The economic value of earth observation from space

A review of the value to Australia of Earth observation from space

Prepared for the Cooperative Research Centre for Spatial Information (CRC-SI) and Geoscience Australia

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Economics Policy Strategy

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Key points

- EOS contributed at least $3.3 billion to Australian GDP in 2008-09.
- On conservative assumptions it is estimated that the contribution to GDP could grow to around $4.0 billion by 2015.
- Additional benefits in climate change adaptation, emergency response and natural resource management are conservatively valued at $1.0 billion per year.
- The commercial sector comprises around 35 small to medium enterprises with estimated combined annual sales of between $30 million and $40 million in 2010.
- The economic cost of a denial of service requiring ‘source shift’ is likely to be at least $100 million in the year during which it occurs.
- A complete denial of service would put billions of dollars of benefits at risk - even if the impacts on Australia’s defence preparedness are ignored.
- Australia launching a single major, high cost satellite for civilian purposes is not necessarily seen by industry participants as the best ‘insurance’ against a denial of service nor would it provide adequate data for all users.
- A portfolio of investments to secure access to a number of satellites, to funnel data and to raise awareness and coordination across government is generally considered to be more cost-effective.
- Launching a small number of low cost ‘micro’ satellites, notably for use in weather applications, might also form part of a sensible investment portfolio.
- In the medium term, major government applications of EOS are likely to be in climate change, natural resources and emergency management, as well as in defence and national security.

Executive summary

This report provides, for the first time, an assessment of the value of Earth observation from space (EOS) to the Australian economy. In the absence of definitive survey data on some of the components of value, conservative assumptions were adopted throughout, thus yielding a lower-bound, highly defensible estimate of the value of EOS to the economy.

Economic impact in 2008-09

Over 90 government programs depend on EOS to a greater or lesser degree. Surveyors, farmers, miners, insurers, fishers, engineers, and other commercial users are also increasingly using EOS to pursue their business objectives.

The EOS sector's direct contribution to Australian GDP is estimated at $1.4 billion in 2008-09. This includes imagery, technology and a significant amount of skilled labour. In addition, it is estimated that EOS related productivity benefits were worth $1.9 billion to the Australian economy in 2008-09.

Taking these two impacts together, the *minimum* economic impact of EOS in 2008-09 is estimated to be $3.3 billion.

The true economic value of EOS

The GDP estimate does not include important benefits in addressing overarching national challenges. Evidence from EOS will not always translate into better decisions but even marginal improvements in some of the areas where EOS is known to play a significant role will be highly valuable. The following are estimates of the value of a small contribution by EOS in key areas:

- Improved response to climate change: $300 million per year
- Better natural resource management: $500 million per year
- Emergency response benefits: $200 million per year.

Based on EOS making a small contribution, the scale of these additional benefits is therefore in the region of $1.0 billion per year. This will increase as the use of EOS becomes more important and widespread.

Table ES 1 **The annual economic impact of EOS in Australia**

	2008-09 estimate
Direct contribution to GDP	$1.4 billion
Productivity impact on GDP	$1.9 billion
Other benefits – climate change, NRM, disasters	$1.0 billion

Data source: ACIL Tasman analysis

Private sector footprint

Currently the vast majority of Australian EOS activity takes place in government. Official national statistics on private sector EOS activity are not available. Depending on how EOS is defined, an estimated 35 to 100 small to medium sized companies could be classed as falling into the sector. The commercial sector which provides imagery and basic data processing only is estimated to have a turnover of $30-40 million per year in Australia; however if wider private sector EOS use is included the footprint would be a multiple of this.

Interviews with important private sector players in the EOS space suggest that business is very strong, with annual growth rates in sales of around 25% and higher reported. If such rates of growth could be sustained, the private EOS sector would grow significantly over the next decade. The potential for growth depends on the rate at which EOS technology services are adopted in industry and on the extent to which Governments outsource value adding services.

The impact of a loss of satellite imagery and data

The issue with a so-called 'denial of service' in EOS is different from a denial of service for communications or positioning satellites. A denial of service in these two areas could quickly disrupt the operation of a modern economy.

If access to EOS ceases for whatever reason, the economic impact would be more gradual than that for communications or positioning. Our stakeholder consultations revealed that most users could compensate for a loss of data for a few days or even weeks, but after this, serious problems would start to set in for many users.

The prospect of a denial of service to Australian users is very real as Landsat 5, the satellite on which many government programs depend, will not be replaced until 2013 at the earliest. Landsat 5 is operating well beyond its planned life span, is running completely on back up and has recently had serious technical problems.

Landsat 7 currently provides a back up option although it too has a serious technical issue which means that approximately one quarter of each 'scene' captured by Landsat 7 is missing. If Landsat 5 were to fail, users would thus be forced to live with data gaps or fill them from commercial sources at least until the Landsat Data Continuity Mission (LDCM) is in orbit (and assuming the US government continues its free access policy).

If Landsat 5 were to fail say in 2010, there would be serious data gaps for around 2-3 years of imagery and gap filling coverage would have to be acquired from commercial sources.

EOS users could probably compensate for a loss of data for a few days or even weeks, but after this, serious problems start to set in for many users.

In another context, the Bureau of Meteorology and those depending on weather observation data would be seriously affected within days, or possibly within hours, if the satellites on which the Bureau depends became unavailable.

In economic terms, the immediate effect of a denial of service would be the under-utilisation of resources in government programs. Whilst these resources would not sit idle, there would be significant inefficiencies and disruption to effort.

It cannot be anticipated which events might be overlooked or even lost as a consequence of a denial of service. This could have critical implications for the modelling of natural processes – for example if a serious coral bleaching or fish mass mortality event were to occur during a blackout period, it may be hard to piece together important pieces of the puzzle retrospectively.

In our view a realistic assessment of the economic impact of an unplanned denial of service requiring 'source shift' is at least $100 million in the year during which such a denial of service occurs. This would include lost government internal productivity and the cost of acquiring data from alternative sources, as well as the value of some lost outcomes.

This cost might be reduced through use of other commercial satellites. However many departments would not have budgetary cover for such emergencies.

A complete denial of service

A complete denial of service would seriously damage a range of EOS capabilities and jeopardise the benefits identified in this report. Such a scenario is admittedly a low probability event, given the number of satellites in orbit, but it remains a possibility.

The longer term 'cost' to the Australian economy, based on our estimates, is likely to run into billions of dollars. There would also be consequences for Australia's defence capability.

Implications for large scale government investment

A full discussion of possible investment strategies that Australia might pursue with respect to EOS capabilities in the future is beyond the scope of this report. However during consultations views were expressed on what Australia might do to address concerns over continuity of access to EOS data.

Putting its own satellite into orbit is one of Australia's options to address some of the risks associated with a denial of service. Depending on the type of satellite, this could cost $300 million to $500 million to develop and launch and would involve ongoing operational costs. Several interviewees commented that under an 'ideal' scenario Australia would have its own EOS satellite, such as a hyper spectral geostationary satellite, that would provide Australian coverage. The Korean capability was cited in interviews as a comparison. Such a satellite would supply useful data for the region including Indonesia as well as Australia, and could thus also help to strengthen regional partnerships.

However, a much more comprehensive as well as cost-effective way to address vulnerability and continuity of access issues could be to secure guaranteed access to several of the satellites launched by other countries. One prospective partner for this type of arrangement would be the European Space Agency. There may also be opportunities with other partners including the National Remote Sensing Centre of China.

This type of investment would have to be part of a broader, coordinated portfolio of investments to ensure that access translates into use and benefits. There are still many opportunities across various Departments and tiers of government to collaborate and share resources. Efforts to funnel data, as well as initiatives targeting general awareness of EOS across government should be part of the portfolio. A coordination function may also be required to dovetail these complementary investments.

A cost-effective alternative to a dedicated meteorological satellite for Australia could be to launch several micro-satellites which could provide sounding data through GPS radio occultation at a cost of perhaps $20 million in space.[1]

Finally, it is believed that a quantum shift in data availability over the coming decade will mean that Australian ground-station infrastructure and networks will require an upgrade.

All of this could be achieved at much less than the cost of launching a major satellite. A rough order of magnitude costing identified during this consultancy suggests that the investment required would be in the region of $100 million to $200 million.

Opportunities for growth

The work and consultations undertaken during the preparation of this report indicate that EOS is primed to be a major growth sector over the next decade.

1 Interview Bureau of Meteorology 24 June 2010.

The common view was that we have just seen the 'tip of the iceberg' in terms of the contribution which EOS could make.

In the short time period during which this report was compiled, numerous examples of where EOS is not as yet being used to its full potential were identified, including:

- monitoring of illegal fishing across State and Commonwealth fisheries
- the Bureau of Meteorology stated that EOS is still underutilised in the weather space
- petroleum and mining companies are likely to use it more, for example in environmental monitoring and in ocean monitoring more generally
- monitoring coastal vulnerability
- the Australian Bureau of Statistics is currently exploring the potential for EOS to feed into its reporting
- compliance monitoring in the NRM context across various States, including greater frequency of observations and reports
- there is potential for EOS to be utilised in the agricultural policy and forecasting space (for example by ABARE)
- national environmental accounts will draw heavily on EOS
- policing can draw more on EOS (e.g., to identify illegal narcotic crops), and so on.

It is therefore expected that given the appropriate stimulus and coordination, EOS could have a significantly higher impact on the economy by 2015. Growth in government programs is probably somewhat budget constrained over the next 3-5 years; however the impacts of EOS in terms of productivity and final outcomes are set to grow fairly rapidly.

On conservative growth assumptions, the annual contribution to GDP of EOS is estimated to reach around $4 billion by 2015. Benefits to climate change, natural resources management and emergency management are also expected to grow, however the value of $1 billion is considered to remain appropriate as a reference value. There will be addition benefits accruing to Australia's defence and national security. These have not been estimated.

1 Introduction

Geoscience Australia's National Earth Observation Group commissioned this study through the Cooperative Research Centre for Spatial Information.

The primary aim of this study was to determine the value of Earth observation from space (EOS) activities to the Australian economy. The three main objectives of this study were to:

1. estimate the direct and indirect economic value of space based Earth Observation activities to the Australian community in 2008-09 year
2. determine the direct and indirect economic impact of an unplanned denial of all Earth Observation data to the Australian economy in 2008-09 year
3. identify contemplated large-scale government applications of Earth Observation data and estimate their direct and indirect economic value.

In subsequent discussions it was agreed that the report would also provide an estimate of the size of the EOS industry, particularly the SME sector in the 2008-09 financial year.

The scope of this report did not include the value of EOS services for national security or defence.

1.1 What is Earth observation?

The Earth can be observed from a variety of distances; however this report is concerned with activity linked to observing the Earth from space.

This type of Earth observation includes use of optical, radar, chemistry and gravity sensors and/or other devices mounted on satellites to capture and transmit EOS data, as well as the infrastructure, skills and technology that is required to receive, process and analyse data on the ground.

The major other source of Earth observation data, which is omitted from this report, comes from lower altitudes, that is, from cameras and sensors mounted on platforms that can be flown by airplanes, drones or even hot air balloons.

1.2 EOS and the wider geospatial sector

Earth observation as an activity is traditionally closely linked to the geospatial sector, and many EOS specialists have a background in the discipline of remote sensing.

However, as an activity, EOS is carried out by a number of people and organisations both outside and within the geospatial industry; for example, in its broadest sense, any citizen who uses Google Earth is involved in a form of Earth observation, and is obtaining value from using EOS.

This makes it important to distinguish between what might be termed the economic footprint and the true economic impact of EOS, as discussed later in this report (see Section 2.1).

1.3 Why observe the Earth?

There are a number of reasons why Earth observation is carried out, such as to:

- better understand planetary and other processes (basic science)
- meteorology, weather forecasting, measurement and monitoring of cloud cover and weather patterns
- detect, track and trigger warnings relating to threats such as wildfires, cyclones, floods, etc., and assess damage
- monitor and measure crops, vegetation, forests, tree cover, water resources and land use change (e.g., to determine carbon flux)
- explore for and identify mineral and petroleum resources such as precious metals or gas and oil (which can be detected from space by a variety of means)
- map bathymetry in shallow waters
- identify and monitor environmental changes (e.g., desertification, sea surface temperature changes, climate change and so on)
- monitor public and private infrastructure (e.g., roads, pipelines, etc.)
- locate positions and monitor movements on the ground (military/tactical applications and for national security)
- assist with town planning and development (e.g., understanding environmental impacts and compliance issues)
- understand insurance risk, and
- study historical sites.

In other words, the reasons for observing the Earth are manifold and range from national security to profit driven endeavour, and from basic science to practical issues around the management of our environment and natural resources.

This report provides examples in all these areas of EOS use in Australia. In many if not most cases, EOS provides a means for achieving something that would otherwise be impossible (e.g., mapping large swathes of remote country); in other applications, EOS simply provides a cheaper and quicker option than the existing methods for achieving the same outcome.

Many benefits have already been reaped from the use of EOS, and significant costs have already been avoided – but perhaps more importantly, this report argues that the potential for further benefits and cost avoidance from EOS is growing very rapidly. This is because EOS is proving to be a critical enabler of key decision making processes around a number of 'big ticket items' – areas such as climate change, environmental reporting and compliance, and natural resource management.

1.4 Special features of EOS activity

Earth observation typically combines accurate geo-referencing with a *description* of the point under observation. In other words, it is almost always about the *condition* of a geo-referenced object such as a piece of land, a pipeline, or a part of the ocean.

Using modern EOS techniques it is possible to extract a host of useful information from the data and imagery provided by satellites – including inferences about moisture, heat, evaporation, salinity, vegetation, or even natural resources hidden beneath the ground. These are the objective measures which feed into models and can underpin evidence-based policy.

Rather than geo-referencing and tracking an object as it moves through space (such as a car or tractor), EOS is typically about observing what happens at a geo-referenced point over time. A single image can hold significant value; however, in many applications it is the 'return data' that are of most interest as they capture changes that happen over time.

A significant component of the value of EOS comes from fusion of data from different sources and analysis to provide new insights and information. For example fusion of gravity, radar and optical images, combined with hydrological modelling can produce information on surface and groundwater resources that might not be otherwise available or economic from ground measurement methods.

Many of the uses of archived data and images could not have been imagined twenty or thirty years ago, but access to a time series of images has meant that one can now track changes that occurred over large areas of the Australian continent. This information can be 'married' with other datasets, for example, to explore causal relationships (e.g., research on climate change) or to monitor compliance (e.g., water drawdown consistency with prior allocations).

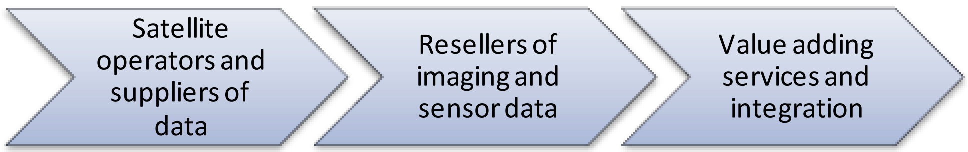
As sensors, processing capacity, and coverage continue to improve, so will the ability to detect trends, attribute causality, monitor compliance, model change, and exploit imagery both for commercial gain as well as to help inform government policy. At the same time, increasing national and international obligations to record, monitor and report environmental changes mean that EOS is set to be a major growth area for the foreseeable future.

1.5 The structure of the Australian EOS marketplace

1.5.1 The value chain

The EOS value chain essentially consists of EOSsatellite operators, suppliers of data or imagery ('resellers') and a range of value adders and users of the data products. The market is complex because resellers often carry out more or less sophisticated value adding, and because the value adders may themselves be the users.

Figure 1 **EOS value chain**



Data source: ACIL Tasman, *(ATSE, 2009)*

The process begins with raw data downloaded from a satellite which is then processed and orthorectified to remove tilt, terrain, atmospheric and other digital image distortions. The resulting image can then be used like a map, for example, as a layer in a geographic information system (GIS). Detailed scanning or further processing of the image can reveal important information according to the specific needs of the end user.

Spectral images can provide information on ocean depth, moisture content, biomass, salinity, cloud movements, ocean currents, sea level, ocean salinity and a range of other physical and chemical properties of vegetation and ocean characteristics.

Around 70 per cent to 80 per cent of the turnover accrues to suppliers of the data. The remainder of this turnover accrues to resellers and value adding organisations[2].

Final users range widely from managers in government departments who give advice on the basis of EOS, to citizens who utilise online imagery, to local government officials who use maps for planning and approval processes, and even to oil and gas companies that base key investment decisions in part on geoscience and other information that is in part collected through space based EOS.

Increasingly, agribusiness is starting to use EOS imagery to plan and monitor crops, yields and forecast likely production from season to season.

1.5.2 Sources of imagery and data

Satellites and ground stations

According to NASA, there are around 3,000 useful satellites in space, with some 40 countries owning satellites.[3] Other sources suggest that only around 900 of these are operational[4]. Only some of these satellites were designed for the purpose of observing the Earth, but many satellites are potential sources of EOS data, including satellites whose primary purpose is weather monitoring or scientific research. A list of important EOS satellites is provided in Appendix B.

The type of equipment ('sensor') mounted on a satellite determines the nature of the EOS data obtained from that satellite. So-called optical sensors can capture images that would be visible to the human eye (e.g., Google Earth type imagery), as well as data from bands with different spectral ranges (e.g. infrared data, which can for example be used to detect moisture in vegetation). Optical sensors are akin to a film or digital camera taking pictures of the Earth from a distance. Optical sensors are also called 'passive' sensors as they rely on the sun's reflected energy to image the Earth.

By contrast, other instruments are classified as 'active' because they do not rely on the sun's reflected energy. These include, for example, the so-called Synthetic Aperture Radar (SAR) sensor which is a microwave sensor capable of

2 Personal communication from consultations.

3 Oberright, John E. "Satellite, Artificial." World Book Online Reference Center. 2004. World Book, Inc. http://www.nasa.gov/worldbook/artificial_satellites_worldbook.html.

4 http://www.ucsusa.org/assets/documents/nwgs/quick-facts-and-analysis-4-13-09.pdf

imaging the Earth regardless of time of day, cloud, haze or smoke over an area. The instrument is classified as active as it emits the microwave energy necessary to image the Earth's surface. [5]

Some satellites circle the Earth whilst others are 'geostationary', i.e., remain over the same area as the Earth turns – they are not actually stationary but their orbit is such that they appear stationary when seen from a point on Earth.

Satellites can 'point' their sensors at areas of interest on Earth and capture data as they fly over these selected areas. On-board data storage capacity determines the amount of imagery satellites can collect in one pass-over. When full capacity is reached, the data must be shed or downloaded to ground stations (some satellites can also operate in direct downlink mode).

For so-called 'public good' satellites such as Landsat 5 the areas targeted for observation and the duration of coverage depends on arrangements between governments (for example, in return for running a ground station a country may receive access to the satellite as it passes overhead as long as it agrees to pass on the data to other governments as well).

Satellites send the data to ground stations that have been built specifically for this purpose (including satellite dishes and computing infrastructure). These ground stations are usually government owned. A satellite which orbits the Earth several times a day may send data to a number of different ground stations across the globe.

A geostationary satellite would tend to send data to a dedicated ground station or regional cluster of ground stations. Some ground stations upload their data or imagery directly to the Internet, from where it can then be accessed by users worldwide – sometimes within a matter of hours from the time the images were taken.

Commercial satellite operators sometimes operate ground stations as well, or they lease facilities and services from governments, universities or research institutions that are capable of providing these. In this case, satellite owners pay the operators of the ground stations a fee but retain copyright of the data downloaded from their satellites, which they then sell on to final users.

To obtain imagery and data, if it has not already been placed in the public domain by one of the major government agencies such as the US Geological Survey, end users will typically have to pay either the government agencies which own and operate ground stations, or commercial re-sellers.

[5] http://www.ga.gov.au/remote-sensing/satellites-sensors/jers-1.jsp#sensor

As indicated earlier, Australia does not own an EOS satellite and as such the sector depends on imagery and data supplied by satellites owned by other countries, some of which is obtained from commercial resellers further discussed below.

At present, government continues to be the predominant player in Australian EOS. Perhaps the most important feature of the Australian market for imagery is that the Australian government has historically depended on data from the Landsat satellites operated by the National Aeronautical and Space Administration (NASA) – the majority of the EOS data currently processed by the main government users comes from Landsat 5.[6]

Landsat 5 is at risk of failing in the near future – it was launched in 1984 with a primary mission lifetime of three years, but remarkably it is now in its 26th year of operations. It is still relied upon because Landsat 6 failed on launch and Landsat 7 has a serious technical problem which compromises its imagery.

Landsat 5 is running completely on back up and has recently had technical problems as well. The Landsat Data Continuity Mission (LDCM) is due to be launched in December 2012 which means it will not be operational until the beginning of 2013 at the earliest.

Governments in Australia also draw other public and commercial satellite services. The public services include data from the MODIS sensors flown on the Terra and Aqua satellites operated by NASA. Commercial satellites used by governments include the IKONOS and GeoEye satellites operated by GeoEye, the QuickBird and WorldView satellites operated by DigitalGlobe, the IRS-P6 satellite operated by the Indian Space Research Organisation (ISRO) and the SPOT satellites operated by the Centre Nationale d'Etudes Spatiale (CNES).

1.5.3 High resolution versus low resolution imagery

Broadly speaking the Australian market for imagery can be divided into relatively low or 'medium' resolution (10-30m) imagery such as that from Landsat 5, of which the government is the primary user. This type of data is particularly useful for gathering broad descriptive environmental data such as on land use and land use change, vegetation and land cover, and so on, where a high degree of resolution is not required for reporting or other purposes. The US government makes the Landsat data available for free (or at very low cost).[7]

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[6] Stakeholder interviews; several interviewees volunteered the figure of "over 90%" however this may have referred to data volumes in specific programmes.

[7] The US government has not been able to make freely available some of the Landsat data which was collected by and held in regional archives managed by owners of ground stations

At the other extreme of the market is so-called 'very high' resolution imagery (2.5 meter resolution or better, such as Digital Globe and GeoEye can provide), a market segment in which the commercial satellite providers are in fact beginning to compete with aerial photography as some of the commercial satellites can provide imagery at a resolution of better than 50 centimetres. This is still the smallest market for satellite imagery, largely because the traditional users of very high resolution imagery, such as local councils, have well established relationships with the aerial imagery providers.

In between the 'medium' and 'very high' resolution imagery market is 'high' resolution imagery which has a resolution of between 2.5 and 10 meters. Demand for this resolution is among the highest and this is where the bulk of commercial reselling takes place. It is also the part of the market in which private end users are increasingly important. Private industry might, for example, purchase satellite imagery to monitor and provide evidence of environmental compliance for their rural, remote projects. In such cases, it can be more cost-effective to order images from commercial suppliers than to pay for an aircraft to be flown out to the area to take a limited number of images. More examples of where commercial users are using this type of imagery are provided throughout this report.

1.5.4 Industry and market size

There is no classification under the Australian and New Zealand Standard Industrial Classification (ANZIC) that would adequately define the geospatial industry in Australia. In turn, the same applies to that component of the geospatial industry that represents the EOS sub-sector.

ACIL Tasman has previously attempted an estimate of the geospatial industry using data from the Australian Bureau of Statistics; this indicates that in 2007 the Australian spatial information industry may have comprised around 3,234 businesses generating estimated total revenue of around $2.5 billion (ACIL Tasman, 2008). Many of these businesses would utilise maps generated from EOS services; however, the majority would not categorise their businesses as highly dependent on EOS.[8]

A mini survey was undertaken of geospatial companies but the response was limited (the results are discussed in section 2.1.2 below). However from the returns that were received, and from follow up consultations with companies, it is considered that geospatial firms that are not in the direct EOS business

worldwide. For some of the historical imagery Landsat users therefore have to pay some amount, which typically is nevertheless well below commercial rates.

[8] This conclusion is based on industry consultations, a mini survey and internal ACIL Tasman data.

would attribute revenue of between around $5,000 per annum and $80,000 per annum to EOS related services.

Consultations undertaken for the purpose of this study suggested that there are up to 35 private sector companies of this group, operating in Australia, that provide services more directly dependent on EOS generated data. Based on feedback from commercial stakeholders, revenues that might be attributed to EOS in these firms ranged from say $100,000 per annum to $6 million per annum. Drawing on this data and a rough understanding of some of the major sales achieved during the past five years or so (such as the land cover imagery for NSW), it appears plausible that annual revenue from sales of EOS imagery and data by the major resellers in Australia is in the region of $30 million to $40 million per annum. Key stakeholders interviewed during this consultancy felt that this estimate of the market was reasonable[9].

There is however some uncertainty around this figure – feedback from Geoscience Australia suggests that this may not include sensitive datasets held and updated by Defence or Police departments. Some major resellers also have regional headquarters outside Australia and it is not clear whether their sales have been fully captured. It is suspected that the size of the market is therefore larger but this could not be confirmed during the preparation of this report.

The precise market size is not critical to the discussion around the economic benefits of EOS. From feedback received during the consultancy, sales of data and imagery only account for a very minor share of EOS costs – perhaps only 2% of a typical budget. If some datasets have been sold 'twice over' this might raise the cost estimates by a small percentage but should not affect the net benefits derived in any significant way. It is however a matter of priority to government to identify spending and facilitate exchange of data where possible.

As a simple 'thought experiment' one can apply this proportion (2%) to the estimated size of the geospatial industry ($2.5 billion) as discussed earlier. This would suggest that the core EOS sector in Australia might be up to $50 million – not too far off from the $30 million to $40 million ventured earlier. Given the dynamic nature of the market, it is however impossible to determine accurately whether it is nearer $30 million or $50 million at the time of writing.

[9] This includes revenues that accrue to data suppliers as well as resellers and value adding organisations.

2 The economic impact of Earth observation

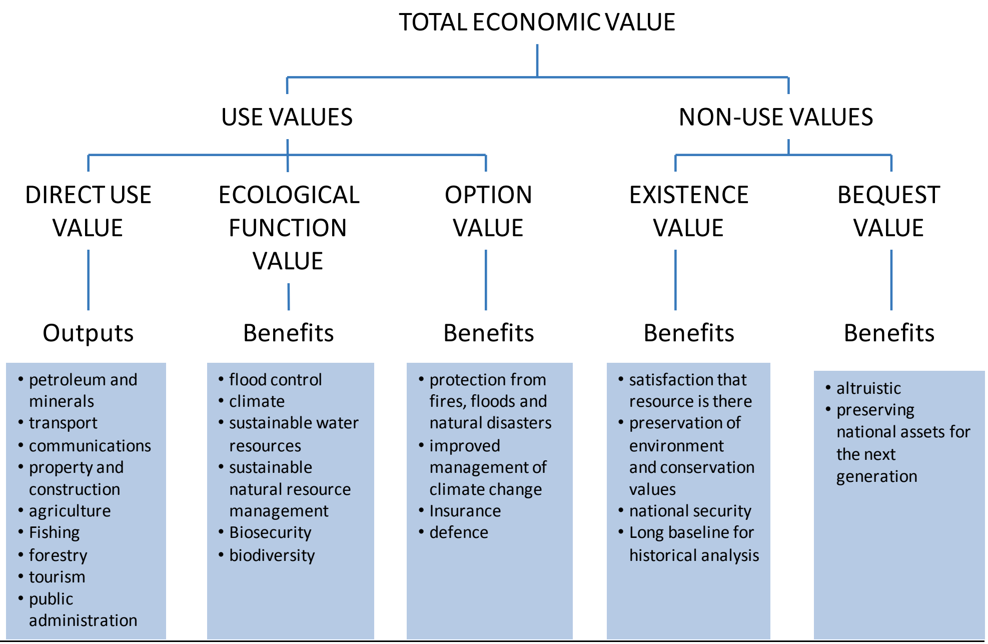
2.1 Economic footprint, impact and value

The economic 'footprint' of the sector or activity describes the effort that is directly associated with EO; this would include the effort by government and research organisations as well as in the private sector. Footprint is a narrower indicator than impact.

Economic 'impact' may include direct and indirect impacts and multiplier effects, productivity impacts, costs avoided, changes in resource stocks, and so on. In the environmental or NRM sphere it may notably also include so-called non-use values – a summary of total economic value is presented in Figure 2, where the broader distinction between use and non-use value is made.

People may have a willingness to pay (WTP) for the existence of species and biodiversity (existence value), the ability to pass on a healthy environment to future generations (bequest value), options created or retained (option value), and indicators of status (prestige value). This group of intangibles is perhaps the most controversial. Nevertheless, WTP is an indicator of an activity's perceived value to the community.

Figure 2 **Components of total economic value**



Source: Based on a conceptual framework from Young (1992).

Economists consequently use different measures to capture footprint, impact and value and there is no single 'right' answer to approach this. Often it depends on the type of data that are available, especially when the area under consideration is not specifically identified in the national accounts or has not been covered by a detailed national survey (as is the case with EOS).

2.1.1 Estimate of EOS footprint in Australia (2008-09)

Our approach to the economic footprint of EOS in Australia is to attempt a broad estimate of 'value added' that can be attributed to EOS. This is equivalent to its contribution to Gross Domestic Product (GDP), because GDP is the summation of all value added across the economy. The concept of value added as used by economists is subject to certain accounting conventions which need not be discussed here, however it may be noted that value added includes the value of labour inputs. As wages form a high proportion of government outlays, typically over 50% (but much higher for some programmes) a large proportion of government expenditure is value added.

The EOS related value added contribution from the government sector is not clear cut because it is not obvious how to attribute an appropriate proportion of a program's budget to EOS. Geoscience Australia has compiled a detailed list of 92 government programs and projects that depend to varying degrees on EOS (excluding defence, police and national security applications). These programs were assessed as falling into three groups: those highly dependent on EOS, those with medium dependency, and those with a low level of dependency. The list is included at Attachment C and a summary of the results is shown in Table 1.

Table 1 **Summary of Commonwealth and State agencies EOS usage, 2008-09**

Expenditure	Usage level			
	Low	**Medium**	**High**	**Total**
Less than $100,000	1	2	8	11
$100,000 - $1,000,000	3	6	26	35
$1,000,000 - $10,000,000	4	12	20	36
$10,000,000 - $100,000,000	2	2	3	7
$100,000,000 - $1 billion	0	0	2	2
Greater than $1 billion	0	1	0	1
Total	**10**	**23**	**59**	**92**

Data source: Geoscience Australia

In total, these programs accounted for around $1.3 billion in active government programs as at 2008-09. Depending on the weighting allocated to each level of dependency on EOS, and the proportion that is value added, the extent of the footprint across this pool of EOS programs can be estimated at between $0.3 billion and $1.0 billion. In addition, defence has a significant EOS program.

Overall the potential footprint in government uses is therefore $0.8 billion to $2.0 billion, but this still omits police and local government as well as potentially some other government users.

The value added in the private sector should, in theory, be added to this as part of the total Australian EOS footprint measure; however is difficult because:

1. No survey of private sector EOS has ever been undertaken; therefore whilst it is known that many companies engage in aspects of EOS, the extent of this activity is unknown; for example the labour time spent by a GIS analyst in accessing and interpreting EOS imagery could quite legitimately be included in a footprint measure.

2. Secondly, the attribution issue will be the same as in the government sector. EOS is often an important enabler but it typically represents only a minor part of a project and budget.

2.1.2 Value of EOS to Australia Mini-Survey

An attempt to fill the data gap was undertaken with a mini-survey for this report. This was sent out to around 600 members of the Spatial Industry Business Association (SIBA) by the SIBA Secretariat. The main aim was to collect some indicative data.

The response to the survey was small. However follow up consultations indicated that most geospatial firms derive only a small proportion of their revenue from EOS services – ranging from around $5,000 per annum to as high as perhaps $400,000 per annum. A smaller number of resellers and value adding companies however earn revenues in the range of $4 million to $6 million.

It may be noted that if Australian resellers of imagery and value adding companies have a turnover of $30 million to $40 million in total (as discussed in Section 1.5), but spend around 75 per cent their earnings on acquiring the imagery, then value added would be less than $10 million in this sector.

Given the absence of reliable data for the private sector and the range of the estimates discussed above, however, this report concludes that a conservative estimate of the economic footprint of EOS in Australia – the contribution to GDP – was between $1.0 billion and $2.0 billion in 2008-09 (see Table 2).

Table 2 **The EOS sector's direct contribution to GDP in 2008-09**

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 includes a broad estimate of the contribution Commonwealth and State Governments and from defence and national security which is probably an underestimate of the ultimate value in these sectors.

2.1.3 Productivity impact in 2008-09

EOS as a subset of spatial information

ACIL Tasman (2008) modelled the impact of geospatial information on productivity across the Australian economy. This covered all modern geospatial information technologies and geospatially driven applications, of which EOS is a subset. The report provided a large number of case studies and examples of applications, many of which had EOS components.

The finding of the modelling carried out for the report was that the productivity impact under a realistic scenario was $12.57 billion in 2006-07. Given that EOS is a subset of this, it is reasonable to attribute a proportion of the estimated productivity gain to EOS.

Presence of EOS across sectors

Table 3 summarises the areas covered in the 2008 report and gives an initial assessment of the significance of EOS in each area. Stakeholder consultation carried out for this report added a number of applications which were not included in the 2008 study. Table 3 shows that EOS occurs in almost all of the areas covered in the previous ACIL Tasman report.

Only manufacturing is an area for which examples of EOS could not be readily identified. Sectors in which EOS appears to play only a minor role are construction, transport, communications, retail, tourism, local government, and health. Whilst EOS is of some benefit to these areas, the relevant EOS effort would likely be captured under property and business services (e.g., consultants who assist the construction sector and others).

Also, as mentioned in the table, local government currently mainly relies on aerial surveys rather than EOS, although this may change with time if the cost of EOS falls.

An example of the use of imagery which led to direct economic benefits in agriculture is presented in Box 1. The example is from a farm in the USA, but the type of benefit in the example could apply to many farms in Australia.

Table 3 **Use of EOS across the economy or areas of application**

Sector/Area	EOS used?	Examples/Comments
Agriculture	Yes	Adaptive land management, precision agriculture
Forestry	Yes	Canopy survey and forest condition
Fisheries	Yes	Sea surface temperature information, weather
Mining and petroleum	Yes	Pre-competitive mapping, seepage, reclamation monitoring
Property and business services	Yes	Surveyors, development project managers, real estate, environmental compliance consulting
Construction	Minor	Mostly use aerial
Transport and storage	Minor	Flexi-routing for air (wind) and sea (currents)
Utilities (electricity, water and gas)	Minor	Catchment studies, environmental compliance
Communications	Minor	Baseline maps
Retail and trade	Minor	Baseline maps
Tourism	Minor	Interactive online maps
Manufacturing	No	None identified
Australian Government	Yes	Various (see below)
State governments	Yes	Monitoring and reporting of environmental conditions and compliance, planning and development
Local government	Minor	Mostly use aerial photography
Natural resources management, environment and climate change	Yes	Carbon accounting, resource auditing, climate change modelling
Biosecurity	Yes	Controlling foot and mouth disease; locusts
Defence and national security	Yes	Situational awareness
Counterterrorism	Yes	Event tracking and response management
Emergency management	Yes	Impact assessment, response targeting
Maritime and air safety	Yes	Weather predictions, rescue operations
Health and ageing	Minor	Mapping of disease incidence, monitoring spread, population mapping

How much to attribute to EOS?

The proportion of the ACIL Tasman (2008) productivity impact which may be attributed to EOS is difficult to determine. Stakeholder consultation confirmed that EOS is a minor part of the geospatial sector as a whole – in particular the commercial sector is dominated by applications in positioning and communications. Some of the high productivity impact applications such as real time logistics can therefore clearly not be claimed by EOS.

All interviewees echoed the sentiment that whilst it may be a small part, EOS is often an essential part of a project – EOS monitors and measures changes in baseline data and adds context to other data. Maps generated using satellite imagery provide base line reference data in GIS models that when, combined with GNNS data, are used in mostly sectors of the modern economy. Their value should not be underestimated and this should be reflected in the productivity estimate.

The consultants tested the idea that EOS might reasonably be attributed a share of 15% and researchers as well as commercial users and resellers concurred that this would be reasonable and, in fact, conservative in a number of applications. In the absence of better information a figure of 15% is used to capture the EOS contribution to the productivity impact modelled in ACIL Tasman (2008).

Total productivity impact

Subject to the comments above, using a 15% attribution factor, the productivity impact from EOS in 2008-09 is estimated at $1.9 billion using the results of the ACIL Tasman (2008) report as a reference point.

Box 1 Satellite imagery improves agriculture techniques

In May 2003, DigitalGlobe announced that Bowles Farming, a 12,000-acre family farm producing cotton, alfalfa and small grains crops agriculture customer in California used its 30 foot resolution SPOT satellite imagery to solve a problem on the farm.

In 2002, the business operations manager for the farm noticed that 45 acres within a 141-acre field of cotton were producing poor yields due to leakage from an irrigation canal that was causing salt build-up in the soil. The initial proposed solution to this was to install tile along the canal to provide adequate drainage and divert excess water. This solution would cost $127,000 for the purchase of 9,700 feet of tile and two pumps.

After examining DigitalGlobe's AgroWatch maps produced from SPOT imagery captured in August 2002, Cannon determined the size of the total affected area was less than half of what he initially anticipated - 4,250 feet rather than 9,700 feet. Once the actual extent of the drainage problem was identified through satellite imagery, the operations manager determined that he required only 4,250 feet of tile and one pump, saving the farm $69,000 on materials alone. The anticipated revenue increase on the yield is expected to be $17,150 after the first year.

Bowles Farming also planned to use the imagery to improve crop quality, nutrition and asset management, as well as assess land acquisitions in the longer term.

Source: http://media.digitalglobe.com/index.php?s=43&item=107, accessed 24 June 2010

Important note on the scope of the 2008 report

It is important to understand the elements of economic impact that were covered in the ACIL Tasman (2008) report, as this determines which additional value can be scoped later in the current report.

Firstly, it is important to note that efficiencies in government service delivery were included in the 2008 report. A productivity benefit of 1.05% was assumed in that report for the realistic scenario based on observed impacts of spatial information on functions across whole of government, including asset management, resources management, reduced costs of service delivery, improved services, infrastructure planning, defence and emergency preparedness, risk management, compliance and regulation.

This means that in order to avoid double counting the current report cannot claim these efficiencies again – in effect the current report is working on the assumption that 15% of the 1.05% impact in government in the previous study is due to EOS. For this reason, the remaining discussion of government programs does not focus on internal efficiencies but on final outcomes.

Secondly, it is vital to understand that since the ACIL Tasman (2008) report's results were based on a general equilibrium model, it already included multiplier effects – that is, how the impact feeds through the different sectors of the economy. The current report cannot therefore claim additional multiplier effects for 2008-09.

Thirdly, and very importantly, it is critical to the rest of the analysis presented in this report that the ACIL Tasman (2008) impact estimate did not include future benefits and the value of a number of intangibles, although some of those benefits were touched upon in the report. As will be argued below, key benefits from EOS lie in better addressing future challenges. Some of the discussion included in the ACIL Tasman (2008) report is therefore deepened in the sections that follow.

Finally, it is also noted that the ACIL Tasman (2008) report did not fully scope the benefits in the weather sector (Bureau of Meteorology, etc.) as that sector was not selected for more detailed study. For the current study, use of satellite imagery in the weather sector and weather data is included.

2.2 The value of EOS in facing major economy wide challenges

The report now turns to additional value that can legitimately be claimed by EOS, i.e., over and above the direct value added and productivity impacts in 2008-09. This adds a key dimension to the value proposition for EOS. It is largely about a portfolio of EOS enabled capabilities which helps to address future challenges.

Significant value from EOS arises in cross-cutting areas and public good type challenges that affect the nation as a whole. For this report, the following areas were identified:

- Climate change
- Natural resource management
- Natural disasters and emergency response, and
- National security and biosecurity.

Final outcomes in these areas include a healthier environment, a more sustainable economy and a safer community when compared to the case without EOS. Reduced dry-land salinity, increased biodiversity, improvements in water use, more sustainable fishing stocks, and so on, are measures of these types of outcomes.

Cumulative impact and policy coordination

Many agencies and organisations utilise EOS, ranging from research to monitoring of compliance, and also including private sector effort. They may have differing terms of reference, charters or objectives, but many are engaged in activity that ultimately works towards the same national priorities and overcoming similar challenges.

The critical point for the value proposition for EOS developed in this report is that *cumulatively*, across all applications, EOS will play a role in achieving better outcomes than would otherwise be possible. Stressing the cumulative impact also means taking account of important *interactions* between different sectors; for example, better water management makes agriculture more sustainable but at the same time offers the possibility of generating more environmental flows.

Having objective measures based on EOS also means there is greater certainty for decision making processes, which can help to bring critical decisions forward as well as improve the quality of the decisions made. An associated benefit is that it assists different Departments in coordinating policy.

Instead of focusing on single applications or organisations the approach taken here is therefore to put the role of EOS across a range of areas into the context of an overarching challenge or problem. In this way it can be demonstrated that EOS can reasonably lay claim to a contribution in each of these areas which affect the nation as a whole. This should also assist with a portfolio approach when examining plausible future investments in EOS.

To some degree, the classification in the sections that follow is artificial as EOS sits across all of these. Where better imagery assists forecasting thus helping the economy to adapt to climate change, it also benefits natural resource managers and emergency response. These headings have been chosen largely for convenience and to reflect the responses received during stakeholder consultation.

As a result of the multi-dimensional impacts of EOS there is a risk of double counting economic benefits. This has been carefully avoided in the conservative estimates that are included in the sections that follow.

2.3 Climate change and weather

Climate change is a challenge facing all sectors of the Australian economy. According to the Department of Climate Change and Energy Efficiency the best estimates are that without mitigation climate change will cause a

- further 1ºC of warming in temperatures
- up to 20 per cent more months of drought
- up to 25 per cent increase in days of very high or extreme fire danger
- increases in storm surges and severe weather events.

Concerns about the impacts of climate change is already affecting policy and investment decisions which will have long lasting impacts on sectors such as agriculture and energy. Clearly, any effort to improve the knowledge base and skill in this area will be of value to a variety of players.

For the purposes of this report the discussion of climate change has been combined with weather, as the two areas are strongly linked thematically and the benefits of better weather prediction were not quantified in the ACIL Tasman (2008) report.

The consultation phase for this project revealed that EOS is playing a role in addressing the challenge of climate change in a number of ways:

- understanding and modelling basic weather and climate change processes
- predicting impacts of climate change including their location
- guiding practical impact mitigation efforts
- assisting market assessment and response (insurance, land values, etc.)
- meeting international reporting obligations such as through the carbon accounting framework
- providing objective measures to enable evidence-based policy.

Government stakeholders in this area include the Commonwealth Departments of Climate Change and Energy Efficiency (DCCEE) and of the Environment, Water, Heritage and the Arts (DEWHA), CSIRO, the Bureau of Meteorology (BOM), the Bureau of Rural Sciences (BRS), State Environment Departments such as the NSW Department of Environment, Climate Change and Water (DECCW), as well as a number of others.

BOM expenditure on all weather observations is estimated at $100 million; however, most of this is spent on an extensive surface in-situ network, and a 'rough' estimate of expenditure attributable to EOS is around 15% of the total including staff costs.

Improved weather predictions

EOS is fundamental to modern weather and climate models. The BOM stated that EOS has been the "single largest contributor" to the improvement of weather models ('model skill') over the last twenty years or so,[10] estimating that it led to the ability to forecast an additional 2-3 days ahead.

Given that weather impacts on business decisions on a day-to-day basis (e.g., decisions to irrigate, when and where to fish, when to generate electricity, etc.) this clearly implies a very important economic contribution. Weather models are also critical in driving better preparedness and response to natural disasters (further discussed in Section 2.5 below).

Some of the ways in which EOS contributes in the field of climate change may come as a surprise to the layperson, for example, a submission by Professor Dekker from CSIRO states that:

> The oceans play a central role in Australia's climate variability. El Nino conditions in the Pacific Ocean (and) positive Indian Ocean Dipole Conditions ... increase the likelihood of drought in Australia. ... Robust climate change projections require a good understanding of ocean processes and an adequate representation of these processes in coupled atmosphere-ocean climate models. Capabilities now exist in Australia and elsewhere to make projections of climate change for 50 to 100 years ahead. The (at present unknown) climate predictability on these time scales **will depend critically on correctly observing ocean conditions** for initialising these predictions. Improving our understanding of climate conditions, attributing observed changes in climate, and predictions of future climate are all critically dependent on ocean remote sensing capabilities.

Satellite measures of sea surface temperature, wave height and length, currents, and water quality (e.g., chlorophyll) are all used. Remotely sensed data are critical inputs to the global ocean model, and data for the Australasian region are critical to calibrating the model to make better predictions. This affects both weather predictions in the short term and longer term climate change models.

This sentiment was echoed by experts at Australia's Integrated Marine Observing System (IMOS), who also stated that:

> Since the early 1990s, satellite altimetry missions sensing sea surface height have revolutionised our measurement and understanding of climate change and variability (e.g., measurement of mean sea level rise and the El Niño and La Niña oscillations).[11]

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[10] Interview - Bureau of Meteorology, 24 June 2010.

[11] Interview and email correspondence, Edward King and Christopher Watson, 23 June 2010.

Whilst EOS has already brought about a step-change in the ability to model and predict weather and climate impacts, Australia is still a step behind other nations which have dedicated meteorological satellites in orbit, and which can further improve model skill. A dedicated satellite carrying instruments for vertical sounding can provide valuable measures of temperature, cloud and water vapour through the different levels of the atmosphere all the way down to the ground.

BOM currently relies heavily on the Japanese MTSAT series satellites (as well as the NOAA polar orbiters), but these do not provide such soundings. If MTSAT were to fail, back-up information could likely be sourced from Chinese and (in future) Korean satellites.

A more cost-effective alternative to a dedicated meteorological satellite for Australia could be to launch several micro-satellites which could provide sounding data through GPS radio occultation at a cost of perhaps $20 million in space.[12]

BLUELink ocean forecasting project

The BLUELink ocean forecasting project is one example of EOS having direct economic impacts as well as improving Australia's longer term capability to respond to climate change. Delivered in partnership by the BOM, CSIRO and the Navy, it delivers practical benefits to fishers as well as other users. For example, where fishermen used to charter spotter planes to identify prospective fishing areas (e.g. locate warm fronts where fish tend to aggregate), now the BLUELink data can guide fishers to prospective fishing grounds. BLUELink provides information on coastal and ocean currents and eddies, surface and subsurface ocean properties, and these also feed into defence applications, safety-at-sea, and ecological sustainability.

Rainfall to Pasture Growth Outlook Tool

Another example of the practical benefits in the climate/weather space comes from the Rainfall to Pasture Growth Outlook Tool, developed by the Department of Agriculture, Fisheries and Forestry, which was recognised by the Business Review Weekly as one of Australia's top five innovations of 2005. The service supports pasture and grazing management. Farmers are provided historical, current and forecast weather information for their local area that allows them to estimate pasture growth in relation to rainfall, soil moisture and other climatic conditions. Information is based on data collected from over 3,300 weather stations across Southern Australia.

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12 Interview Bureau of Meteorology 24 June 2010.

National Carbon Accounting System (NCAS)

Measuring and monitoring are critical to society's appreciation and response to climate change. In their absence there is no way of telling whether and to what degree a problem exists and what, if anything, should be done about it. The leadership, up-skilling and demonstration effects of the National Carbon Accounting System (NCAS), which is heavily reliant on EOS are very significant in this regard. NCAS was a case study in the ACIL Tasman (2008) report of which some highlights were:

- The NCAS combines satellite imagery with models and data to provide a 30-year dynamic account of greenhouse emissions across the continent.
  - It tracks greenhouse gas sources and sinks from the land. Land-based sources and sinks are of key interest to Australia, forming around 30% of the national emissions profile from activities such as land clearing, cropping, grazing and forestry.
- Landsat MSS imagery (with 80 m pixels) was used for epochs before 1984 and Landsat TM and ETM+ imagery has been used for more recent epochs. Areas of cloud and fire scars were clipped out and the imagery ortho-rectified to a base set, which was decided as the 2000 epoch. Accuracy was very important when ortho-rectifying because each pixel needed to be compared to its corresponding pixel from each different epoch.
- CSIRO created a conditional probability method using Landsat imagery which predicts the probability of a set vegetation type occurring for each pixel. If a pixel has a high (90%) probability of being woody vegetation during the 1972, 1975 and 1977 epochs but, in 1979, the probability is classed as 10%, the interpretation is that clearing occurred between 1977 and 1979.
- NCAS is fundamental to Australia's response to climate change. It is instrumental in ensuring that Australia can report that it is complying with the Kyoto Targets and meeting the requirements of Parts 3.3 and 3.7 of the Kyoto Protocol. It follows that it will be fundamental to a future carbon trading scheme.

As has already been indicated in the introduction to this section, which stressed the multi-dimensional aspects of EOS, a scheme such as NCAS could equally have been discussed in the NRM section below (see Section 2.4), as it involves cooperation and interactions with implications for a variety of players in the NRM space as well.

2.3.2 Valuing the benefits

Given the large landmass of Australia it is clear that EOS provides a critical input to measuring, monitoring, reporting, predicting, preparing for and responding to the challenge of climate change.

The economic impact of climate change is a topic of significant debate and research. As the impacts will occur in the future, the value of EOS will depend on decisions and actions taken in future which may ameliorate the negative impacts of climate change. Climate change also represents an opportunity to some industries which will grow in response to climate change (e.g., mitigation experts, new insurance products, etc.), and EOS has the capacity to assist these industries.

More broadly speaking, the ability to forecast long term climate change impacts with greater accuracy affects where one can expect populations to move (as more severe weather events may force people to move, or as areas become more attractive for settlement and development). It also affects where governments, including local authorities, should direct infrastructure investment and disinvestment (e.g., new roads or closures of areas). Better forecasting will also allow for a smoother transition, i.e., less volatility, in regional land and property markets.

It is clear that even a marginal contribution to future cost avoidance, better insurance, smoother transition, and so on, will be of significant value. Some indicators of economic impact of weather and climate change are:

- ABARE (2006) examined the benefits of better climate forecasting to agriculture, and over a 15-year forecast period these were estimated at an average annual gain to the Australian economy of $318.1 million using a computable general equilibrium model. The report also conservatively estimated a further $39.4 million in annual benefits from better weather information in fishing and aquaculture.
  - Given that EOS is the single most important cause of improvements in weather modelling as discussed earlier, a large proportion of this could legitimately be claimed by EOS
- NASA's Jet Propulsion Laboratory at the Californian Institute of Technology cites a number of relevant statistics on its website:
  - The annual cost of electricity in the USA could decrease by at least $US 1 billion if the accuracy of weather forecasts was improved by just 1° F.[13]
    - … As Australian model skill has caught up the US due to EOS, as stated by the BOM, this benefit would already have been reaped in Australia although further improvements are still likely. Adjusting the estimate from the US economy to the Australian economy, and allowing for differences between the electricity systems in each

[13] SPACEship-to-shore: Society Benefits from Ocean Altimetry Data, slideshow can be accessed at http://topex-www.jpl.nasa.gov/science/soc-benefits.html

country, the annual savings due to EOS in Australia may be in the region of $85 million.

- Perhaps most importantly, the NASA presentation also estimates that one-third of the US economy is weather/climate sensitive, putting $US 3 trillion "at risk" in the US. In the Australian context one third of GDP equates to around $350 billion which might be "at risk" – although what "at risk" means is not defined by the NASA presentation. Also the Australian economy is possibly less weather sensitive than the US economy.
- The NASA presentation also states that "in pure economic terms, studies show that national institutions providing weather, climate and water services to their citizens contribute an estimated $20-$40 billion dollars each year to their national economies" (mid-point: $30 billion)
- A paper by Ackerman and Stanton (2008) on the costs of climate change refers to research showing that the total cost of global warming would rise over this century and reach up to 3.6% of GDP under a business-as-usual scenario. As early as 2025 the cost as a proportion of GDP could be as high as 2%, equating to around $30 billion in the Australian context at today's prices and if the Australian economy grows at slightly over 2% p.a.

The range of reference figures for the potential costs avoided from weather projections and climate change mitigation is therefore extraordinarily broad – from $350 billion "at risk" to $20-40 billion, to less than $1 billion per annum in the small subset of benefits identified by the ABARE study (but which can be more closely linked to EOS).

The ACIL Tasman (2008) report also commented on the economic benefits delivered by the National Carbon Accounting Scheme (NCAS). The report noted that NCAS will provide significant support towards monitoring and reducing net emissions of green house gases; and that the value of reducing emissions to 108 per cent of Australia's 1990 emission levels by 2010 (Australia's Kyoto target) would be around $1.4 billion at a carbon price of $15 per tonne CO_2.

Treasury modelling for the proposes CPRS projected that Gross National Product (GNP) per capita would be around 2 per cent lower by 2020 under mitigation scenarios than under a no change policy. In other words, the costs to economic welfare of mitigating the impacts of climate change would be of the order of $30 billion by 2020 if GDP grows at around 2% per year.

- Improving the efficiency and effectiveness of this response therefore could reduce the cost. EOS has the potential to do this although we do not have sufficient information to estimate the proportionate value of its contribution to mitigation scenarios.

On balance, noting in particular the ABARE estimate for agriculture and also the potential savings in electricity costs as well as the contribution of EOS via

NCAS, a saving of $300 million per annum would be at the lower end of the scale – this would correspond to a 1% reduction in the total annual cost of climate change of around $30 billion cited above.

Table 4 **Climate change related EOS benefits**

Category	Annual estimate
Australian GDP “at risk”	Possibly up to $350 billion
Reference cost or benefit estimates (based on NASA estimates, Ackerman and Stanton (2008) and Australian Treasury modelling)	$30 billion
- 1% of reference figures	$300 million
Identified Australian benefits from better weather modelling and forecasting	Up to $500 million
ACIL Tasman reference estimate	**$300 million (min.)**

2.4 Natural resource management

In addition to climate change, population growth, urban sprawl, and rising incomes have given rise to an increasing number of issues around the use of natural resources and natural resource management (NRM). This section briefly reviews the value of better NRM due to EOS – this is clearly a vast topic and the following paragraphs cannot do the field justice. Farmers, foresters, traditional land owners, government agencies and a variety of interest groups are just some of the stakeholders in the NRM debate. Different areas of research and levels of the debate include questions around adoption and implementation, legal aspects, biodiversity and ecosystem values, as well as social issues.

Nevertheless, it is clear that EOS is a critical enabler in the NRM space. It plays a role all the way from resource discovery through to monitoring and managing the natural resources available to, and enjoyed by Australians. Government agencies rely increasingly on EOS to fulfil their mandates. Planners and decision makers right across the community can make more rational decisions when presented with objective evidence provided by EOS. The size of the Australian continent and the waters surrounding it make EOS the only viable solution in many NRM applications.

2.4.1 Water

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.

Water managers and planners have been using data from satellite sensors with the right spectral range (for example Landsat, MODIS and SPOT) to support catchment level monitoring and forecasting, to estimate parameters such as Evapotranpiration, calibrate catchment models, estimate interception from forests and assess the impacts of land use change on water availability. EOS data is increasingly being used for compliance monitoring.

There are concerns that current water allocations are not sustainable - particularly in the Murray Darling Basin. The Murray Darling Basin Authority (MDBA) is developing a Basin Plan which will, for the first time, seek to manage surface, groundwater and environmental resources as whole.

The MDBA is now implementing a project for mapping of the resources of the basin. EOS will be an important contributor to this program along with airborne surveys.

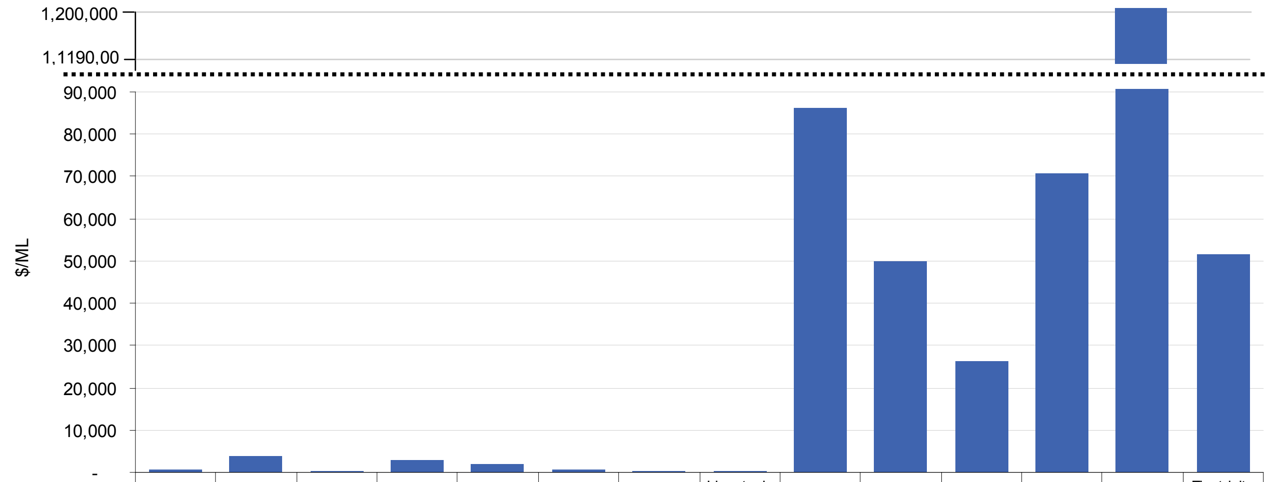
Nationally, the Council of Australian Governments (COAG) entered into an agreement in 2004 to pursue a ten year program of water reform under the National Water Initiative (NWI). Under the Initiative COAG agreed to a program of reform to:

- establish well defined, secure water entitlements for consumptive users
- introduce improved and well structured water planning that gives rise to entitlements
- establish efficient water markets and water trading
- clarify and protect environmental and public good outcomes
- improve knowledge systems and water accounting, and
- jointly manage surface and groundwater.

Returning over-allocated and over-used catchments to a sustainable level of extraction is an important objective of this initiative. EOS technologies have a role to play in this endeavour. Using an EOS based methodology, the Land and Water Division of CSIRO delivered the 'Sustainable Yields' project to support water managers in the MDBA. The methodology is now being rolled out to other regions and has reportedly been adopted internationally.

Water is a critical resource for the economy, the environment and for urban and regional communities. Its value added in industry can range from around $1,000 per ML for agriculture to over $50,000 per ML for minerals extraction and energy generation to well over $1 million/ML in oil and gas extraction (see Figure 3).

Figure 3 **Value added per ML of water used by industry, 2004-05**



	Dairy farming	Vegetables	Sugar	Fruit	Grapes	Cotton	Rice	Livestock, pasture and grains	Coal mining	Metal ore mining	Other mining	Wood and paper	Oil and gas extraction	Electricity and gas supply
Gross value added/ML	717	3,867	376	2,744	1,833	498	162	255	86,127	49,906	26,175	70,759	1,200,151	51,552

Data source: ACIL Tasman estimates using ABS data from Water Account Australia, 2004-05, Cat. No 4610.0 and Australian National Accounts, Cat. No. 5206.0

An indication of the current value of water is provided in recent reports by the Productivity Commission– one on market mechanisms for recovering waster in the Murray Darling Basin and the other on urban water pricing (Productivity Commission, 2010).

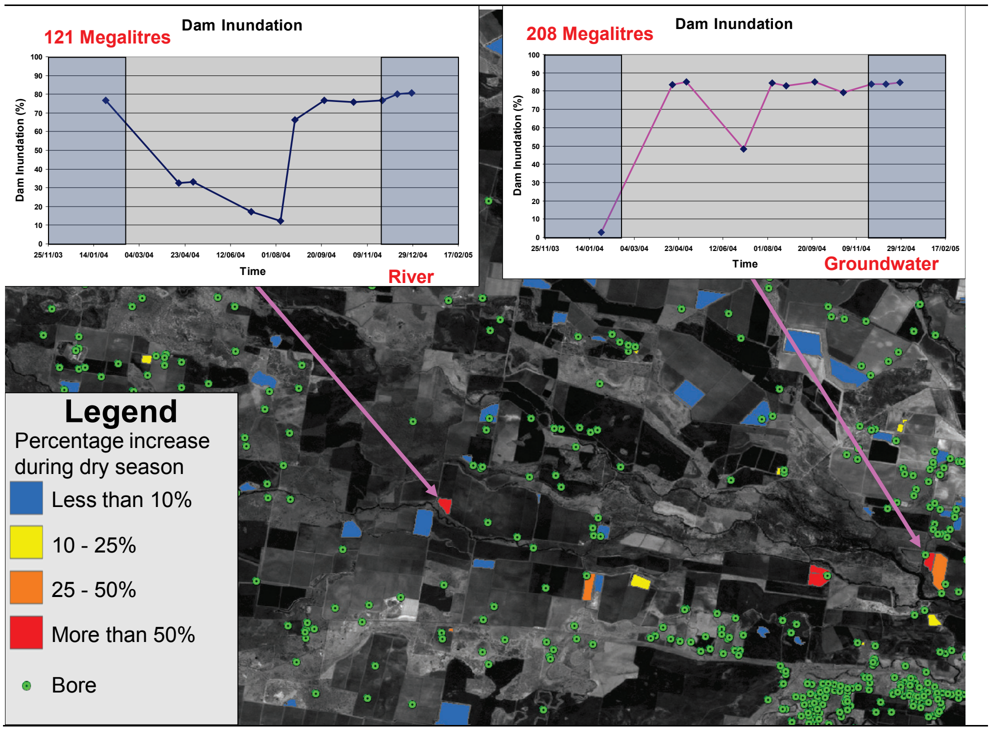
These reports include estimates of current prices for water in urban and regional catchments ranging from between $100 per ML to $500 per ML. We have assumed a conservative estimate of $200 per ML as an indication of the marginal value of water in Australia. The total quantity of water consumed in Australia in 1994-95 was 18,767 GL as recorded by the Australian Bureau of Statistics (ABS, 2005).

On this basis, a 1 per cent reduction in water use or improvement in supply could in theory be worth around $37 million or thereabouts. Better management of water resources could therefore deliver benefits in the tens of millions of dollars in terms of improved allocative efficiency.

EOS is an important enabling technology for the better management and accounting of Australia's water resources - one of the key goals of the NWI. Research by Geoscience Australia and CSIRO is exploring the potential to combine optical and gravity data from EOS with meteorological data and hydrological modelling, to measure both surface water and ground water resources.

Figure 4 shows for example how EOS data could be used to measure levels of storage in dams and deduce the source of replenishment.

Figure 4 **Using EOS to measure dam levels and supply sources**



Note: The blue sections in the charts illustrate periods of precipitation.

Data source: Geoscience Australia

While the current generation of satellite sensors may not be adequate for such purposes, according to our consultations, the next generation of satellite sensors will have better capability for such applications. Joint management of surface and groundwater is one of the major challenges facing water measurement and accounting in Australia. Systems that improve monitoring and measurement of surface and groundwater would be highly beneficial for Australia.

2.4.2 Land and vegetation

EOS provides the fundamental knowledge about the land which underpins the debate and informs policy. This includes imagery and data on land use, land/ground cover and condition (type, mix and extent), soils, sub-surface conditions (e.g., rock, hydrology, etc.) and elevation models as well as a number of other measures. Benefits from EOS in this area include assisting farmers and other landholders to improve their land use patterns for efficiency as well as maintenance of biodiversity and ecosystem values. Some of the applications and values of EOS will be hard to predict. For example, a recent front page headline in the national press read "Remnants of ancient Gondwana's forests found" and in the article it emerged that:

> ...high resolution satellite imagery available on Google Earth convinced CSIRO ecologist Michael Doherty the forest remnants were worth a closer look... "it was clear from the Google images they were cool temperate rainforest, not eucalypt forests" ... discoveries include two mosses, bats-wing ferns, spleenworts, mountain silkwood vines and a species of bush tucker quandong.[14]

Such discoveries may not always produce direct use values, although there is little doubt that they have the potential to add to scientific knowledge and that non-scientists place some value on simply knowing that such remnant forests (and biodiversity) exist.

Pastures from Space

As has already been pointed out this report has already provided an estimate of the productivity impact of EOS including in agriculture and to avoid double counting this cannot be included again. However, an example of this type of gain is the Pastures from Space project which can provide biomass estimates at the paddock level using Landsat as well as SPOT data. Using these data pasture growth rates can be estimated. Several hundred farms are already using this product in Western Australia, and potential scope of the project includes 90% of Australia's sheep and lamb flocks as well as 90% of the Australian dairy cows and 40% of beef cattle. Co-operative Bulk Handling Ltd (CBH) is reportedly considering the potential for using the tool for yield forecasting as part of market planning. As discussed by Sneddon *et* al (2007), for example, there is considerable potential for remotely sensed data to reduce the uncertainty in wool production forecasting.

The Pastures from Space capability also extends to predictions of underground and surface water. The team uses very large data sets and can also measure the movements of sediments and water holding capacity of river systems. Meat & Livestock Australia (MLA) has reportedly used this for rangeland natural resources management, and the Avon Wheat Belt NRM group have also used it under the *Caring for the Country* program.[15]

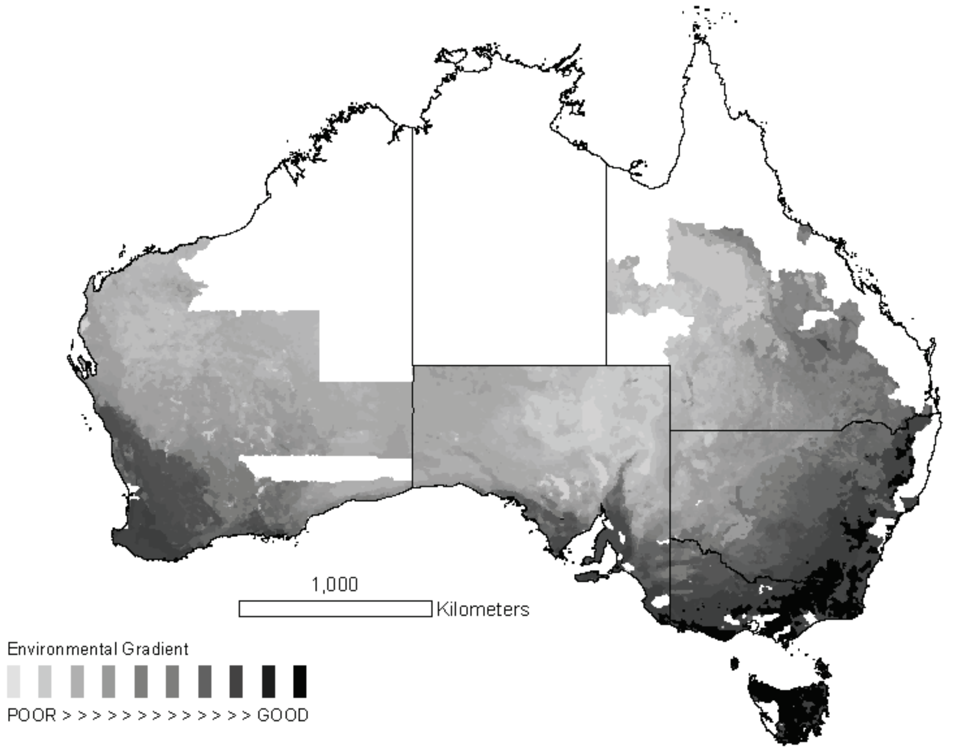
It is therefore clear that even where a primary target of an EOS enabled innovation was in private application this capability can translate not only into efficiencies of resource use in the commercial domain but also into more

[14] Article by Rosslyn Beeby, Science and Environment Reporter, The Canberra Times, 16 June 2010.

[15] Interview CSIRO, 28 May 2010 (Dekker, Malthus, McVicar).

public good type NRM benefits. This latter set of benefits is included in the additional value that EOS can claim over and above the productivity benefits already estimated.

Figure 5 **Classification of sheep grazing areas of Australia based on NDVI and temperature (1996-2005)**



Source: Sneddon *et al* (2007)

Government stakeholders deliver different NRM related services and outputs, often cooperating in the process. DCCEE, DEWHA, CSIRO, DAFF/BRS, and State agencies are all involved in international and national reporting, where they will often also collaborate with Universities. They may for example combine remotely sensed data on vegetation type, extent and condition with threats such as fires and other information such as landholding type for their assessments and reports.

Vegetation cover and condition

Expertise sits in different pockets across a host of agencies, and new products emerge somewhat organically. For example, during consultation BRS commented on a new research project begun with Geoscience Australia to develop a dynamic land cover product for Australia. According to discussions with the BRS, using sight data from the States and having checked 26,000 sites the new product has an accuracy of at least 75%. Such a product could be helpful with understanding functional vegetation condition and the National Water Commission and the Department of Environment, Water, Heritage and the Arts have already expressed an interest in the product.

Different types of satellite data can also be combined to derive information about cropping patterns, for example to differentiate between rain fed and irrigated parcels of land. Figure 6 below, which was provided by Geoscience Australia, gives a pictorial representation with notes on the types of information than can be extracted from the data. This has implications in monitoring and compliance applications as further discussed below.

Another EOS project referred to during consultation measured functional response of vegetation to rainfall or fire. A finding of this project was that in parts of Australia over 85% of fires were *unplanned* fires. This could have implications for how to manage fires in those areas, at least where it is unacceptable to have large uncontrolled fires or where biodiversity or old growth forests may be at risk.

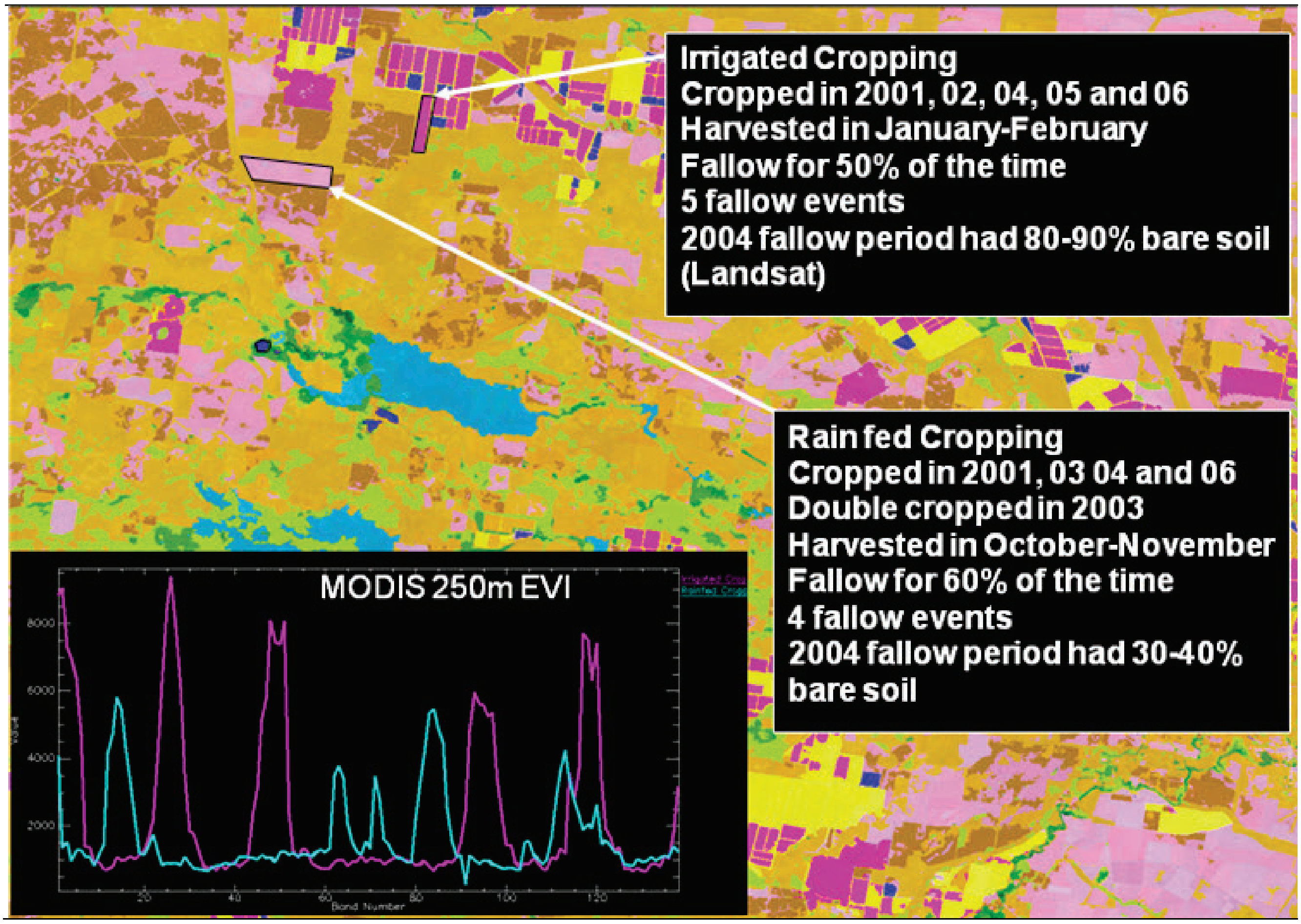
Avoiding dust storms

A further example of the use of EOS with practical implications comes from DAFF which invested around $1 million in 2009-10 to take a research method based on MODIS out of CSIRO and upscale it to Landsat. This related to understanding where the rangelands and extensive cropping regions are so that people living in suburban regions may not be exposed to major dust storms in future. This could have long term health and quality of life implications for residents in those areas.

Monitoring and compliance

One of the biggest (and growing) areas of EOS use in NRM is monitoring land use and the extent/absence of ground cover (bare soil) which increasingly feeds into legislation that also has compliance associated aspects. This is perhaps the most obvious application of EOS to achieve environmental objectives. Queensland and NSW have high profile projects which are critically dependent on EOS.

Figure 6 **Combining Landsat and MODIS to characterise cropping dynamics**



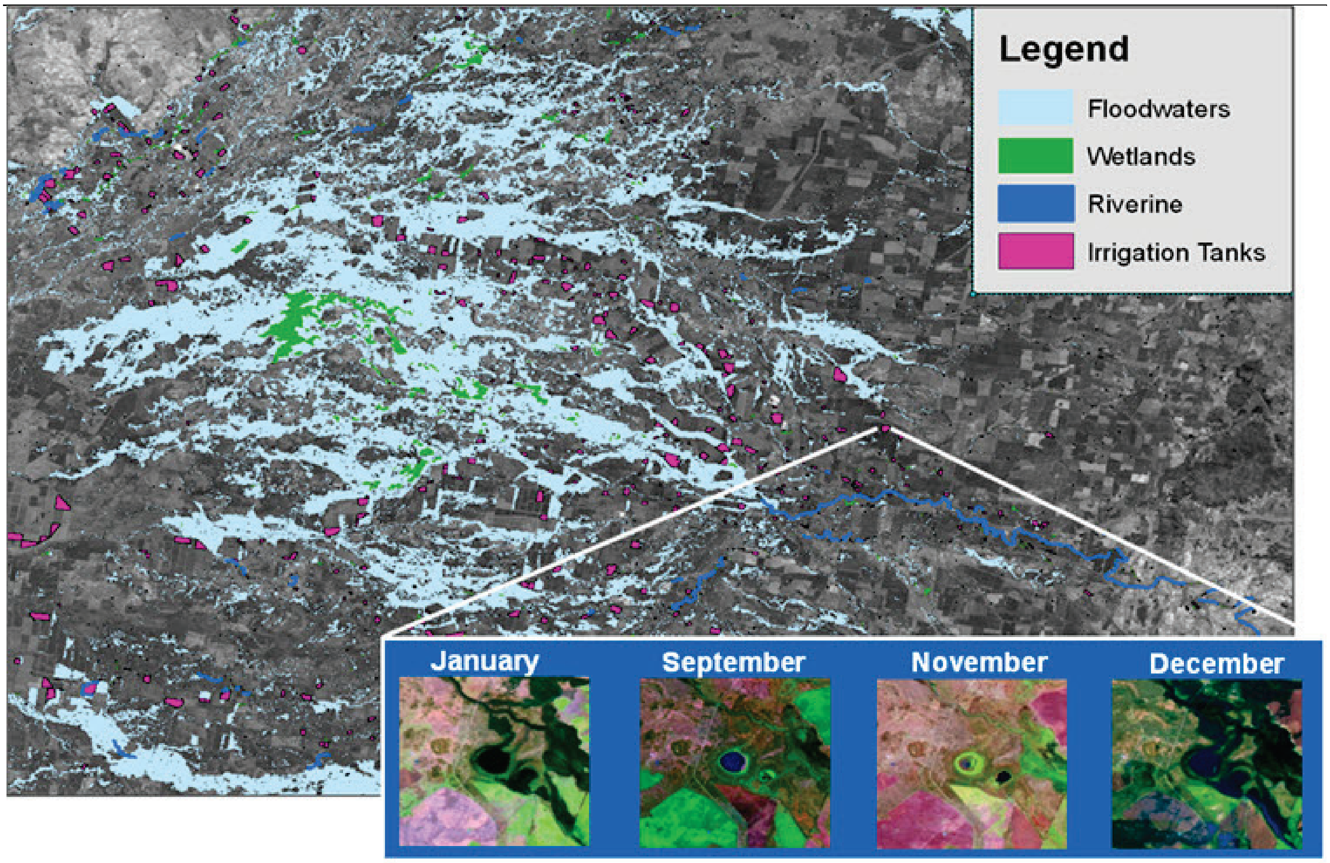
Source: image supplied by Geoscience Australia. The pink line in the MODIS 250m EVI captures the irrigated crop and the blue line the rainfed crop.

The Statewide Land and Trees Study (SLATS) in Queensland is a noted example, which was also covered in the ACIL Tasman (2008) report. The Vegetation Management and Other Legislation Amendment Bill 2004 as well as preceding Acts bestow powers and responsibilities including the responsibility to monitor vegetation clearing throughout the State to determine whether it has been legally undertaken or not. Remotely sensed imagery provides invaluable historical evidence of the presence of vegetation where it has later been cleared. In the event that clearing is illegal court proceedings may ensue.

Efforts are underfoot to try and improve the speed with which reporting and compliance efforts take place. In Queensland, the reporting currently feeds into the Premier's annual report first and is then passed on to compliance officers. This means that investigations on the ground may sometimes take place many months after clearing occurred and this can make it more difficult to obtain a conviction. The initial aim of current efforts is to move to quarterly publication, i.e., to compile and pass on reports to the compliance team with the Director General's agreement, and in the longer term perhaps report even more frequently. These trends indicate that the environmental legislation may begin to 'bite' more seriously and therefore the effective contribution of EOS to NRM may also be expected to increase in future.

Once again the implications of this type of use of imagery and data carry across to other areas of NRM. Inferences can, for example, also be made about water drawdown and its consistency with allocations (see Figure 7). This may become more important in future with water permits or markets taking shape.

Figure 7 **Geoscience Australia land cover project**



Data source: image supplied by Geoscience Australia.

2.4.3 Fisheries and coastal habitats

The previous sections were concerned with terrestrial NRM; however, the vast expanse of the oceans surrounding Australia and the need to manage the oceans sustainably is another area in which EOS helps achieve outcomes that could not otherwise be achieved.

The BLUELink project was already mentioned and this has efficiency as well as ecological benefits. EOS is also used extensively in fisheries research (study of benthic habitats), to assist with setting boundaries for marine parks, to identify spawning grounds and migration routes and the setting of sustainable catch levels, as well as the policing of fishing activity. The understanding of many of these issues is once again interrelated. The ACIL Tasman (2008) report covers a number of geospatial technologies involved in sustainable fisheries management which are also relevant to the discussion here.

Under good conditions, the shallow seafloor near the shore can be mapped from space using multispectral imaging, i.e., creating multiple images of a scene using light from different parts of the spectrum. Multispectral images can be used to detect bathymetric features and benthic habitats (the blue-green band provides the greatest penetration of water).

Coastal and near shore environments have been the focus of remote sensing activities for more than 25 years. The following environmental characteristics are regularly monitored using various forms of remote sensing:[16]

- Water Surface
  - roughness of sea surface
  - extent and type of an algal bloom
  - extent of an oil spill
- Water Column
  - extent of dissolved and particulate organic matter
  - extent of suspended sediments (inorganic matter)
  - extent of algal pigments (providing biomass and algal concentration)
  - transparency and vertical attenuation of light
  - bathymetry and seabed relief
- Underwater Substrate
  - type of substrate (such as sand, mud, seagrass, macroalgae and coral)
  - condition and abundance of seagrass
  - condition of coral
- Terrestrial
  - land cover and land use in coastal areas
  - extent and composition of wetland (mangrove and saltmarsh)
  - vegetation density and biomass.

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16 As listed on OzCoasts, the Australian Online Coastal Information website; see http://www.ozcoasts.org.au/geom_geol/toolkit/Tech_EO_satm.jsp

This type of monitoring provides crucial information on the condition of the Australian ocean and wildlife habitats and is used in various types of models, assessments and reports with influence on NRM decisions.

Just as terrestrial monitoring can assist with compliance issues, so can the monitoring of oceans. The Australian Fisheries Management Authority (AFMA) is already using satellite imagery to assist with identifying areas in which illegal fishing activity may be occurring.[17] Knowing where fishers are likely to be assists with targeting aerial surveillance as there is a limit to the area aircraft can cover and the time that they can stay in the air.

AFMA hopes to make much greater use of satellite imagery to help supplement or even substitute the aerial surveillance effort in future. One area for improvement here is collaboration between State and Federal agencies which each have their own approach to compliance and could exchange more information including satellite imagery.

In the US, remote sensing has also assisted with collection of lost or abandoned fishing nets. These can be hundreds of meters long and balls of net can be tens of meters across, which is sufficiently large to be picked up on satellite images. Concentrated in relatively small areas of ocean by winds and currents, these nets present a hazard to wildlife, entangling marine mammals, turtles and sea birds.[18] Similar projects could provide ecological benefits in Australia as well.

2.4.4 Valuing the benefits

Putting a dollar value on the NRM benefits derived from EOS is extremely difficult for a number of reasons, one of them being that there is little agreement about how to value the environment, biodiversity and ecosystem services. These 'valuable but free' services include soil formation, regeneration of habitat, provision of shade and shelter, pollination, water filtration, erosion control, regulation of river flows and ground water, and so on.

A famous paper by Costanza *et al.* (1997) put the global value of ecosystem services as US$33 trillion which was nearly twice as high as global GNP at the time the paper was published. Translated to the Australian context in 2008-09, this might suggest a reference value of around $2 trillion per annum for ecosystem services in Australia. NRM aims to maintain this value, or at least avoid major reductions in this value. If a $2 trillion valuation is accepted then even a marginal improvement in managing Australia's natural resources leading

[17] Interviews with John Andersen and Glen Salmon, June 2010.

[18] http://news.mongabay.com/2005/0504a-rhett_butler.html

to, say, a 1% reduction in the loss of valuable ecosystem services would be worth $20 billion per year.

Costanza *et al.*'s figure has been subject to widespread criticism, notably from within environmental science where many believe it reduces the complex array of ecosystem processes to a single meaningless number. Hence the view for example that:

> A better alternative is to assess the real array of ecosystem responses so that causes can be diagnosed, future states can be predicted, and benefits of treatments can be compared. (Suter, 2009)

Another way to approach the value of EOS in NRM is to examine the possibility of avoiding costly decisions, especially costly and irreversible decisions such as large scale investments in public infrastructure. For example, it would cost an estimated 80 billion dollars to lay a national network of pipelines if the idea to pump significant volumes of water from Queensland to southern States was to be implemented; however one of the clear findings based on objective EOS measures is that the volume of water available from Queensland would simply be insufficient to warrant such an investment. This means that a costly mistake such as the aforementioned network of pipelines will hopefully be avoided.

A figure mentioned during the consultation phase was that the government is investing an estimated $15 billion in channels and pipelines across the country over the next few years. Again, if EOS can make a small contribution to choosing the appropriate routes and/or avoiding unnecessary expenditures then the contribution of EOS might well be worth $100 million or more per year. As discussed earlier, a 1 per cent reduction in national water consumption itself (not the infrastructure investment) would potentially be valued at around $37 million at recent prices for buyback of water entitlements for environmental flows. This figure is likely to increase in future as the lower cost uses and water efficiency measures are exhausted and as higher cost supply sources such as desalination are required.

One study of the value of Earth observation for marine water quality management by Bouma *et al.* (2010), using water quality in the Great Barrier Reef lagoon as an example, estimates that EOS could be worth up to US$82 million per year ($95 million at current exchange rates).

Salinity, acidity and sodicity of soils are among Australia's major land related NRM issues. Estimates published on the Australian Natural Resource Atlas website, for example, suggest that an additional $187 million per annum would have been obtained in agriculture during 1996-97 if dryland salinity had not limited crop/pasture yields; also, a best-bet estimate of the impact of water table rise and dryland salinity on infrastructure costs in non-metropolitan Australia is cited at $89 million per year.

A number of further aggregate downstream impacts of land degradation were determined for increased severity of salinity, erosion, sedimentation and turbidity over the 20 year period from 2000 to 2020 using data available from the National Land and Water Resources Audit. Together these ranged from $2 billion to $4 billion over the 20 year period (mid-point $150 million per year). These estimates would not have been possible without EOS, although the extent to which costs can be avoided because of the use of EOS is unclear.

Adding together the dryland salinity (yield/infrastructure) and other land degradation costs would suggest an annual impact of $426 million. If EOS through its role in identifying and managing the problem can reduce this impact by 5% this would be worth $21.3 million each year.

A report by ACIL Tasman (2007) on the economic and social value of biodiversity and functioning ecosystems in Australia provides some case studies showing how different economic valuations can be arrived at. Bees, for example, provide free pollination services to Australian agriculture valued at up to $2 billion per annum.

To take another example, tourists spend $2-3 billion each year in Australia with major motivators for visiting Australia being its unique wildlife, nature-based activities and wilderness areas, the outback and bushwalking (Hundloe and Hamilton, 1997). If EOS assists better NRM this should help to maintain some of these values – again, a precise proportion cannot be arrived at but the value could certainly be in the tens of millions of dollars per year in these two case studies alone.

Finally, another example of where EOS helps to avoid costs and ecosystem damage is through better control of feral animals or pests. Locust plagues routinely threaten agriculture across Australia and the ACIL Tasman (2008) report highlighted the savings to a government program to control locusts (i.e., government internal savings). The damage itself which can and has been avoided using EOS as an input was not included in the ACIL Tasman (2008) report. At the time of writing this report, at least one serious plague of locusts was threatening central Queensland, and the Victorian Government committed $43.5 million in early June 2010 to fight another type of plague locust which is currently threatening $2 billion worth of crops in Victoria. The efforts to control the locusts depend critically on information about their location and EOS plays a role in providing up to date imagery and measuring progress in containing the spread of locusts over the annual reproductive cycle.

Biosecurity in general is a major potential area of application for EOS, and apart from locusts there are many other threats, management of which will draw upon EOS. By monitoring spread of different types of mosquitoes or ticks it is for example possible to better plan for and manage human as well as animal health issues related to disease outbreaks which have the potential to cause very widespread damage, affect rural communities and cause economic disruption. There is a large body of literature on costs associated with outbreaks – costs vary by crop, disease type, pathogen, duration, and so on – but in many cases the potential impact runs into several billion dollars. EOS plays a role in reducing the probability of having an incursion.

A full stock-take of all areas of NRM affected by EOS was clearly not possible for this report. However, the limited subset of examples listed above already indicates that a reasonable, conservative assessment of the annual contribution of EOS in the NRM sphere would easily exceed $500 million.

Table 5 **NRM related EOS benefits**

Category	Annual estimate
Reference value of ecosystem services	$2 trillion
- 1% change (loss or gain)	$20 billion
Identified Australian benefits	
- WTP measures, various	Significant, likely hundreds of millions
- Pipeline investments / infrastructure	$100 million +
- Water buybacks (1% value estimate)	$37 million
- Great Barrier Reef water quality	$95 million
- Land degradation	$21 million
- Biosecurity	Tens of millions
ACIL Tasman reference estimate	**$500 million**

2.5 Natural disasters and emergency management

EOS information is used in all stages of disaster management: planning, preparedness, response and recovery. It is also used in certain aspects of planning for and responding to biosecurity threats. Imagery from satellites is fundamental to disaster management where impacts can be felt over vast geographical areas and on occasions timely information is needed at times when communication lines are cut.

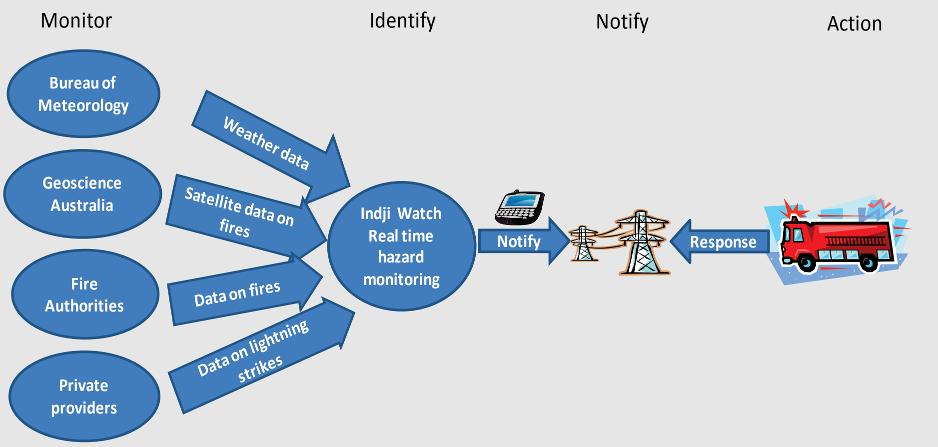
The Sentinel Bushfire Monitoring System is one example of the use of EOS for disaster planning and management. Sentinel is an internet-based mapping tool designed to provide spatial information to emergency service managers across Australia. The system is a collaborative venture between the Defence Imagery and Geospatial Organisation (DIGO), Geoscience Australia and the Land and Water Division of CSIRO. Sentinel currently obtains data from the

NASA Satellites Terra and Aqua- the raw image data is acquired by Geoscience Australia's Data Acquisition Facility at Alice Springs.

The data is processed to create a surface temperature image. Locations of high temperature are identified, extracted and entered into a spatial database. From there, the data can be queried and added to dynamically-created maps using a web-based mapping system. Users can access the map website to query the database for fire locations, and select layers of contextual information to create maps showing the areas of interest. One example of how this information is used is demonstrated in Box 2.

Box 2 **Indji Watch hazard warning system**

The Indji Watch web-based hazard monitoring system uses spatial information to deliver real-time analysis of risks and hazards against the physical location of fixed or mobile assets, and initiates intelligent actions and warnings when assets are under threat. Based on research supported by the CRC for Spatial Information (CRC SI) and developed by an Australian geospatial company it is an example of an application that draws on EOS data.



Source: NGIS

Landgate, the Western Australian land authority, also offers a similar service Firewatch. Datasets include fire hotspots from MODIS and NOAA imagery, Landsat and MODIS satellite imagery, burnt area maps since 1997, greenness images updated daily and weekly, lightning data and other useful map layers.

The information provided by these services is used by weather forecasters, emergency management agencies, fire services and other service providers to prepare for and respond to natural disaster events of all kinds.

More effective planning and response for national disasters lowers future economic, social and environmental damage. The lower average annual damage costs represent economic and social benefits. EOS data can lower average annual damage costs from natural disasters in a number of ways. More comprehensive mapping data for planning and development can reduce the risk of damage to property and people. Better information on the location of risks can result in better preparation and management of incidents. EOS data can also assist in planning and executing response and recovery plans.

Estimating the benefits is difficult in practice. In some cases the benefits are directly related to the mitigation actions as can be the case in fires and floods. However in many cases the benefits are indirect, accruing across a range of stakeholders and the environments. In some cases benefits to the environment or the sustainable management of natural resources extend to subsequent generations.

One approach to estimating the benefits that arise from mitigation of natural disasters by to calculate the expected average annual value of the damage costs avoided. Expected average annual damage cost is the product of the probability that an event will occur in any year multiplied by the damage cost that a particular event would cause. This is a difficult computation to make in practice.

The Bureau of Transport and Regional Economics undertook a comprehensive assessment of the costs of disasters in 2001 (BTRE, 2001). The report makes the following findings:

- The average annual cost of natural disasters occurring between 1967 and 1999 (with a total cost per event over $10 million) was $1.14 billion including the costs of deaths and injuries ($1.45 million in $2010).
  - This estimate is strongly influenced by three major events – Cyclone Tracey in 1974, the Newcastle Earthquake in 1989 and the Sydney Hailstorm in 1999.
- The average annual cost of natural disasters excluding these extreme events would be $860 million.
- The total cost of most disasters is between $10 million to $50 million.
  - While the sum of these events is relatively small (around 10 per cent) in contrast to the cost of more infrequent extreme events there was some evidence that the number of reported disasters per year was increasing.
- Floods were the most costly of all disasters (29 per cent of total cost).
- Storms (26 per cent) and cyclones (24 per cent) caused similar levels of damage.
- The costs of bushfires were a relatively small proportion of total disaster costs. However bushfires are the most hazardous type of disaster in terms of deaths and injuries.

The most costly hazards by jurisdiction were:

- New South Wales (floods, storms)
- Queensland (floods, tropical cyclones)
- Victoria (floods, bushfires)
- Western Australia (tropical cyclones, storms)
- South Australia (floods, storms)
- Tasmania (bushfires, floods)
- Northern Territory (tropical cyclones, floods)
- Australian Capital Territory (bushfires, storms).

The likelihood of potential natural disasters is not known with certainty. Past patterns of bushfire incidents and extreme weather events provide some indication of the probability that such events will occur in the future. There are some studies historical events that provide a reliable indication of such events. However the literature on this matter in Australia is not comprehensive.

In the discussion below we have not attempted to undertake a statistical analysis of frequency or average annual damage costs that would be required to estimate the reduction in expected average annual damage costs that could be attributed to EOS. We have however drawn together information that has come to light in consultations and desk top research to provide plausible estimates for the purposes of this report.

2.5.1 Fire

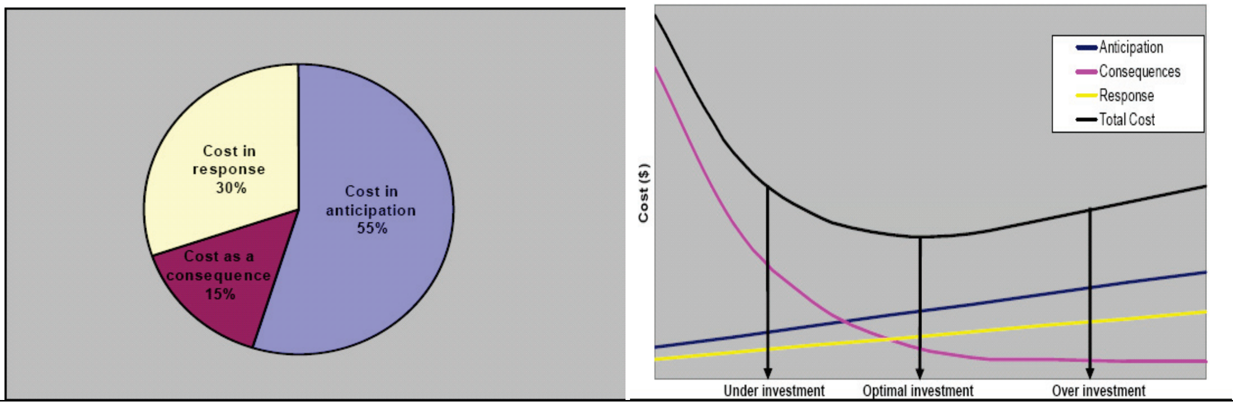
Bushfires occur relatively frequently in Australia. In some cases the resulting damage does not involve loss of life or major property damage. In others, the consequences are catastrophic.

The damage from national disasters can vary widely. Bushfires can result in lower production but no loss of life or property, as in the case of periodic fires in rural Queensland (see Box 3). Alternatively, fires can have major consequences for lost life and property as in Canberra in 2003 and in Victoria in 2008.

The total annual cost of fires in Australia has been estimated in a report prepared by Ashe, McAneney and Pitman at $8.5 billion (Ashe, 2006). The report found that 55 per cent of fire mitigation activities occurred in anticipation of bush fires, 30 per cent in response and 15 per cent in consequences (see Figure 8).[19] The cost of 'consequences' was therefore around $1.3 billion.[20]

It also noted that the marginal return on investment in consequences was negative whereas marginal returns to investment in anticipation and response investments were positive. EOS supports the latter activities. If this observation is correct, further public investment in EOS in future should deliver increasing returns compared with public spending on the consequences of fires.

Figure 8 **Distribution of costs of fire mitigation**



Data source: (Ashe, 2006)

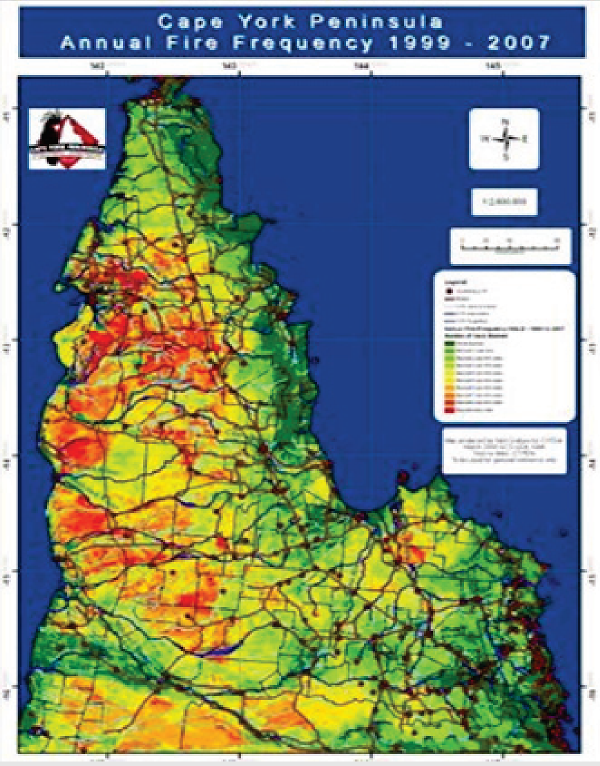
EOS data for fire management are supplied through the Sentinel (discussed above) and Firewatch services. Consultations with Geoscience Australia and Landgate in Western Australia indicated that EOS comprised about 95 per cent of the services provided.

In most cases these services were used for planning and preparation activities, monitoring of fires and movement of fire-fronts in advance of fire incidents and ongoing reporting during fire events. They were not used directly for deploying fire fighting resources.

19 Anticipation related to costs of preparation, fire services etc. Response related to mobilization of activities to fight the fires. Consequences related to the cost of the fires to the community.

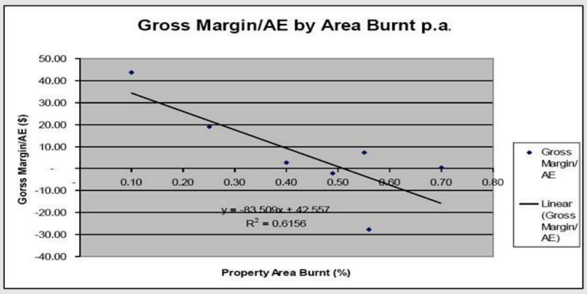
20 This estimate is significantly higher than the estimate referred made by the BTRE mentioned previously. The latter did not include the cost of anticipation of the fire event (planning and preparation) which may have accounted for some of the difference. However allowing for only costs associated with consequences the expected annual cost of fires would be around $1.3 billion.

Box 3 **Use of EOS for rural fire research and management**



This fire frequency map was produced using shows the land that has been burned over time. The dark green areas represent areas that have not been burned from 1999 to 2007. The bright red areas have been burned every year in the same period, with various degrees of burning represented by the lighter shades of orange, yellow and green.

The project combined 8 years (1999-2006) of satellite image mapping and interviews with land managers to assess the relative use of no fire management, fire fighting only, early dry season and/or storm burning in achieving property management objectives (such as restricting dry season fires, maintaining healthy cattle, preventing/reversing woody thickening).



CYSF and natural resource management agencies like the Rural Fire Service have gained valuable economic insights regarding fire management on pastoral properties and, by implication on conservation areas and indigenous lands as well. The project showed that lower gross margins (GM)/Adult Equivalent (AE - 400kg animal) were associated both with increasing average annual burn areas and lower stocking rates.

Source: Drucker, 2008

The effectiveness of planning and preparing for fire mitigation, establishing warning systems and developing response plans draws significant benefits from EOS. The ability to combine data from satellites with data such as ocean currents, vegetation cover or hazard incidents, significantly improves monitoring of potential hazards and development of warning systems and management strategies. There are no estimates in the literature of how less effective fire management might be without EOS - a conservative estimate is likely to be around 20 per cent. Depending on the estimates of costs this could mean that EOS delivers benefits of between $32 million and $255 million per annum[21].

[21] The first estimate is based on 20 per cent of $160 million being the 2001 BTRE estimate in 2010 dollars. The second estimate is and 20 per cent of $1275 million which is the 2006 Macquarie University estimate in 2010 dollars

2.5.2 Floods

The annual damage costs of flooding were estimated to be the most costly of all the natural disaster categories studied in the BRTE report – representing 29 per cent of the estimated annual damage costs of $1.14 billion in 2001 dollars (BTRE, 2001). This is equivalent to $331 million in 2001 dollars or $423 million in 2010 dollars.

Flood mitigation measures comprise both structural and non-structural activities. Structural activities include construction of levies, control structures and flood mitigation dams and storages. Non-structural activities are however important to reducing average annual damage. Non-structural activities include better planning for developments in the flood plain, flood plain mapping and flood zoning. Hazard warning systems are also important non- structural activities that focus on response measures.

Earth observation services are important for non-structural activities. Most imagery around metropolitan and town areas is acquired by airborne photography. However in remote areas satellite acquisition is more cost effective and can provide more regular monitoring of water movements in major storm events as well as providing data to support flood mitigation planning at the catchment level.

Using a conservative estimate, EOS could contribute around 5 per cent to reducing the average annual damage costs – equivalent to around $20 million in 2008-09.

2.5.3 Cyclones and storms

The BTRE estimated that cyclones and storms created 60 per cent of the average annual damage costs over the 1967 to 1999 period, or $874 million in 2010 dollars.

Extreme weather events affect business and the community and in some cases cause devastating consequences for communities. Cyclone Tracey created a major discontinuity in the development of Darwin. Less severe weather events can still cause major damage to property, crops and infrastructure. Severe storms have de-roofed dwellings, damaged infrastructure and caused severe dust storms in Australian cities over the past decade.

Apart from the resulting costs of damage, storms also have an impact on insurance premiums. Consultations with Landgate and WASTAC indicated that insurance premiums in Western Australia include up to $100 loading for storm damage for a normal dwelling. Any actions that reduce the damage from storms will help to reduce premia accordingly.

Using a conservative estimate, we have assumed that EOS could reduce the average annual damage costs of extreme weather events for Australian communities by around 5 per cent. This is equivalent to a reduction in average annual damage costs of $44 million.

Cyclones are also potential threat to offshore oil rigs and facilities. Offshore operators such as Woodside rely on BOM data to track and monitor cyclone movements. BoM operates a Tropical Cyclone Warning Centre in Perth. Within the centre, AVHRR data is used to assist in analysing the properties of large weather systems which supplements their positioning by radar, MTSAT-1R imagery augmented with modelling.

Woodside also rely on BoM BLUELink ocean monitoring services to assist with planning, design and operation of their offshore petroleum platforms and infrastructure. Ocean phenomena such as internal waves (undersea currents) and ocean eddies that can have serious impacts on sub-sea structures. EOS based oceanographic monitoring assists in planning for and responding to internal wave events. Much of this data is collected through MODIS.

Looking back at the impact EOS has made to forecasting as stated by the BoM (a 2-3 day gain, which would give commercial operators more than enough time to prepare for the weather event, fly out personnel, etc.), a higher proportion may indeed be justifiable.

Cost of delay (shut down due to the event) cannot be avoided but may be reduced. ABARE (2006) estimated average annual disruption costs due to severe weather to the oil and gas sector at $114.7 and $64.9 million to the iron ore sector. Better weather information can help avoid some or all of these costs; the ABARE report assumes 10% may be avoided thorough better weather forecasting.[22]

On the basis that BoM weather forecasts in this context are almost totally dependent on EOS, total average annual savings to the Australian economy from improved accuracy in weather forecasting are estimated to be $11.5 million per year for the petroleum sector and $6.7 million for the iron ore companies – a total annual saving of $18.1 million (AATC, 2006).

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22 A major benefit also lies in the insurance against catastrophic events such as a major oil leak; however this value has not been included here as the event probability is highly speculative – nevertheless it is an important benefit from a number of perspectives such as the general public's concerns about the environment and the regulator's risk assessment.

Table 6 **Estimated benefits and costs of the global ocean observing system**

Industry source	Estimated productivity gain	Annual value
	$ million	$ million
Oil and gas		
Shipping	10%	0.3
Deferred production	10%	9.8
Exploration rigs	10%	1.4
Iron ore		
Shipping	10%	0.2
Deferred production	10%	6.5
Total		18.1

Note: Not all benefits would be realised immediately
Data source: *(AATC, 2006)*

Overall impact of better management of extreme weather events

Forecasting weather events such as those above are virtually 100 per cent dependent on EOS. There are no estimates in the literature on how this might have contributed to lowering the average annual damage costs of such events. However given its importance, we consider that an estimate of around 5 per cent of the average annual damage estimate from the BTRE study would not be unreasonable and probably conservative. Using this logic, the benefits of EOS in 2008 could be of the order of $44 million to $60 million per annum (including the ABARE estimates above).[23]

2.5.4 Valuing the benefits

We have drawn on estimates of the economic value of EOS as either the reduction in expected average annual value of natural disasters for fires, floods and cyclones and storms, or as the increase in productivity in terms of additions to GDP as in the ABARE studies of the petroleum and iron ore industries. The two are not the same measure as they take varying account of resource transfers within the economy. They can only be regarded therefore as orders of magnitude in terms of economic benefit.

The total benefit that might be attributed to EOS from mitigation of natural disasters is estimated to range between $100 million and around $200 million per annum expressed in reduction in expected average annual damage costs or in increased economic activity.

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23 Derived as 5% of the annual cost of cyclones and storms from the BTRE study - $874 million in 2010 dollars. Extra value from petroleum and iron ore activities offshore North Western Australia around $12 million in 2010 dollars.

Table 7 **Disaster related EOS benefits**

Category	Annual estimate
Cost of natural disasters	$1.5 billion
Cost of fires (broader estimate)	$8.5 billion
All costs associated with disasters and emergency management	>$2 billion
- 5% change	>$100 million
Identified Australian benefits	
- Flooding	$20 million
- Fires	$32 million - $255 million[1]
- Cyclones and extreme weather	$44 million - $60 million
- Total	$100 million - $335 million
ACIL Tasman reference estimate	**$200 million**

[1] Depends on whether anticipatory investment is included and on which estimate of costs is used.

Note: Estimates are approximate and can be compared only in general terms as some are reductions in expected average annual damage and some are expected increases in annual economic output.

Data source: Reports cited in Section 2.5.

2.6 National security

EOS has a wide range of applications in sustaining and protecting national security. Defence use of EOS includes:

- information and intelligence in support of national security
- situational awareness in operations
- protecting critical infrastructure and contingency planning
- hydrography
- navigation
- estate management.

The Defence White Paper released in 2009 emphasised the importance of information superiority as one of the key capability priorities for the Australian Defence Force. This included the need for comprehensive levels of situational awareness in the ADF's primary operational environment and the capacity for continuous wide area surveillance of the northern approaches to the Australian continent.

A significant new emphasis identified in the White Paper was access to high quality space based imagery to meet the ADF needs for mapping, charting, navigation and targeting data. The paper announced the Government's intention to acquire a satellite with a remote sensing capability. This is most likely to be based on high-resolution SAR.

The Defence Intelligence and Geospatial Organisation (DIGO) is the lead geospatial and imagery intelligence organisation in the Department of Defence.

The organisation provides geospatial intelligence, from imagery and other sources, in support of Australia's defence and national interests.

DIGO reported that it drew on the capabilities of 15 Commonwealth agencies and 34 private suppliers. Important providers included Digital Globe, GeoImage, SKM, GeoEye, SPOT Image and APOGEE. Annual expenditure on EOS projects by DIGO has been estimated at around $500 million but could be higher.

The value of a secure and safe community and protection from terrorism and hostile acts against the nation is almost incalculable. The cost of the attacks against the World Trade Centre has been extremely high for the United States, both in economic and social terms. The costs include increased surveillance and establishment of a new agency for homeland security. Higher surveillance has also resulted in extra costs to businesses and the community in more rigorous inspections at airports and greater intelligence gathering to anticipate potential attacks.

ACIL Tasman was not able to obtain detailed information on the value EOS applications for national security and defence in Australia. However, the current and potential role of EOS in protecting the nation as well as through national security related activities such as nuclear non-proliferation efforts (e.g., through monitoring of illegal reactor sites, etc.) is clearly very important.

2.7 Future large scale applications for Government

2.7.1 Trends

Government administration, program management and policy development have become increasingly dependent on mapping and other data supplied by EOS over the past fifteen years. Consultations indicated that the rate of adoption has accelerated in recent years as the challenges of achieving sustainable levels of water extraction, natural resource management, and climate change have become central policy issues. This is in addition to the increasing use of EOS in support of national security and defence.

The increased use of EOS sourced data by Governments has been accelerated by parallel developments in information systems and web access that has facilitated the fusing and sharing of data between agencies. It has also supported considerable innovation in applications in support of policy development and program implementation. Innovation appears to be accelerating as more accurate data become available and as simulation techniques improve. Examples are the use of EOS for monitoring vegetation change, support of the National Carbon Accounting System and in the use of hyper-spectral and SAR data to improve ocean monitoring and weather forecasting. Over the next five to ten years these systems can be expected to become mainstream in some departments.

Future large scale applications are likely to be driven by emerging policy priorities of government. The four key drivers are natural resource management, climate change, emergency management and national security. Major applications in these areas include:

- weather forecasting and climate change
  - increased use of EOS data for atmospheric and ocean monitoring in conjunction with simulation and climate models to provide more frequent and reliable forecasts of weather for agriculture and for planning for and managing extreme weather events
  - modelling with EOS data to develop a greater understanding of basic weather and climate change processes
  - monitoring of changes in carbon sequestration by forests in Australia in support of national carbon accounting and meeting Australia's current and future international obligations to reduce emissions of greenhouse gases
  - monitoring ocean physics in support of evidence based policy development for climate change.
- Natural resources management
  - significant increase in use of EOS to support monitoring and accounting for surface and groundwater in all water catchments in Australia but particularly in the Murray Darling Basin and for groundwater management in Western Australia
  - wider use of instruments for monitoring of vegetation cover, type, change and condition (including the use of more accurate measurement of data such as moisture, temperature etc) and for monitoring compliance with land clearing covenants
  - use of EOS data to provide biomass estimates in agriculture and to support improved agricultural advisory services from government
  - better management of extreme natural events such as dust storms, floods, droughts and coastal inundation to better plan for mitigation efforts and inform future planning strategies for both government and industry
  - use of EOS data for improved monitoring of ocean conditions and sustainable management of fish resources
  - increased us of EOS for pre-competitive geoscience through innovation in the use of data to identify oil seeps and mineralisation in remote and frontier areas.

- Emergency management
  - With predictions of more extreme weather events occurring in future as a consequence of climate change and greater community concerns over the management of fires, floods and extreme weather events, the use of EOS to better predict, plan and manage emergencies is likely to increase.
  - It is likely that governments will require better information to plan and respond to floods, fires and extreme storms to reduce their social and economic impact.
  - Use of this data by industry and communities is also likely to rise as higher bandwidth improves web access which will also support development and deployment of applications such as Indji Watch and other emergency management systems.
  - It is also possible that greater demand for such services will arise in future from both industry and the community to complement the efforts of emergency management agencies.
  - In the insurance sector, EOS benefits will also become more marked (e.g., call centre claims coordination, etc) and according to expert feedback EOS is already being used by insurers in negotiations with the major international re-insurers.
- Defence and national security
  - The Defence White paper made it clear that information superiority is a priority for the future. It indicated the Government's priority an assured access to space based imagery the meet Defence's needs for mapping, charting, navigation and targeting data. It has indicated its intention to acquire a satellite with remote sensing capability possibly based high resolution SAR.
  - While we did not value the use of EOS for defence and national security we believe that its value will increase significantly in the coming years as national security and protection of critical infrastructure become increasingly focused on better information.

2.7.2 Value in the future

It can be expected that the value of EOS data for weather forecasting and climate change will grow significantly over the next five years as greater use of the data for weather prediction and carbon accounting occur driven both by need and technical capability.

The value of EOS in NRM is also likely to grow particularly fast due to the growing need for use in vegetation mapping, water accounting, fisheries management and environmental and natural resource compliance monitoring. This will be achieved through the increased capability to fuse data and utilise simulation and modelling to describe water and vegetation conditions.

The value in emergency management is also likely to increase as coordination, transparency and access across the sector improves (e.g., integration of systems across States), and as community demands for improved planning and response measures grow. Increased value due to a higher frequency of fire, flooding and extreme weather events associated with climate change has already been mentioned.

Growth in government programs is probably somewhat budget constrained over the next 3-5 years. These financial imperatives mean that our estimate of the EOS sector's direct contribution to GDP of $1.4 billion may not change very significantly over the next five years, although the consultations during the preparation of this report suggest that various Departments are actively investigating more intensive use of EOS. An example of this came in the discussions with AFMA where acquisition of data for monitoring of illegal fishing is actively being considered.

As shown in this report, a number of other Departments are also considering more active involvement in EOS. Similarly, at the local and State government levels EOS is starting to be considered over aerial photography. This indicates that there will be some further shift towards EOS; however, given the broad range on which our $1.4 billion estimate is based, we feel that $1.4 billion will remain an appropriate reference figure for the next 3-5 years.

By contrast, there is potential that the impacts of EOS in terms of productivity and final outcomes could grow quite rapidly, in particular as some of the major current project become fully operational and legislation begins to bite more seriously (e.g., in the land cover/vegetation monitoring space).

In Section 2.1.3 we estimated the total productivity impact of EOS in 2008-09 to be $1.9 billion to the Australian economy. Since that work was completed ACIL Tasman has undertaken similar studies in New Zealand and the United Kingdom. In the course of this work we have also revisited the extent of adoption of geospatial technologies in Australia. We have noted that adoption has increased across the economy. This has been supported by the consultations we have undertaken for this project. We therefore believe that there is scope in for the $1.9 billion productivity impact to grow to $2.5 billion by 2015 (representing an average annual growth rate of 4.7% over the six years from 2008-09 to 2014-15).

On balance, given the appropriate stimulus and coordination, we believe that the GDP impact of EOS could be in excess of $3.9 billion in 2015. Other benefits, which we have broadly identified as being worth $1.0 billion or more in 2008-09, may also grow. However, once again, we note that since the $1.0 billion estimate was based on a fairly broad range of estimates, it will probably remain as a reasonable reference figure for the next 3-5 years.

3 Critical issues and investment for the future

In framing its policy towards the EOS sector government needs to take into account the current status of the EOS community. The sector has a number of strengths including:

- cutting edge user community
  - will be able to drive further innovation
- range of EOS based information products already on the market
  - platform for further growth exists

By contrast, potential weaknesses of the Australian EOS sector are:

- absence of 'guaranteed' source of supply and lack of autonomy in sovereign control over the flow of space-based information
- shortage of specialists (hence underutilisation of EOS in some areas, for example, local government)
- lack of coordination between government users
- potential 'ageing' of ICT and other infrastructure as data volume and type will change dramatically over the coming decade
- some constraint on growth opportunities for small to medium sized private suppliers arising from the provision of satellite data by government agencies.

A denial of service, or unplanned disruption to supply of EOS data (whether it is for technical, policy or pricing reasons) is one of the threats facing the Government sector.

3.1 Denial of service

The issue with a so-called 'denial of service' in EOS is different from a denial of service for those depending on communications or positioning satellites. It is generally accepted that a denial of service in those two areas would seriously disrupt the operation of a modern economy[24]. With regard to EOS, by contrast, it is most importantly the future benefits identified above that are put at risk if there is a denial of service.

There are three potential situations that would result in a denial of service:

- malfunction
- operator initiated restriction of access to data from a particular satellite

[24] (Department of Commerce, 2009)

  - as might arise if a natural disaster in the northern hemisphere created an scheduled reassignment of a satellite on which Australia depends
- natural or intentional/unintentional interference
  - including disruption of service cause by space debris

If access to EOS ceases for whatever reason, the economic impact on civilian use would be more gradual than that arising from an interruption to satellite based communications or positioning.

The prospect of a denial of service to Australian users is very real as Landsat 5, the satellite on which many government programs depend, will not be replaced until 2013 at the earliest (and which currently provides data free of cost to Australian users). Landsat 5 is operating well beyond its planned life span, is running completely on back up and has recently had serious technical problems.

Landsat 7 currently provides a back up option although it too has a serious technical issue which means that approximately one quarter of each 'scene' captured by Landsat 7 is missing. If Landsat 5 were to fail, users would thus be forced to live with data gaps or fill them from commercial sources at least until the Landsat Data Continuity Mission (LDCM) is in orbit (and assuming the US government continues its free access policy). Many government departments do not currently have budgetary provision to source from commercial sources.

Our stakeholder consultations revealed that EOS users could probably compensate for a general loss of data for a few days or even weeks, but after this, serious problems start to set in for many users.

In another context, the Bureau of Meteorology and those depending on weather observation data would be seriously affected within days, or possibly within hours, if access to the satellites upon which the Bureau depends were disrupted.

In economic terms, the immediate effect of a denial of service would be the under-utilisation of resources in government programs. Whilst these resources would not sit idle, there would be significant disruption to effort. Additional budget might be required to acquire data from other satellites such as ALOS or SPOT if available.

It cannot be anticipated which events might be overlooked or even lost as a consequence of a denial of service. This could have critical implications for the modelling of natural processes– for example, if a serious coral bleaching or fish mass mortality event were to occur during the blackout period then it may be hard to piece together important pieces of the puzzle retrospectively.

In our view a realistic assessment of the economic impact of an unplanned denial of service requiring 'source shift' is at least $100 million in the year during which such a denial of service occurs. This could either be from lost government productivity (e.g., 1-2 months of effort lost, given that identified expenditures in EOS dependent programs is $1.3 billion) and/or the cost of acquiring data from alternative sources (which could cost over $50 million) and/or the loss of outcomes or benefits. The longer term impact would be a multiple of this, depending on the extent of the data gap.

3.1.1 A complete denial of service

A complete denial of service would seriously damage a range of EOS capabilities including Australia's ability to monitor and respond to an emergency situation (e.g. a tsunami or terrorist attack). Such a scenario is admittedly a low probability event, given the number of satellites in orbit, but the consequences could be extreme.

A complete denial of service would seriously jeopardise the benefits identified above accruing from productivity improvement and from climate change, natural resources management and mitigating the effects of natural disasters. Taking into account lost efficiencies in government, the 'cost' to the Australian economy could certainly run into billions of dollars in the first year alone. There would also be consequences for Australia's defence capability.

3.2 Implications for large scale government investment

A number of different perspectives have emerged in relation to Australia's involvement in EOS. In the wider debate around space policy, there are proponents of the view that Australia should pursue its own space capability, notably through its own satellites. This view is partly driven by arguments around national security and autonomy. The recent Kokoda report (Biddington 2008), for example, also recommends that Australia should:

> ...acquire space competencies and capabilities which will add national benefit in their own right whilst adding weight and credence to an independent national space strategy. Whilst this strategy could be expected to acknowledge and promote a continuing close affinity on space matters with the US, it would also provide room for Australia to exercise, where appropriate, independence of thought and action in pursuit of longer term national interests.

During the interviews conducted for this report, several industry participants commented that under an 'ideal' scenario Australia would have its own EOS satellite, such as a hyper spectral geostationary satellite that would provide coverage for Australia. The Korean capability was cited as a comparison. Such a satellite would supply useful data for the region including Indonesia as well as

Australia. It was also argued that this could help strengthen regional partnerships.

Australian users need access to a wide range of data from EOS. A full discussion of possible strategies that Australia might pursue to meet these needs is beyond the scope of this report.

The following discussion focuses on civilian use and particularly on the need for continuity of access to EOS data. It is drawn from views expressed to ACIL Tasman during consultations.

Commissioning a satellite

Putting its own satellite (or constellation of satellites) into orbit is one of Australia's options to address the risks associated with a denial of service. Depending on the type of satellite, this might cost $300 million to $500 million to develop and launch and would involve ongoing operational costs.

A cheaper and different investment could be in some form of constellation of micro-satellites such as the one discussed in the discussion on weather in Section 2.3 above. This might cost around $20 million but may not provide the range of sensors required for some of the emerging applications discussed in this report. Launching a small number of micro weather satellites could however form a sensible component of a portfolio of satellite access arrangements. Australia is still one generation behind leading countries in terms of access to weather data and such a strategy is one approach to addressing this concern[25].

In the Defence White Paper the government indicated its intention to acquire a satellite with remote sensing capability – most likely based on high resolution, cloud penetrating SAR. This addresses a specific requirement of the Australian Defence Forces. Civilian requirements are somewhat broader. Each application would draw on different instruments. It would be very costly for Australia to commission the number of satellites to meet all the civilian requirements.

Buying a seat at the table

A cost-effective way to address vulnerability and continuity of access issues, that would minimise risk in all but the most extreme and highly unlikely circumstances, would be to invest $10 million to $30 million annually to secure guaranteed access to one or several of the satellites launched by other countries. One prospective partner for this type of arrangement would be the European Space Agency, as is the China–Brazil Earth Resources Satellite

[25] Interview – Bureau of Meteorology

program (CBERS). Excellent continuing coverage from a range of instruments could be guaranteed at less than $50 million.

An extension of this approach would be to invest in a portfolio of partnerships to provide a broad coverage of the sensor data.

Investing in infrastructure (dishes, etc)

Australia is one generation behind the USA and Europe in terms of access to, and processing capability of weather data and it is believed that a significant shift in data availability over the coming decade will mean that Australian ground-station infrastructure and networks will require a significant upgrade.

Data funnelling

Discussions through the consultation phase made clear that there is still considerable scope for data sharing across government. It makes sense to invest in central resources which can be accessed by a number of parties (i.e., not subject to firewall restrictions).

Coordination

In order for any large scale investment in a portfolio of resources to translate into effective benefits, the whole range of investments needs to be assessed for complementarity in the first place (i.e., not spend on competing products, and not spend 'twice over' on the same products), and secondly awareness, skills and implementation processes need to be dovetailed so that benefits are realised across the whole of government.

Creation of the Space Policy Unit in the Department of Innovation, Industry, Science and Research (DIISR) as part of the Australian Government's $48.6 million Australian Space Science Program has been an important development. However, it may not (yet) have the resources necessary to oversee coordinated implementation of technical efforts in the EOS area. Some thought needs to be given as to how the various EOS investments might best be managed from a whole of government perspective.

4 Findings

4.1 Economic value of EOS

In this report we have addressed economic value of EOS from three perspectives:

- the direct contribution to GDP in 2008-09
- the productivity impact on GDP in 2008-09
- other benefits accruing to society from the use of EOS in 2008-09

Each perspective illustrates a different aspect of economic value. The first indicates size of the economic footprint of the EOS sector. The second represents the impact that EOS activities had on economic activity elsewhere in the economy. They reflect different aspects of the contribution of EOS to GDP and when added together provide an indication of the economic impact of EOS in the economy.

The third number is a measure of other economic benefits that have not been captured in the above numbers and include concepts of costs avoided and other intangible benefits. The findings are summarised in Table 8.

Table 8 **The annual economic impact of EOS in Australia**

	2008-09 estimate
Direct contribution to GDP	$1.4 billion
Productivity impact on GDP	$1.9 billion
Other benefits – climate change, NRM, disasters	$1.0 billion

Data source: ACIL Tasman analysis

Taking the direct contribution to GDP and the additional productivity impacts into account EOS is estimated to have contributed at least $3.3 billion to GDP in 2008-09.

Additional benefits in improved management of climate change, natural resource management and emergency response are worth at least $1 billion in additional value.

4.2 Impact of a denial of service

This issue was viewed from two perspectives – an unplanned but limited denial of service and a complete denial of service.

4.2.1 A limited but unplanned denial

Losing Landsat 5 would result in serious gaps in imagery for around 2-3 years and would require selective gap filling that would have to be acquired from commercial sources. Resources in Government would be under-utilised and additional costs would be incurred in acquiring data from commercial sources. There would also be some benefit reduction in lost outcomes.

Our assessment of the impact of the economic impact of such an event, or an event requiring a source shift, would be at least $100 million (see Section 3.1 above). However, there are other satellites that could be used that might reduce this overall cost providing that Government agencies were able to secure additional budget to replace the otherwise free services.

4.2.2 Complete denial of service

A complete denial of service is a low probability but if it occurred it would seriously damage a range of EOS dependent capabilities. It would have critical impact on modelling of natural processes and impede a wide range of natural resource management and weather related services and research.

A complete denial of service could negate the productivity impacts and other benefits identified in Table 9 above. A precise estimate is impossible to venture but the costs would certainly run into billions of dollars annually taking into account loss of efficiency in government as well. The impact on Australia's defence capability would be extreme.

4.3 Size of the commercial sector

Depending on how EOS activities are defined the commercial sector could comprise between 35 and 100 small to medium enterprises.

The component of this sector that supplies imagery and basic data processing only is estimated to have a turnover of $30 million to $40 million per year in 2010.

4.4 Large scale government applications and future value

Current use of EOS in government is moving from the early adopter stage to an early majority stage of adoption. EOS now enables many applications in defence and national security, climate change and weather forecasting, natural resources management and mitigating natural disasters. The use of EOS for these purposes is likely to increase over the next five to ten years as policy demands increase, government and commercial applications mature and as further developments in fusion of the data and improved web access increases the supply of EOS related services.

Some important applications include:

- monitoring of illegal fishing across State and Commonwealth fisheries
- the Bureau of Meteorology stated that EOS is still underutilised in the weather space
- oil, gas and mining companies could use it more, for example in environmental monitoring and clean up monitoring
- the Australian Bureau of Statistics is currently exploring the potential for EOS to feed into its reporting
- compliance monitoring in the NRM context across various States, including greater frequency of observations and reports
- there is potential for EOS to be utilised in the agricultural policy and forecasting space (for example by ABARE)
- national environmental accounts will draw heavily on EOS
- policing can draw more on EOS (e.g., to identify illegal narcotic crops), and so on.

Growing applications in defence and national security include:

- information and intelligence in support of national security
- situational awareness in operations
- protecting critical infrastructure and contingency planning
- hydrography and navigation

Future expenditure by government on EOS services has not been estimated. However ACIL Tasman considers that it would not be unreasonable to conclude that the productivity related impacts on GDP and the other benefits could increase by around 30 per cent by 2015.

This would mean that:

- contribution to GDP could grow from $3.3 billion to around $4 billion by 2015
- additional benefits in climate change adaptation, natural resource management and emergency response could increase as well but our reference figure of $1 billion will probably remain the appropriate reference figure for the next 3-5 years as it is based on a broad range of estimates
- additional value in national security will also accrue but has not been estimated.

A Glossary of terms

Term	Explanation
ABARE	Australian Bureau of Agricultural and Resource Economics
ALOS	Advanced Land Observing Satellite
BOM	Bureau of Meteorology
VHRR	Very High Resolution radiometer
CSA	Canadian Space Agency
CRC SI	Cooperative Research Centre for Spatial Information
CPRS	Carbon Pollution Reduction Scheme
ESA	European Space Agency
EC	European Commission
AuScope	Geoscience program concerned with the structure and evolution of the Australian Continent funded under the National Collaborative Research Infrastructure Program
IMOS	Integrated Marine Observing System funded under the National Collaborative Research Infrastructure Program
ISRO	Indian Space Research Organisation
TERN	Terrestrial Ecosystems Research Network funded under the National Collaborative Research Infrastructure Program
CNES	Centre Nationale d'Etudes Spatial
DIGO	Defence Imagery and Geospatial Organisation
EOS	Earth observation from space
GA	Geoscience Australia
SPOT	Satellite Pour l'observation de la Terre
GDP	Gross domestic product - the total value of goods and services produced after deducting the cost of goods and services used to produce them but before deducting the allowances for fixed capital. It is equivalent to value added plus taxes less subsidies.
LIDAR	Light detection and ranging – a technology for mapping height, topography and other natural features where distances need to be measured remotely.
NOAA	National Oceanographic and Atmospheric Administration
DLR	Deutsches Zentrum fű r Luft-und Raumfahrt
SAR	Synthetic Aperture Radar
NASA	National Aeronautics and Space Administration (USA)
WASTAC	Western Australian Satellite Technology and Applications Consortium

B Some important EOS satellites

Table B1 **Some important earth observation satellites and their uses**

Satellite	Agency/ Company	Instruments	Type	Function
ALOS	JAXA	AVNIR-2 PALSAR PRISM	Advanced visible and near infrared radiometer Phased array type L band synthetic aperture radar Panchromatic remote sensors for stereo mapping	Cartography, digital terrain models, environmental monitoring, disaster monitoring, civil planning, agriculture and forestry.
Aqua	NASA	AMSU-A AIRS MODIS CERES HSB AMSR-E	Init imaging multi spectral radiometers Atmospheric infrared sounder Moderate resolution imaging spectrometer Earth radiation budget radiometer Atmospheric temperature and humidity sounders Imaging multi spectral radiometers (passive microwave)	Atmospheric dynamics of water end energy cycles, cloud formation, precipitation and radiative properties, air/ sea fluxes of energy and moisture, sea ice ex tent and heat exchange with the atmosphere.
CosmoSkyMed-1	ASI/MiD (Italy)	SAR2000	Synthetic aperture radar	Environmental monitoring, risk management, maritime management, topographic mapping, law enforcement, science.
Envisat	ESA	DORIS-NG ASAR MERIS MIPAS GOMOS SCIAMACHY RA-2 AATSR	Precision orbit Imaging microwave radars Medium resolution imaging spectrometer Atmospheric temperature and humidity sounders and atmospheric chemistry Scanning imaging absorption spectrometer for atmospheric chemistry Radar altimeter Imaging multispectral radiometers	Physical oceanography, land surface, ice and snow, atmospheric chemistry, atmospheric dynamics/water and energy cycles.

Satellite	Agency/ Company	Instruments	Type	Function
ERS -2	ESA	MWR ERS Comms GOME RA ATSR/M AMI/SAR/Image AMI/SAR/wave AMI/scatterometer	Imaging multispectral radiometers (passive microwave and atmospheric temperature and humidity sounders. Atmospheric chemistry monitoring Radar altimeter Imaging multi spectral radiometer Imaging microwave radars Imaging microwave radars Scatterometers measure wind fields at the ocean surface, wind direction (360 degrees) and wind speed up to 30 m/s	Earth resources plus physical oceanography, land surface, ice and snow, atmospheric chemistry, atmospheric dynamics, water and energy cycles. Measures wind speed, significant wave height, sea surface elevation, ice provide, land and sea ice topography and boundaries.
FY-2C Geostationary meteorological satellite	NRSCC	IVISSR (FY-2)	Improved multi-spectral visible and infra red spin radiometer	Meteorology and environmental monitoring, data collection and redistribution.
GRACE	NASA/DLR	Microwave ranging	Gravity Recovery and Climate Experiment	Measurement of the Earth's gravitation al field
GeoEye -1	GeoEye	Multispectral and panchromatic s	Panchromatic and multispectral images	Imagery for a range of natural resources, and environmental analysis and map creation.
IKONOS	GeoEye	High resolution panchromatic and multispectral sensors	Panchromatic and multispectral images	High-quality satellite imagery for map creation, change detection, and image analysis
INSAT	ISRO	VHRR DRT-S&R CCD Camera	Meteorology, data collection and communication, search and rescue	Weather monitoring and forecasting, search and rescue.
IRS-1D	ISRO	LISS –III PAN WiFS	Linear image self scanner – high resolution optical scanner Pan chromatic and multi spectral imager – high resolution optical imager Wide field sensor – high resolution optical imager	Land surface, agriculture and forestry, regional geology, land use studies, water resources, vegetation, coastal and soils studies.
JERS -1	JAXA/NASA	SAR OPS	Synthetic aperture radar Very near infrared optical sensor	Surveys of geological phenomena, land usage, observation of coastal regions, geologic maps, environment and disaster monitoring

Satellite	Agency/ Company	Instruments	Type	Function
Landsat -5	NASA	MSS Landsat comms	Multi-spectral radiometers Communications	Measures surface radiance – used for land applications – land surface, environmental monitoring, agriculture and forestry, disaster monitoring an assessment, ice and snow cover.
Landsat -7	NASA/USGS	ETM Landsat comms	Enhanced Thematic Mapper plus Communications	Measures surface radiance – used for land applications – land surface, environmental monitoring, agriculture and forestry, disaster monitoring an assessment, ice and snow cover.
MSTAT – 1 R	JMA/JCAB	MSTAT Comms JAMI MSTAT DCS	 Advanced meteorological imager Data collection system	Meteorological and aeronautical applications
MSTAT - 2	JMA/JCAB	Imager MSTAT comms MSTAT DCS	Meteorological imager Data collection system	Meteorological and aeronautical applications
NOAA	NOAA	AVHRR	Advanced very high resolution radiometer (imaging)	Measurement of land and sea surface, cloud top temps and cloud cover aerosols, vegetation, atmospheric water vapour and liquid water content
NOAA -16	NOAA	SEM ARGOS HIRS/3 SBUV/2 AMSU-B AVHRR/3 Comms	Space environment monitor Data collection by Doppler measurements High resolution infra red sounder Solar backscatter ultraviolet instrument Advanced microwave sounding unit for temperature and humidity Advanced very high resolution radiometer.	Meteorology, agriculture an forestry, environmental monitoring, climatology, physical oceanography, volcanic eruption monitoring, ice and snow cover monitoring, total ozone studies, solar flux analysis, search and rescue.
Pleiades 1	CNES	HiRI	High resolution optical imager	Cartography, land use, risk, agriculture and forestry, civil planning and mapping, digital terrain models, defence
Pleiades 2	CNES	HiRI	High resolution optical imager	Cartography, land use, risk, agriculture and forestry, civil planning and mapping, digital terrain models, defence.
Quickbird	Digital Globe		Panchromatic and multispectral sensors	High-quality satellite imagery for map creation, change detection, and image analysis

Satellite	Agency/ Company	Instruments	Type	Function
Radarsat -1	CSA	SAR AIS	Synthetic aperture radars – imaging micro wave radars Automatic identification system	Environmental monitoring, physical oceanography, ice and snow, land surface.
Radarsat -2	CSA	SAR	Synthetic aperture radars – imaging mi cro wave radars	Environmental monitoring, physical oceanography, ice and snow, land surface.
RapidEYE	DLR	MSI	Multi spectral imager – high resolution optical imager	System of five satellites for cartography, land surface, digital terrain models, disaster management, environmental monitoiring. High resolution with short observing cycles for commercial and scientific applications.
Resourcesat-1	ISRO	AWiFS LISS-IV LISS-III	Advanced wide field sensor – high resolution optical imager Linear self imaging scanner Linear self imaging scanner – high resolution optical imagers	Land applications including environmental monitoring, agricultural and forestry, disaster monitoring, vegetation mapping, resource assessment, cross stress detection, crop production, land use and land cover change.
SPOT-4	CNES	HRVIR VEGETATION DORIS	High resolution optical imager - 60kmx60km images Imaging multi spectral radiometers Doppler orbitography and radio-positioning	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring.
SPOT-5	CNES	HRG VEGETATION HRS DORIS-NG	High resolution optical imager - 60kmx60km images Imaging multi spectral radiometers High resolution stereoscopy optical imagers Doppler orbitography and radio-positioning for precise orbit determination	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring.
TanDEM-X	DLR	X-band SAR	Synthetic aperture radar	Cartography, land surface, civil planning and mapping, digital terrain models, environmental monitoring.
Terra	NASA	MOPITT MODIS MISR ASTER	Atmospheric chemistry Moderate resolution imaging spectrometer Multi angle imaging spectroradiomter Advanced spaceborne thermal emission and reflection radiometer	Atmospheric dynamics, water and energy cycles, atmospheric chemistry, physical and radiative properties of clouds, air land exchanges of energy, carbon and water vertical profiles of CO2 and methane vulcanology
TerraSAR X	DLR	X-band SAR	Synthetic aperture radar	Cartography6, land surface, civil planning, digital terrain models, environmental monitoring.

Satellite	Agency/ Company	Instruments	Type	Function
THEOS	GISTDA	PAN MS	Panchromatic and multi spectral imager – high resolution optical Multi spectral radiometer	Cartography, land use, land cover change management, agricultural and natural resource management.
Worldview I and II	Digital Globe		Panchromatic and multispectral sensors	Provide highly detailed imagery for precise map creation, change detection and in-depth image analysis

Data source: (CEOS/ESA, 2008), CRCSI, Geoscience Australia

C EOS dependent programs in Government

Table C1 **Australian Federal and State programs dependent on Earth Observation**

Agency/s	Program/Product	Description	Satellite/Sensor list
High EO dependency			
AAD, GA, DCC, BoM	Satellite Altimetry	Satellite altimetry provides accurate measurements of altitude and heights	MODIS, MERIS NOAA
ACBPS	Border Protection	The Australian Customs and Border Protection	Radarsat-2, TerraSAR-X, CosmoSKYMED
ACTPLA	ACT Planning and Land Authority	Satellite imagery used for land use monitoring	Landsat, SPOT
ANZLIC	DEM and Surface Modelling	The National Elevation Data Framework (NEDF)	
BF CRC	Grasslands curing assessment	Satellite derived vegetation indices may be used to quantify vegetation condition	MODIS
Bushfires NT	Fire mapping: National Parks and Arnhem Land Fire Management Area	Satellite imagery plays a vital role in bushfire containment and management	Landsat, NOAA – AVHRR, MODIS
CRCSI / LPMA / UNSW	Radar Watch	Radar Watch is a research demonstration program to promote radar EO	ADS40, ALS50, HJ-1A/ 1B, Landsat, ERS-1/2, JERS-1, Radarsat-1, Envisat, ALOS, Radarsat-2, COSMO-SkyMed, TerraSAR-X
CSIRO, BoM	Water Information Research and Development Alliance (WIRADA)	Evapotranpiration monitoring for regional and national scale water budgets	Landsat, MODIS
CSIRO, BoM, DEWHA, DIISR	Centre for Weather and Climate Research (CAWCR)	CAWCR is a partnership between CSIRO and the Bureau of Meteorology	MODIS, WINDS, MTSAT, AATSR, Calipso, Cloudsat
CSIRO, GRDC	Biomass Monitoring	Measurement of biomass can be made over a range of scales from point source to regional level	NOAA-AVHRR SPOT, Landsat
CSIRO, IMOS, AIMS, DEWHA	Ocean Colour Monitoring	Large area monitoring of marine	MODIS
CSIRO, Landgate (WA) AGRIC (WA)	Pastures from Space	Pastures from Space is a farm management tool	MODIS
CSIRO, State geological surveys, GA	International Hyperspectral Imaging Satellite Programs	An International collaboration focusing on applications in the geosciences	Hyperion, ASTER
CSIRO, TERN, DEWHA	AusCover TERN	Terrestrial Ecosystems Research Network (TERN) will provide a network for terrestrial ecosystem research .	Landsat, ALOS, MODIS
DCCEE, CSIRO	National Carbon Accounting System (NCAS)	The National Carbon Accounting System	Landsat, Quickbird, Ikonos
DEC	.Fire Mapping and Modelling	The mapping and locations of fire patterns within the DEC Estate	Landsat, ALOS, MODIS
DEC	Vegetation Monitoring	Key DEC responsibilities include broad roles in conserving biodiversity and protecting, managing, regulating and assessing many aspects of the use of the State's natural resources	Landsat, ALOS, Quickbird

Agency/s	Program/Product	Description	Satellite/Sensor list
DECCW	DustWatch	The DustWatch Program monitors aerosols	MODIS
DECCW	Elevation and vegetation structural mapping	Vegetation monitoring, wetland and water resource management	
DECCW	Groundwater Dependent Ecosystems (GDE) Water Balance	Groundwater dependant ecosystem location mapping	MODIS
DECCW	Groundwater Quality and Coastal GDE Mapping	Mapping of coastal groundwater dependant ecosystems	Landsat
DECCW	Inland wetland inventory and monitoring	The Inland Wetland Inventory is a storehouse of standardised information	Landsat, SPOT, MODIS, ALOS
DECCW	Mapping Wetland Inundation Histories for Iconic NSW Wetlands	Mapping wetland inundation histories	Landsat
DECCW	Marine Monitoring Reporting and Evaluation	Chlorophyll estimates are required	MODIS
DECCW	NSW High-Resolution Vegetation Monitoring Program	The High-Resolution Program complements the SLATS (Landsat) Program	SPOT
DECCW	NSW Woody Vegetation Monitoring Program (NSW SLATS)	SLATS is a major vegetation monitoring initiative	Landsat
DECCW	Rural Floodplain Management	Remote sensing is an essential component of rural floodplain management	Landsat, SPOT, MODIS, ALOS
DECCW	Vegetation Monitoring – Grassland	A range of satellite derived vegetation indices have been widely used to classify land cover	Landsat, SPOT, MODIS, ALOS
DECCW/Industry	Sea Surface Temperature and Height Anomaly	Manly Hydraulics Laboratory provides access to sea surface temperature products	MODIS, AVHRR, SeaWIFS, Envisat RA2 altimeter and AATSR radiometer, ERS1/2 altimeters and ATSR-2 radiometer
DPLGSA	Electronic Housing Code Pilot (EHC)	e-Planning	Landsat
DERM	Biomass monitoring	It is now practical to measure above-ground biomass	SPOT, Landsat
DERM	Groundcover monitoring	Land degradation problems persist in large areas of rural and regional Australia	Landsat, SPOT
DERM	QLUMP land-use program	Queensland Land Use Monitoring Program (QLUMP) mapping	Landsat, SPOT
DERM	Queensland Wetland mapping and Classification	The Queensland Wetland Mapping and Classification project provides a comprehensive coverage of wetlands	Landsat
DERM	Reef Catchment Monitoring (RCM)	Land managers, pastoralists, policy and planning staff can make important management decisions	Landsat
DERM	Soil exposure assessment	Reef Catchment Monitoring to characterise land use, gully erosion and the extent of riparian vegetation	
DERM	Statewide Landcover and Tree Study (SLATS)	SLATS is a major vegetation monitoring initiative	
DEWHA	Approvals and Wildlife	Remote sensing is critical for day-to-day compliance monitoring	MTSAT-1R, Fengyun-2C, Fengyun-1, NOAA, MODIS

Agency/s	Program/Product	Description	Satellite/Sensor list
DEWHA	Parks Australia	Remote sensing is increasingly used for park management	Landsat, SPOT, MODIS, CBERS
DEWHA, BoM	National Weather and Climate	The Bureau of Meteorology is concerned with all aspects of climate and weather	ALOS
DFAT, DCCEE, CSIRO, AusAID, GA	International Forest Carbon Initiative (IFCI)	The International Forest Carbon Initiative is a key Australian contribution to global action on REDD	Landsat
DOW	Monitoring Groundwater Decline	The Land Monitor Project produces maps based on Landsat data	Landsat, SPOT, MODIS, ALOS, AVHRR
DPI	Evapotranspiration modelling	Evapotranspiration of irrigated pastures	Landsat, ALOS
DPI, DSE	Land use	Victorian land-use has been monitored from regional to paddock scale	MODIS, NOAA (AVHRR), MTSAT
DWLBC	Statewide Native Vegetation Detection	The Statewide Native Vegetation Detection project created a classification of land cover	Landsat, MODIS
GA	Sentinel Hotspots	Sentinel is a national bushfire monitoring system	ALOS
GA, BRS	National Land Cover Mapping	Land-cover mapping at Geoscience Australia provides a national dynamic mapping system	MODIS, Quickbird, Ikonos, Landsat
GA, DFAT	LoSaMBA	The LoSaMBA project defines Australia's national maritime boundaries	Landsat
GBRMPA	Predictive Ocean Atmosphere Model for Australia (POAMA), ReefTEMP	Remote sensing is gaining increasing usage in reef management	Landsat, MODIS, SPOT, ASTER, NOAA (AVHRR), Quickbird
Landgate	Agimage - SW of WA	Agimage provides land management professionals access to satellite maps	Landsat, MODIS, SPOT, ASTER, NOAA (AVHRR), MTSAT, Quickbird
Landgate	CarbonWatch	Landgate is developing a suite of online carbon accounting tools	Landsat, MODIS, SPOT, ASTER, NOAA (AVHRR), MTSAT, Quickbird, AMSRE
Landgate	FireWatch Program	Satellite imagery is an important component of fire management	Landsat, MODIS, SPOT, ASTER, NOAA (AVHRR), MTSAT, Quickbird
Landgate	FloodMap Program	FloodMap provides emergency services personnel with datasets and an online map	SPOT
Landgate	OceanWatch Program	OceanWatch provides access to sea surface temperature, optical attenuation, and chlorophyll products	Landsat
LPMA	Valuation for Taxation Purposes	Using imagery for taxation valuation purposes	SPOT
NTLIS, NREA	Rangeland monitoring	Remote sensing is the primary means of monitoring	Digital Multi-Spectral
NSW OOW	Monitoring: State of the Catchments	The NSW Office of Water is responsible for measuring and reporting on progress	Digital Multi-Spectral
WA Water Corporation	Urban Monitor	The Perth Water Corporation is a partner agency in collecting high resolution mutli-spectral imagery	MODIS, MERIS NOAA
WA Water Corporation	Urban Monitor Vegetation Monitoring and cover estimates	High resolution airborne multi-spectral imagery are used to evaluate change in forest cover and effectiveness of forest management to increase water yield from Wungong Catchment	

Agency/s	Program/Product	Description	Satellite/Sensor list
Medium EOSdependency			
AIMS	Long Term Monitoring Program (LTMP)	LTMP has been surveying the health of reefs in the Great Barrier Reef annually since 1993	
BRS, DAFF, CLWRA, MDBA, DCCEE, DEWHA, NT DIPE, QLD DNRM, SA DWLBC, VIC DPI, TAS DPIWE	Australian Collaborative Land Use Mapping Program (ACLUMP)	ACLUMP promotes the development of nationally consistent land-use through land use mapping coverage for Australia at both continental and catchment scale	Landsat, SPOT, NOAA-AVHRR
CSIRO, GSWA, GSQ, Ausscope, UWA, Curtin University, Industry, GA	WA Centre of Excellence (CoE) for 3D Mineral Mapping (C3DMM)	C3DMM builds capabilities that deliver publicly accessible 3D mineral mapping products from a new generation of remote sensing and drill core logging hyperspectral technologies of value to the Australian Resources sector.	Hyperion, ASTER
DEC	Caring For Our Country	Audit and compliance of native vegetation	
DECCW	National Land and Water Resources Audit	Native vegetation mapping for the whole of NSW	Landsat, NOAA -AVHRR
DERM	Land Audit and Compliance	Regional ecosystem maps describe the extent and conservation status of remnant vegetation	Landsat, ALOS
DEWHA	Regional ecosystem mapping	Remote sensing provides contextual data	Landsat
DEWHA (Australian Antarctic Division)	Supervising Scientist Division	AADC is a national facility managing scientific data resulting from Australia's Antarctic scientific research program	Landsat, ALOS, Quickbird
DEWHA (ERIN)	Australian Antarctic Division, Australian Antarctic Data Centre	Environmental Resources Information Network (ERIN) aims to improve environmental outcomes	Landsat, SPOT, Ikonos, GeoEye, Worldview, ASTER, Hyperion, NOAA (AVHRR), ALOS, ADEOS, MODIS, RADARSAT, ERS, ENVISAT
DEWHA, States	Sustainable Environment and Water Use	National Environmental Information and Accounting	SPOT, ALOS (AVNIR2), Quickbird, Ikonos, NOAA (AVHRR)
DPIW	State of Environment (SOE)	TASVEG was produced by the Tasmanian Vegetation Mapping and Monitoring Program (TVMMP)	
DSE	TASVEG	Remote sensing is the most practical method for mapping	Quickbird
EMA	Bushfire areas and tree cover	*Emergency Management Australia* gives the Commonwealth the means to assist the States and Territories in time of need	Landsat, SPOT, MODIS, ALOS
GA	Coastal Monitoring	The Coastal Research and Management project provides information and advice	Landsat, Resourcesat-1, Quickbird
GA, States	National Topographic Mapping	National broad-scale operational mapping based on satellite images	Landsat, ALOS, Spot
Landgate	VegetationWatch Program	VegetationWatch produces greenness image maps over Australia	Landsat, MODIS, SPOT, ASTER, NOAA (AVHRR), Quickbird
Landgate	WALIS	WALIS is a partnership of government agencies working with business, education and the general community	

Agency/s	Program/Product	Description	Satellite/Sensor list
Landgate, CSIRO, DEC, DAFWA, DoW, DPI	Land Monitor Project - SW of WA	Land Monitor is a coordinated initiative originally under the National Dryland Salinity Program	MODIS, Terra, SPOT, ASTER, NOAA (AVHRR), Quickbird
Landgate, FESA	Emergency management	Operational staff use the Shared Land Information Platform Emergency Management (SLIP-EM) services	MODIS, NOAA, Landsat
LPMA	Topographic Mapping Program	Mapping topographic features	SPOT5, Airborne Push Broom Sensor
LPMA	Western Lands Monitoring and Compliance	Managing the Crown Estate	SPOT5, Airborne Push Broom Sensor
MDBA	Basin Plan	The Basin Plan relies on comprehensive on-ground and satellite monitoring	
Water Corporation	Vegetation Monitoring	Vegetation Monitor products are used to gain understanding on vegetation dynamics	Landsat
Low EOSdependency			
AEC	Electoral Mapping	Satellite imagery provides essential data to the Australian Electoral Commission	
DEC	National Forest Inventory	Monitoring, with evaluation and reporting, is the key feedback mechanism in Forest monitoring	Landsat
DEWHA, DAFF	National Fisheries Production Database, Australian Fish Distributions and Fishing Areas	The Native Vegetation Information System provides information on vegetation types	
DSE	Marine Mapping and Monitoring	Remote sensing is an essential component of native vegetation monitoring	Landsat, SPOT MODIS, ALOS
DWLBC	National Vegetation Information System (NVIS)	The Imagery Baseline Data Project used aerial photography and satellite imagery of high priority areas across SA	Landsat, ALOS, aerial imagery
GA	Native vegetation extent and condition	Development of tools and techniques for the detection of natural hydrocarbon seepage	Landsat, MODIS, Quickbird, ASTER
GA, CSIRO	Imagery Baseline Data Project	Geoscientific surveys of Australia's mineral provinces	Landsat, ALOS

Data source: Geoscience Australia

D EOS companies in Australia

Table D1 **Company profiles**

Company Name	Company Description	Details of Observation
AAM Pty Ltd	AAM is a geospatial specialist with a long standing reputation. We are well known for expertise on large projects, remote locations and challenging technical requirements in Australia, Asia, Africa and elsewhere.	Very High Resolution Satellite Imagery (GeoEye), High Resolution Satellite Imagery (RapidEye)
Aerometrex Pty Ltd	The principals and managers of Aerometrex have over 25 years experience in mapping and related activities within the fields of quality aerial photography and photogrammetric mapping. Since its foundation in 1977, the company has significantly expanded its scope and scale of operations so that today it is one of Australia's foremost companies in the field of geospatial data collection, management and distribution.	Remote Sensing
Apogee Imaging International	Apogee Imaging International has served the Australian community since 1995 with the provision of remote sensing products from earth observation satellites and aerial imagery. The company's focus is on providing value-added information and geospatial services based on optical and SAR data. Apogee has exclusive access to a growing number of satellites and ifsar precision elevation data. We have the capability to deliver raw, processed and value-added products from these sensors. Our present partners are: Intermap technologies, ImageSat International, Infoterra. Other data sources include JAXA, and Surrey Satellite Technologies	Digital Elevation Models, NEXTIMAGE®, Models
ATDI	ATDI designs, develops and commercialises software and services covering the main areas in the design, planning and use of radio networks operating in a range of frequencies from 10 kHz to 450 GHz. The Company has developed a range of software systems and ancillary services that covers business areas ranging from the production of cartographic information in two or three dimensions to the complete management of radio communication networks. ATDI has also developed consultancy services to satisfy all technical needs and constraints and put its know how and expertise at the service of its customers by offering customised solutions. Today the company is one of the world market leaders for turnkey solutions in planning radio networks and management of frequencies.	The ATDI mapping department can produce or convert any type of data including digital reference mapping (maps, satellite photos, aerial images, etc.), land occupancy or Digital Elevation Models (DEM).
Digital Globe	DigitalGlobe is a global provider of commercial, high-resolution, world imagery products and services. Sourced from its own satellite constellation that includes the Quick Bird and World View Satellites. Our imagery solutions support a wide variety of uses from mapping and analysis to navigation technology.	Digital Globe Supplies a wide variety of imagery solutions through a variety of business models.

Company Name	Company Description	Details of Observation
DMCii	DMCii provides continuous, continent-level imaging with direct downlink of data to customer's ground stations. This service is offered from the UK-DMC2 satellite. At just 120 kg, UK-DMC2 is a very capable low cost Earth Observation (EO) satellite, carrying a higher-resolution (22-metre) multi-spectral DMC imager with an ultra-wide 660km imaging swath. The enhanced micro-satellite is able to image continuously while broadcasting data in real-time to licensed ground stations.	4m Panchromatic Imagery, 32m Multispectral Imagery
e-GEOS	e-GEOS, an Italian Space Agency (20%) and Telespazio (80%) company, is an international player in the geo-spatial business. e-GEOS offers a whole range of products and services in the Earth Observation and in the geo-spatial application domains, based on both optical and radar satellites as well as on aerial surveys. e-GEOS operates its Earth Observation centres in Matera and Neustrelitz, where data from multiple satellites are received and processed, also for near-real-time monitoring	VHR Radar, VHR Optical
Fugro Spatial Solutions Pty Ltd	Fugro is a global geospatial and surveying company that provides a EOS services globally. In Australia it is a reseller of GeoEye data.	Satellite imagery products.
GeoEye Inc	Using high-resolution satellite and aerial imagery sources such as IKONOS®, OrbView®-2, GeoEye-1, the DMC® (Digital Mapping Camera) System, and LiDAR,	Satellite imagery products
Geoimage Pty Ltd	Geoimage Pty Ltd is a privately owned Australian company supplying satellite imagery, image processing and geospatial services y. The company was established in Brisbane in 1988 and has additional offices in Perth and Sydney.	Access to a wide range of satellite data available over Australia and worldwide.
Integeo Pty Ltd	Integeo was founded in 2004 and supplies map intelligence. It has R&D facility in Sydney with branch offices in Canberra and the USA. Integeo is supported by a global partner and distributor network, and has strong technical and marketing relationships with leading database/business intelligence and mapping vendors.	Map intelligence services
Lagen Spatial Pty Ltd	Lagen Spatial both process and supply satellite generated data in Australia as well as providing software solutions for geospatial users	Supply and process satellite data
LRI ASPAC (Pty) Ltd	LRI ASPAC provide airborne and satellite imagery depending on the nature of the task. Dominant work is airborne but the company uses satellite imagery where required.	Supplying satellite imagery
MDA Geospatial Services Inc.	MDA's Geospatial Services provides Earth observation data, information products and services from aerial platforms and the majority of commercially available radar and optical satellites. These products and services are used globally for resource mapping, environmental monitoring, offshore oil and gas exploration, ice reconnaissance, maritime surveillance and disaster management.	Satellite Imagery Products, Advanced Radar Products, Remote Sensing

Company Name	Company Description	Details of Observation
Pitney Bowes	Pitney Bowes is a software provider and data integrator. The company supplies EOS data along with a wide range of other products. EOS is a small part of Pitney Bowes total business.	Supplier and integrator of EOS data.
QinetiQ Pty Ltd	Our principle offering in Australia is client side advice – working primarily with Defence organisations, other Government and prime system integrators as consultants and service providers. Our business premises are located on the eastern seaboard of Australia, with significant offices in Melbourne, Canberra and Brisbane, and smaller teams in Adelaide, Sydney and Newcastle.	Satellite imaging
SKM	Sinclair Knight Merz is a key provider of spatial information services. Our industry specialists are at the forefront of their disciplines.	Spatial Products - DigitalGlobe satellite imagery and AUSIMAGE aerial photography
Spatial Scientific Technologies Pty Ltd	Spatial Scientific Technologies Pty Ltd provides remote sensing services and geospatial contract R&D to clients across Australia and the Asia Pacific region.	Satellite imaging
SpecTerra Services Pty Ltd	SpecTerra is Australia's leading provider of airborne remote sensing imagery for vegetation mapping and monitoring projects. We specialise in the acquisition, processing and analysis of high quality, high resolution Digital Multi-Spectral Imagery.	Satellite imaging
SPOT	Spot Image acquires the SPOT data through a receiving station at its premises In Toulouse and via a network of partner stations around the world.Spot Image is the worldwide distributor of geographic information products and services derived from the Spot Earth observation satellites, including the Vegetation instrument flown on SPOT 4 and 5. Spot Image also distributes complementary optical and radar data acquired by other satellites offering low to very high resolution images. Spot Image was appointed by CNES as sole commercial operator of the SPOT satellites, the first of which was placed in orbit in 1986. Spot Image acquires the SPOT data through a receiving station at its premises In Toulouse and via a network of partner stations around the world.	Spot Image distributes products and services derived from multiple sources of satellite data. Its international sales network enables it to offer 'neighbourhood' service ensuring that users have ready access to all of its products and services.
SYPAQ Systems	SYPAQ's core business spans Management and Technology Consulting, Systems Integration and Business Process Optimisation. We assist organisations transform strategy into capability through the application of a variety of disciplines including Capability Definition, Systems Engineering, Project Management, Business Analysis, Integrated Logistics Support, Commercial and Contract Support, to name a few.	
Terranean Mapping Technologies	Terranean is a leader in the field of mapping and Geographic Information Systems.	Spatial Data Products, Satellite Remote Sensing

Company Name	Company Description	Details of Observation
Thales Australia	Thales in Australia is part of an international electronics and systems group serving the defence, aerospace and space, security, and transport markets in Australia and throughout the world. Thales Alenia Space supplier in meteorology from geostationary orbit, oceanography and space altimetry. Thales Alenia Space is also the European leader in Earth observation and science ground segments, being the prime contractor for major European civil institutional ground segments, the Eumetsat partner for meteorology and climatology, and providing a proven expertise in large telescope for Universe exploration.	

Data source: Geoscience Australia, ACIL Tasman

E Organisations consulted

Organisation
Australian Fisheries Management Authority
APOGEE
Bureau of Meteorology
Bureau of Rural Sciences, Department of Agriculture Fisheries and Forestry
CRC-SI (Cooperative Research Centre for Spatial Information)
CSIRO Division of Land and Water
CSIRO Marine Division
CSIRO Minerals Division
Curtin University
Defence Imagery and Geospatial Organisation
Department of Climate Change and Energy Efficiency
Fugro
GeoImage
Geoscience Australia
IAG
IMOS (Integrated Marine Observing System) / University of Tasmania
Landgate
Murray Darling Basin Authority
National Water Commission
NGIS Limited
SKM
Space Policy Unit, DIISR
Spatial Information Business Association
Spatial Vision
SPOT Image
TERN (Terrestrial Ecosystem Research Network)
Queensland Department of Environment and Resource Management
Victorian Department of Transport
Victorian Department of Sustainability and Environment
Western Australian Satellite Technology and Applications Consortium
Woodside Energy

F References

AATC. (2006). *The Economics of Australia's Sustained Ocean Observing System.* Melbourne: Australian Academy of Technological Sciences and the Western Australian Global Ocean Observing System.

ABARE. (2010). *Assessing the impact of the Australian Government's water purchase program*. Canberra: Australian Bureau of Resource Economics.

ABS. (2005). *Water Account 2004-05*. Canberra: Australian Bureau of Statistics.

ACIL Tasman (2007) *Economic and social value of biodiversity and functioning ecosystems*, Draft Report prepared for the Victorian Department of Sustainability and Environment.

ACIL Tasman (2008) *The Value of Spatial Information: The impact of modern spatial information technologies on the Australian economy*, Report prepared for the Prepared for the CRC for Spatial Information and ANZLIC, available for download at http://www.crcsi.com.au/uploads/publications/PUBLICATION_324.pdf

ACIL Tasman. (2008). *Review of the size of the Spatial Information Industry.* Canberra: Internal document.

Ashe, M. a. (2006). *The cost of fire in Australia*. Sydney: Macquarie University.

Athena Global (2006) Forging a National Remote Sensing Strategy, Report on a Workshop hosted by Geoscience Australia at the National Convention Centre, Canberra, November 22nd 2006

Athena Global (2006) National Remote Sensing Data Requirements – Gaps and Opportunities for Australia, Final report for ACRES – Geoscience Australia, June 2006

ATSE. (2009). *An Australian Strategic Plan for Earth Observation from Space.* Canberra: Australian Academy of Technological Sciences and Engineering.

Biddington, B. (2008) *Skin in the game: realising Australia's national interests in space to 2025*, Kokoda Paper No. 7, The Kokoda Foundation.

Bouma, JA et al (2009) *The Value of Earth Observation for Marine Water Quality Management*, Proceedings of the International Symposium on Remote Sensing of Environment, 4-8 May 2009, Stresa, Italy.

BTRE. (2001). *Economic Costs of Natural Disasters in Australia*. Canberra: Bureau of Transport and Regional Economics.

Department of Commerce. (2009). A day without space - Public Discussion Forum. Washington: US Department of Commerce.

CEOS/ESA. (2008). *Earth Observation Handbook*. ESA Communications Publications Office.

Costanza, R. et al. (1997) The Value of the World's Ecosystem Services and Natural Capital, *Nature*, Vol. 387.

DMC (2008) *DMC builds capacity for global monitoring*, DMC International Imaging, Vol 2, Issue 1, April 2008

Drucker, A.G, Garnett, S.T., Luckert, M., Crowley, G.M. and Gobius, N. (2008). Manager-based valuations of alternative fire management regimes on the Cape York Peninsula, Australia. *International Journal of Wildland Fire* 17, 660-673.

Hundloe, T. and C. Hamilton (1997) *Koalas and Tourism: An Economic Evaluation*, The Australia Institute.

Productivity Commission. (2010). *Market Mechanisms for Recovering Water in the Murray Darling Basin*. Canberra: Australian Government.

Productivity Commisssion. (2010). *Developing a Partial Equilibrium Model of an Urban Water System*. Canberra: Australian Government.

SKM (2010) Understanding Australia's Domestic Space Capabilities, Capability Framework, Final Report, 10 March 2010

Sneddon,J., Donald, G., Edirisinghe, A. and D. Henry (2007) *The delivery of remotely assessed pasture growth rate and feed on offer information to farmers in Western Australia*. CSIRO/UWA Draft Paper, copy received during consultation phase.

Suter, G.W. (2009) A critique of ecosystem health concepts and indexes, *Environmental Toxicology and Chemistry*, Vol 12 No 9, pp. 1533-1539.

Young, M. D. (1992) *Sustainable Investment and Resource Use: Equity, Environmental Integrity and Economic Efficiency*. Parthenon Press, Carnforth and Unesco, Paris.