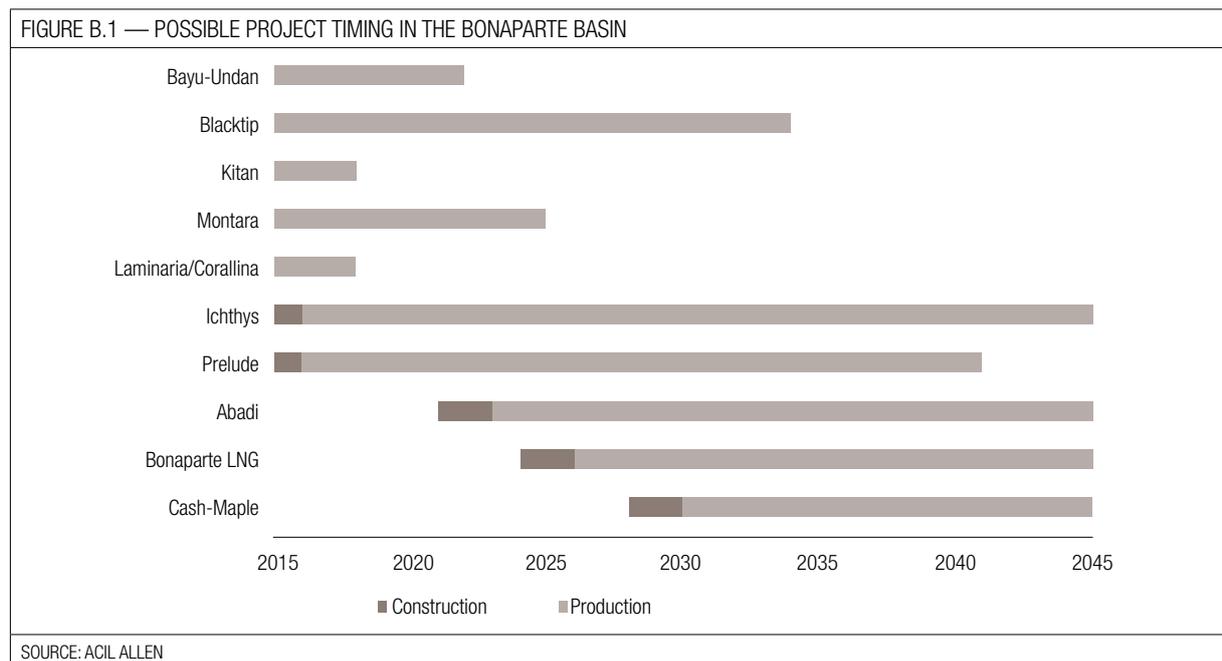
Region	Value add	FTE
Far North	754.7	6032
North	2128.9	15920
Mackay	8602.3	62030
Fitzroy	12,623.60	77058
Wide Bay	646.6	4731
	24756.1	165771

SOURCE: (LAWRENCE CONSULTING, 2014)

	Impact 2015	Employment	Impact 2015	Impact 2025	Employment 2025
	%	FTE	FTE	%	FTE
GBRMP dependent	5.0%	68,978	3,449	10.0%	6,898
GBRMP related	2.5%	165,771	4,144	5.0%	8,289

SOURCE: (GBRMPA, 2014) (LAWRENCE CONSULTING, 2014)

## B.5 Offshore petroleum operations



## B.6 Oil spill monitoring

Oil spills from ships are a relatively frequent occurrence in Australian waters. A total of 21 events were reported over the past 20 years, shown in Table B.7.

Date	Vessel	Location	Size
22/02/1982	Eso Gippisland	Port Stanvac SA	Unknown
03/12/1987	Nella Dan	Macquarie Island	125 tonnes
06/02/1988	Sir Alexander Glen	Port Walcott, WA	450 tonnes
20/05/1988	Korean Star	Cape Cuvier WA	600 tonnes
28/07/1988	Al Qurain	Portland VIC	184 tonnes
21/05/1990	Arthur Phillip	Cape Otway VIC	Unknown
14/02/1991	Sanko Harvest	Esperance WA	700 tonnes
21/07/1991	Kirki	WA	17,280 tonnes
30/08/1992	Era	Port Bonython SA	300 tonnes
10/07/1995	Iron Baron	Hebe Reef TAS	325 tonnes
28/06/1999	Mobil Refinery	Port Stanvac SA	230 tonnes
26/07/1999	MV Torungen	Varanus Island, WA	25 tonnes
03/08/1999	Laura D'Amato	Sydney NSW	250 tonnes
18/12/1999	Sylvan Arrow	Wilson's Promontory VIC	<2 tonnes
02/09/2001	Pax Phoenix	Holbourne Island, QLD	<1000 litres
25/12/2002	Pacific Quest	Border Island, QLD	>70 km slick
24/01/2006	Global Peace	Gladstone, QLD	25 tonnes
11/03/2009	Pacific Adventurer	Cape Moreton, QLD	270 tonnes
21/08/2009	Montara Wellhead	NW Australian coast	Approx. 4,750 tonnes
03/04/2010	Shen Neng1	Great Keppel Island QLD	4 tonnes
09/01/2012	MV Tycoon	Christmas Island	102 tonnes

SOURCE: [HTTPS://WWW.AMSA.GOV.AU/ENVIRONMENT/MAJOR-HISTORICAL-INCIDENTS/INDEX.ASP](https://www.amsa.gov.au/environment/major-historical-incidents/index.asp), ACCESSED ON 27 JULY 2015

## B.7 Agriculture

### B.7.1 EOS use in precision farming in broad acre cropping

Precision agriculture is being increasingly adopted in cropping. Figure B.2 was developed by Dr R Llewellyn from CSIRO and presented at the IGSS conference in Brisbane in July 2015 by agricultural consultant Tim Neale.

It shows high rates of adoption of auto steer, yield monitors and yield maps. Adoption of EOS enabled technologies, whilst not reported on this graph, is still very low but expected to follow similar adoption patterns over the next ten years.

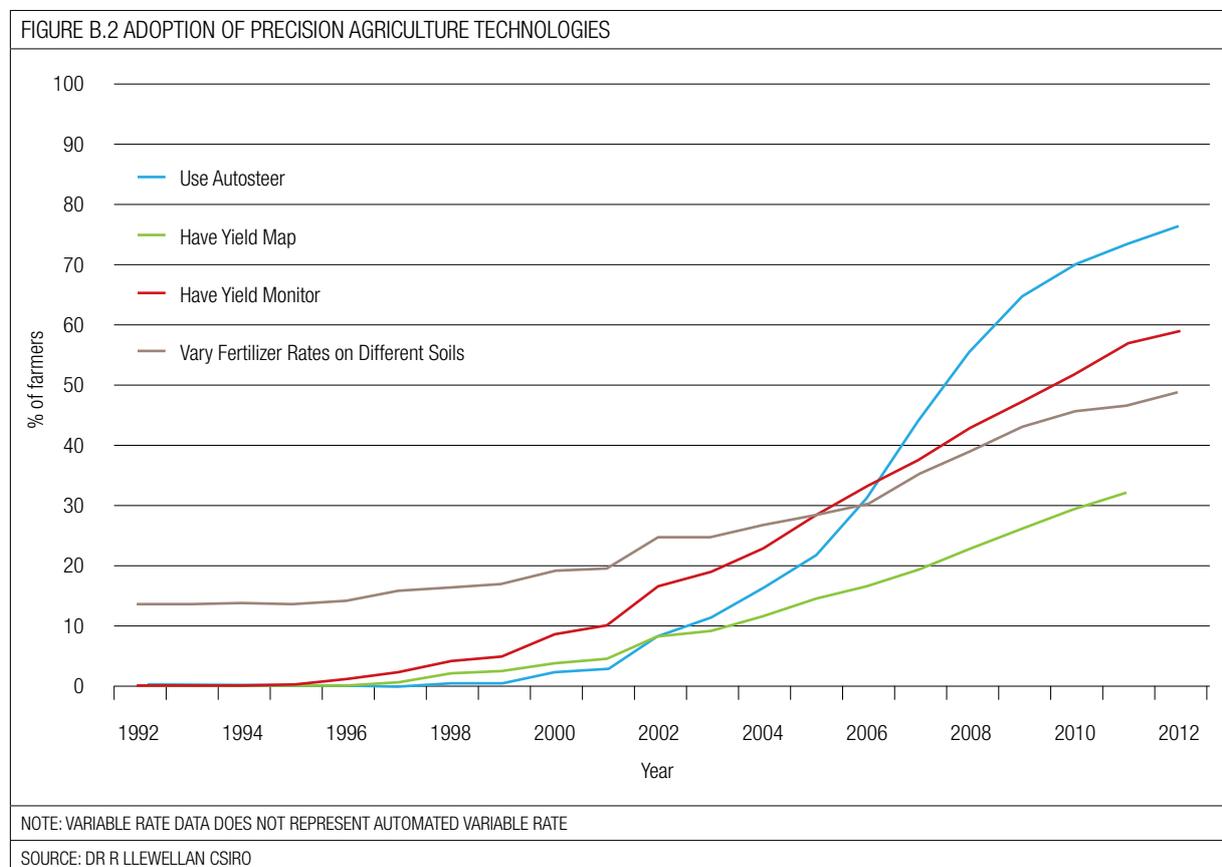
Table B.8 shows an estimate of the increase in productivity from precision agriculture using EOS. The estimate of 0.33 tonnes per hectare is an average for a typical paddock comprising high and low productivity. Precision agriculture can increase

	Proportion of typical cropping enterprise	Increase in production (tonnes/ha)
Low productivity areas	30%	0.50
Medium productivity areas	40%	0.31
High productivity areas	30%	0.18
Average increase in production		0.33
SOURCE: (NEALE, JULY 2015), ACIL ALLEN		

productivity on both components but to different degrees. The average is shown in the table.

This average represents an average of about a 19 per cent increase in production for wheat and a 15 per cent increase in production for coarse grains.

There is limited recent information on the economics of the different aspects of precision agriculture in Australia. Land and Water Australia cited



	Average yield	Increase in yield	Price	Increase in return	Total costs	Savings in costs	Total cost savings	Total benefit	Additional costs	Net benefit
	tonnes/ha	tonnes/ha	\$/tonne	\$/ha	\$		\$/ha		\$/ha	\$/ha
Wheat	1.76	0.33	337.3	110.23	125	10%	12.5	122.73	35	87.73
Coarse Grains	2.21	0.33	265.48	86.76	125	10%	12.5	99.26	35	64.26

studies from 1998 to 2003 citing yield increases for average years of between 10% and 30%, with increases of up to 50% in above average years (Schofield, 2007).

Robertson et al (Robertson, Carberry, & Brennan, 2007) undertook a survey of farmers in 2007 and found that benefits from the use of variable rate technologies (VRT) for fertiliser applications ranged from \$1 per hectare to \$22 per hectare. However, only one of the farmers sampled was using EOS to estimate a Normalised Difference Vegetation Index (NDVI). Furthermore, the benefits were estimated as cost savings rather than increase in yield. Average grain prices are now around 45 per cent higher in 2015 than in 2007 and these estimates would need to be adjusted accordingly to around \$1.5 to \$32 per hectare.

Another study by GRDC in 2007 included yield increases in a survey of the benefits of VRT in crops (GRDC, 2007). This study found that the average benefits ranged from \$9 per hectare to \$22 per hectare in 2007 (\$13 per hectare and \$32 per hectare at current average grains prices).

An estimate of the net benefits that could be expected from the use of precision agriculture in wheat and coarse grains in Australia is summarised in Table B.11. This table draws on the examined

case studies of the abovementioned reports, plus consultations with agricultural consultants and researchers. The calculation includes the impact of increased yield and cost savings arising from application of precision agriculture technologies. It takes into account additional costs associated with investment in capital equipment associated with precision agriculture.

The cost of remote sensing based precision agriculture is less than \$1 per hectare per image capture and could be as low as \$0.10 per hectare for a region or industry-wide price. Typically, the starting point for new subscribers to precision agriculture services is one image per year. Assuming additional input costs of \$34 per hectare, the costs that need to be incurred to realise the benefits calculated above are estimated to be approximately \$35 million per year. The total net benefit is therefore approximately \$184 million per year.

The table indicates potential net benefits of around \$88 per hectare for wheat and \$64 per hectare for coarse grains for precision agriculture as a whole. This is higher than the estimates (Robertson, Carberry, & Brennan, 2007) and (GRDC, 2007) which focused only on VRT. They also would not reflect the advances in the use of EOS in VRT applications.

	Total net benefit from PA	Benefit attributable to VRT	Benefit attributable to VRT	Benefit attributable to EOS	Benefit attributable to EOS
	\$/ha	%of total	\$/ha	% of VRT	\$/ha
Wheat	87.73	50%	43.86	40%	17.55
Coarse Grains	64.26	50%	32.13	40%	12.85

Table B.11 shows a calculation of net benefit that could be attributed to Variable rate technology and EOS.

The table suggests a return to VRT of between \$32 to \$42 per hectare and a return to EOS of between \$13 and \$18 per hectare. These estimates reflect the impact of increased yield and cost savings. They are considered reasonable for estimating the net benefit from the use of EOS.

## B.8 Biosecurity

The calculations for the biosecurity case study are summarised in Table B.11.

	Average annual cost of FMD (\$m)	Impact of EOS (m)	Economic impact (\$m)
2015	860	5%	43.0
2025	860	6%	53.8

SOURCE: (BUETRE, ET AL., 2013) (HAFI, A; ADDAI, D; ZHANG, K; GRAY, E, 2015), ACIL ALLEN ESTIMATES

## B.9 Natural disasters

	Average annual cost of natural disasters \$billion	Contribution from EOS	Value of EOS in mitigating the cost of natural disasters \$ million
2015	7.1	0.03	0.213
2025	9.9	0.05	0.495

SOURCE: (ACIL TASMAN, 2010) (DELOITTE ACCESS ECONOMICS, 2013), ACIL ALLEN ANALYSIS

## B.10 Employment calculations

Employment impacts were estimated for selected case studies assuming that change in employment was proportional to the estimated change in value added. The calculation of these changes is summarised in Table B.13.

	Value added in agriculture 2015	Employment 2015	Impact in 2015	Proportion of value add 2015	Impact on employment 2015	Impact in 2025	Proportion of value add 2025	Impact on employment 2025
	\$ billion	FTE	\$billion	%	FTE	\$billion	%	FTE
Impact of improved weather forecasting on agriculture	22.6	107,300	0.025	0.11%	119	0.1350	0.60%	641
Impact of improved weather forecasting on the aviation sector.	23.3	40,000	0.060	0.26%	102	0.0632	0.27%	108
Impact of improved weather forecasting on the tourism industry	40	534,000		0.15%	682		0.16%	724
Ocean observation direct	0	68,978	0.050	0.00%	3,449	0.0000	7.50%	5,173
Ocean observation indirect	0	165,771	0.025	0.00%	4,144	0.0000	3.00%	4,973
Offshore petroleum	25.6	22,000	0.013	0.05%	11	0.0297	0.12%	26
Agriculture – precision farming	22.6	107,300	0.085	0.37%	402	0.7547	3.34%	3583
Property	54.5	325,000	0.064	0.12%	384.0	0.1288	0.24%	768
Total					9,293			15,997

SOURCE: ACIL ALLEN

## C SUMMARY OF BENEFITS

The compilation of benefits is provided in Table A1.

TABLE C.1 – COMPILATION OF BENEFITS					
Case Study	Sector	Impact	Nature of benefit	2015 \$ million	2025 \$ million
Weather forecasting	Agriculture	Broad acre agriculture	Economic	25.0	135.8
	Aviation	Reduced delays and cancellations for domestic flights	Economic	18.3	22.0
	Aviation	Reduced diversions for domestic and international flights	Economic	30.0	38.3
	Aviation	Reduced average annual costs of volcanic ash incidents	Economic	2.5	3.0
Sub total				75.8	199.1
Ocean observation	GBRMP	Environmental monitoring	Social/environmental	825.0	1,275.0
	Offshore petroleum operations	Weather forecasting and warnings	Economic	11.4	25.6
	Maritime	Offshore oil spill monitoring and response	Economic	1.9	4.1
Subtotal value added benefits				13.3	29.7
Subtotal environmental value to society				825.0	1,275.0
Agriculture	Cropping	Increasing broad acre cropping yields	Economic	17.7	220.9
	Pastoral	Improving pasture utilisation by sheep and cattle	Economic	24.0	480.0
	Biosecurity	Biosecurity measures	Economic	43.0	53.8
Sub total				84.7	754.7
Water	Water NSW	Monitoring water catchment condition, land cover changes and pollution sources	Social/environmental	0.9	0.9
	CSIRO	Enhancing habitat ecosystem services through sustainable diversion limits	Social/environmental	14.0	14.0
	Water use savings	Enhancing efficiency in water use, including in irrigated agriculture	Economic	39.5	80.0
Sub total				54.4	94.9
Landscape and land cover monitoring	Government	Vegetation monitoring to regulate land clearing activities in NSW and other jurisdictions	Social/environmental	20.7	39.2
	Property	Land cover mapping and the cadastre	Economic	64.4	128.8
Sub total				85.1	168.0
Natural disasters	Insured costs plus social costs		Economic	213.0	495.0
Sub total				213.0	495.0
Mining	Licence to operate	Vegetation and mine monitoring	Economic	5.0	6.7
Sub total				5.0	6.7
Total economic				495.7	1,694.0
Total social and environmental				860.6	1,329.1

SOURCE: ACIL ALLEN

## D. REFERENCES

- ABARES. (2014). *Australian Agricultural Commodity Statistics*. Canberra: Australian Bureau of Agricultural and Resource Economics.
- ABS. (2015). *Agricultural income – series 5202010*. Canberra: Australian Bureau of Statistics.
- ABS. (2015). *Industry performance by industry subdivision*. Australian Bureau of Statistics.
- ACIL Tasman. (2009). *The value of spatial information*. Melbourne: CRC for Spatial Information.
- ACIL Tasman. (2010). *The economic value of earth observation from space*. Canberra: CRC for Spatial Information.
- ACIL Tasman. (2010). *The value of Earth Observation from Space*. Canberra: Geoscience Australia.
- AMSA. (2015). *The National Plan*. Canberra: Australian Maritime Safety Authority.
- ANZLIC. (2015). *Land Cover*. [http://www.anzlic.gov.au/foundation\\_spatial\\_data\\_framework/land\\_cover](http://www.anzlic.gov.au/foundation_spatial_data_framework/land_cover), Accessed on 29 August 2015.
- APPEA. (2014). *Submission to energy green paper*. Canberra: Australian Petroleum Production and Exploration Association.
- ATSB. (July 2014). *Emerging trends in Australian aviation safety*. Australian Transport Safety Bureau. Canberra: Australian Government.
- ATSE. (2006). *Economics of Australia's sustained ocean observation system – benefits and rationale for public funding*. Canberra: Australian Academy of Technological Sciences and Engineering.
- AusCover. (2015). *AusCover remote sensing data access facility*. <http://www.auscover.org.au> accessed 29 August 2015.
- Australian Farm Institute. (2015, May). *The Implications of Big Data for Australian Farmers*. Quarterly Newsletter, 12(2).
- BBC News. (22 June 2011). *Australian flights resume as Chile volcano ash clears*. BBC News.
- BITRE. (2015). *Aviation Statistics*. Canberra: Bureau of Infrastructure, Transport and Regional Economics.
- BITRE. (2015). *On time performance 2014*. Statistical Report. Canberra ACT: Bureau of Infrastructure, Transport and Regional Economics.
- BTE. (2001). *Economic costs of natural disasters in Australia*. Canberra: Bureau of Transport Economics.
- BTRE. (2015). *BTRE Statistics – domestic aviation activity\_Domestic\_Annual\_Summary\_1984\_2014a.xls – sourced 10 November 2015*. Canberra: Bureau of Transport and Regional Economics.
- Buetre, B., Wicks, S., H, K., Millist, n., Yainshet, A., Garner, G., . . . Abdalla, C. T. (2013). *Potential socio economic impacts of an outbreak of foot-and-mouth disease in Australia*. Canberra: Australian Bureau of Agricultural and Resource Economics and Science.
- Bureau of Meteorology. (2015). *Australian Hydrological Geospatial*. Melbourne: Bureau of Meteorology – [http://www.bom.gov.au/water/geofabric/documents/Geofabric\\_Info\\_Sheet\\_online.pdf](http://www.bom.gov.au/water/geofabric/documents/Geofabric_Info_Sheet_online.pdf).

- Bureau of Rural Sciences. (2012). *Australian Collaborative Land Use Mapping Program*. Canberra: Department of Agriculture Fisheries and Forestry.
- Calder, W. (2014). *Resources and Energy – the outlook for Australia*. (pp. The Australian Rail Association –Heavy Haul Rail). Bureau of Resources and Energy Economics.
- Chevron. (2013). *Wheatstone oil spill response plan*. Perth: Chevron Australia Pty Ltd.
- Commonwealth and Queensland Government. (2013). *Reef Water Protection Plan 2013*. Brisbane: Queensland Government.
- Commonwealth of Australia. (2014). *Reef 2050 Long term sustainability Plan*. Townsville: Commonwealth of Australia.
- Crean, J., Parton, K., Mullen, J., & Jones, R. (2013). *Representing climatic uncertainty in agricultural models – an application of state contingent theory*. Australian Journal of Agricultural and Resource Economics, 359-378.
- Crean, J; Parton, K; Mullen, J; Hayman, P. (2014). *Valuing seasonal climate forecasts in a state-contingent manner*. Agricultural and Resource Economics, 61-77.
- Daley, G. (June 2011). *Australia ash clears after flight halts projects A\$2,100 cab ride*. Bloomberg.
- Deloitte Access Economics. (2013). *Building Australia's resilience to Natural Disasters*. Sydney: Deloitte Access Economics.
- Deloitte Access Economics. (2013). *Economic contribution of the Great Barrier Reef*. Townsville: Great Barrier Reef Marine Park Authority.
- Department of Agriculture Fisheries and Forestry. (2014). *Queensland's Agricultural Strategy to 2040*. Brisbane: Department of Agriculture, Fisheries and Forestry.
- Department of Environment and Heritage. (2014). *Great Barrier Reef: Reef facts*. Brisbane: Department of Environment and Heritage.
- DMP. (2014). *Western Australian Minerals and Petroleum Statistics Digest 2014*. Perth: Department of Minerals and Petroleum.
- DNV. (2011). *Assessment of the risk of pollution from marine oil spills an Australian Ports and Waters*. United Kingdom: Det Norske Veritas.
- DSITIA. (2014). *Land cover change in Queensland 2011-12 – State wide land cover and tree study report*. Brisbane: Department of Science and Information Technology, Innovation and the Arts.
- Evans, R., Murray, K., Field, S., Moore, J., Shedrawi, G., Huntley, G., . . . Marrable, D. (2012). *Digitise this – a quick and easy way to remote sensing method to measure the extent of dredge plumes*. PLoS One 7(12).
- Freebairn, J., & Zillman, J. (2002). *Economic benefits of meteorological services*. Journal of Applied Meteorology, 33-44.
- GBRMPA. (2014). *Great Barrier Reef Outlook Report 2014*. Townsville: Great Barrier Reef Marine Park Authority .
- GBRMPA 2014-2. (2014). *Great Barrier Reef Marine Outlook Report*. Townsville: Great Barrier Reef Marine Park Authority.
- Gherardi, S., Anderson, L., Sneddon, J., Oldham, C., & Mata, G. (2004). *Pastures from space – value to Australian sheep producers of satellite derived information on pastures*. Perth: Department of Agriculture.

- GRDC. (2007). *An economic analysis of GRDC investment in precision agriculture variable rate technology*. Canberra: Grains Research and Development Corporation.
- Gulfanti, M., Casadevall, T., & Budding, K. (2010). *Encounters of Aircraft with Volcanic Ash Clouds – A compilation of known incidents 1953 to 2009*. Reston Virginia: US Geological Survey.
- Hafi, A; Addai, D; Zhang, K; Gray, E. (2015). *The value of Australia's biosecurity system at the farm gate*. Canberra: Australian Bureau of Agricultural and Resource Economics and Science.
- Heath, A. (2014). *The Domestic Outlook and the Role of Mining*. NSW Mining Industry and Supplier's Conference. Sydney.
- IATA. (Accessed July 2015). *Operational Fuel Efficiency*. <http://www.iata.org/whatwedo/ops-infra/Pages/fuel-efficiency.aspx>.
- ICSM. (2015). *A vision for Cadastre 2034*. Canberra: ANZLIC Committee on Surveying and Mapping.
- John Deere Journal. (2015). <https://johndeere-journal.com/2015/08/the-payoff-from-precision-agriculture/>.
- Johnson, S., & Holt, G. (1997). *The value of weather information*. In K. R. A, Economic Value of Weather and Climate Forecasts (pp. 75-108). Cambridge: Cambridge University Press.
- Keating, B., Carberry, P., & Hammer, G. (1996). *An overview of APSIM*. European Journal of Agronomy, 267-288.
- Lawrence Consulting. (2014). *Economic contribution of the Minerals and Energy Sector to the Queensland economy*. Brisbane: Lawrence Consulting.
- Le Marshall, J., Lee, J., Jyng, J., Gregory, P., & Roux, B. (2013). *The considerable impact of earth observations from space on numerical weather prediction*. Australian Meteorological and Oceanographic Journal, 63, 497-500.
- Lesslie, R., Mewett, J., & Walcott, J. (2011). *Landscapes in transition: tracking landscape change*. Science and economic insights. Issue 2.2, 2.
- Marshal, G; Parton, K; Hammer, G. (1996). *Risk attitude, planting conditions and the value of seasonal forecasts to a dryland wheat grower*. Australian Journal of Agricultural Economics, 211-234.
- National Marine Science Committee. (2014). *National Marine Science Infrastructure Action Plan*. CSIRO.
- Neale, T. (July 2015). *Precision agriculture*. IGNS Symposium. Brisbane.
- NRM Spatial Hub Rangeland Alliance. (2015). *The NRM Spatial Information Hub*. <http://www.crcsi.com.au/library/resource/nrm-spatial-information-hub-flyer> accessed 30 August 2015.
- O'Kane, M. (2014). *Final report of the independent review of coal seam gas activities in NSW*. Sydney: Office of the Chief Scientist and Engineer.
- Oxford Economics. (2009). *Valuing the effects of Great Barrier Reef Bleaching*. Australia: The Great Barrier Reef Foundation.
- Oxford Economics. (2012). *The economic impacts of air travel restrictions due to volcanic ash*. London: Oxford Economics for Airbus.
- Peterson, E., & Fraser, R. (2001). *An assessment of the value of seasonal forecasting technology for Western Australian Farmers*. Australian Agricultural Systems, 259-274.

- Precision Agriculture. (2015). [www.precisionagriculture.com.au/satellite-imagery.php](http://www.precisionagriculture.com.au/satellite-imagery.php) – accessed on 6 May 2015.
- PWC. (2014). *Value adding – Australian Oil and Gas Industry*. Canberra: APPEA.
- QLUMP. (2015). *Background to the Queensland Government land use mapping program*. <https://www.qld.gov.au/environment/land/vegetation/mapping/qlump-background/>. Retrieved June 2015
- Queensland Resources Council. (2014). *Economic Contribution of the Minerals and Energy sector 2014-14*. Brisbane: Queensland Resources Council.
- Robertson, M., Carberry, P., & Brennan, L. (2007). *The economic benefits of precision agriculture: case studies from Australian grain farms*. Sustainable Ecosystems Division: CSIRO.
- RTA. (2009). *Economic analysis manual*. Sydney: Roads and Traffic Authority.
- Schofield, C. (2007). *Land and water Australia's portfolio return on investment*. Canberra: Land and Water Australia.
- Stoeckl, N., Farr, M., Larson, S., Adams, V., Kubiszewski, I., Esparon, M., & Costanza, R. (2014). *A new approach to the problem of overlapping values – A case study of the Great Barrier Reef*. *Ecosystem Services* (10), 61-78.
- Taylor, R., & Perry, M. (22 June 2011). *Ash cloud clears, Australian flights resume*. Canberra: Reuters.
- The Australian. (2010). *Report says PTTEP may lose its licence*. The Australian Newspaper.
- The International Charter. (2015). *The International Charter (Space and Major Disasters)*. <https://www.disasterscharter.org> accessed on 18 November 2015.
- USGS. (2014). *Landsat and Water – case studies of the Uses and Benefits of Landsat imagery in Water Resources*. Washington: United States Geological Survey.
- V, B., Schroeder, T., King, E., & Dyce, P. (2013). *Reef rescue marine monitoring program*. Townsville: CSIRO report to the Great Barrier Reef Marine Park Authority.
- Volcanic Ash Advisory Centre. (2015). <http://www.bom.gov.au/info/vaac/index.shtml>. Bureau of Meteorology.
- Young, M. (1992). *Sustainable investment and resource use*. Paris: Pantheon Press, Carnforth and UNESCO.



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