AuScope

AuScope Infrastructure Program – evaluation of impacts

A Lateral Economics report for AuScope Limited

AuScope Infrastructure Program – evaluation of impacts

A Lateral Economics report for AuScope Limited

August 2016

Contents

Context

Australia's base of geoscience and geospatial – or, Earth science – knowledge and capability is crucial to our economic, social and environmental future.

The AuScope Infrastructure Program (AuScope) has been a collaboration between Australian research institutions in universities and government, with funding support from the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS). A '*world class research infrastructure to characterise the structure and evolution of the Australian continent in a global context from surface to core in space and time*' has been its vision.

Over the period 2007-08 to 2013-14[1], AuScope has incorporated six major programs of physical and virtual infrastructure (note: NCRIS funding in brackets). In summary:

1. three programs of infrastructure development (and/or greater utilisation) resulting in data of various kinds:
    - geochemical data – for Earth composition and evolution ($2.8 million)
    - hyperspectral core logging data – 'national virtual core library' (NVCL) ($2.6 million)
    - seismic and magnetotelluric data – for Earth imaging and structure ($7.7 million)
2. an enhanced National Geospatial Reference Framework for geospatial and Earth dynamics ($15.5 million)
3. tools for advanced data mining and computational modelling and simulation ($7.4 million)
4. a geoinformatics 'AuScope grid' and interoperability to assist data delivery ($5.4 million)

Pathways for Generating Impact

For AuScope and other Earth science infrastructure, how information is generated, processed and used, and for what purpose(s), drives key impacts. This can span from accelerating the discovery of new fundamental knowledge about the Australian continent, to realising important applications for the economy, society or the environment.

Direct and indirect user groups of AuScope-related outputs incorporate:

- individual researchers in universities or structured research collaborations (e.g. cooperative research centres, specialist research groups or facilities, industry partnerships)
- – with clear examples across the breadth of AuScope's ten partner universities and beyond
- State and Territory geological surveys (geoscience agencies) and Geoscience Australia
- – with relative activity and usage skewed towards those jurisdictions with greater size and scope of geological survey work, notably Western Australia and Queensland
- individuals or firms that utilise data or analysis and interpretation produced by the above groups (e.g. mineral or energy exploration firms, natural resource managers)

Evidence that users are more accurately monitoring and understanding the structure and evolution of our continent for various purposes includes:

- a broad and deep range of knowledge generation in a range of fields
    - demonstrated by just under one thousand (984) research publications listed as being associated with AuScope over the period 2007 to 2014, across multiple research areas[2]
- integration of AuScope outputs with the service offers of geological surveys as a foundation for uptake by industry users – although variable across the different components of AuScope
    - with much analysis and interpretation combining different types of AuScope-related data, for example seismic data with other geophysical measurements, as well as geochemistry, geochronology and structural analysis
    - and utilising better management of 'big data' across disciplines and jurisdictions, in line with general moves towards quantitative analysis and computer simulation and visualisation of geological systems (e.g. in 3-D and 4-D models).

1 While the AuScope initiative is continuing, the report focuses on its first seven years.

2 Count of research publications listed in AuScope NCRIS Program 2007-2014 report.

Key Impacts and Benefits

The research and other use resulting from AuScope-related physical and data infrastructure is tremendously diverse. Key areas of impact influenced by AuScope (see Table 1), each of which are reasonably distinct, include:

- fundamental Earth science (arguably of intermediate rather than final impact)
- resource exploration
- spatially sensitive industries
- natural and built environment

Content throughout this report highlights evidence that impacts in these areas are being achieved, or if not yet being achieved that credible pathways from fundamental research to sectoral innovations are being created. Table 1 provides an accessible summary in each of the impact areas.

Some impacts are more certain than others. For example, resource exploration is a major user of Earth science knowledge, and the industry will increasingly demand targeted tools and insights for more precise and cost-effective mineral and energy exploration and extraction. Yet, given commercial sensitivity it is not always publicly-apparent what commercial entities are using what data for what purpose.

Causality and attribution is even more challenging when end-uses are further distant in time or function from specific AuScope activity – for example, public risk managers using insights derived from AuScoperelated knowledge, along with other knowledge, to improve natural hazard mitigation or adaptation strategies. Nevertheless, AuScope work provides options that make such a pathway more possible.

Table 1 – Summary – key examples of impacts and benefits influenced by AuScope

AuScope component	Key examples of impacts and benefits influenced by AuScope	Size of AuScope influence
Fundamental Earth science	Through allowing greater access to and use of rich geoscience and geospatial data: • improved knowledge of large-scale Earth processes/ geodynamics (SAM) • improved knowledge of Earth structure, composition, continental deformation, geochronology and early life (Earth composition and evolution, Earth imaging and structure, geospatial, GRID) • better accuracy of geodetic analyses (geospatial)	Major
Resource exploration	Reduced exploration cost for a given discovery through more efficient acquisition of Earth structure data and related targeting (Earth imaging and structure, Earth composition and evolution, NVCL, SAM, GRID) Discovery and/or resource extraction brought forward through reduced uncertainty for locations with uncertain mineral or energy prospectivity (Earth imaging and structure, Earth composition and evolution, NVCL, SAM, GRID) – e.g. increase probability of discovery, decrease uncertainty of exploration cost	Major
Natural and built environment	Better land use planning and other natural hazard risk management resulting from improved knowledge of tectonic stress and seismic risk (SAM, Earth imaging and structure, Geospatial) Better coastal management informed by improved sea level estimates (Geospatial) Better meteorological products and improved knowledge of weather/ climate patterns through air moisture data, resulting in better disaster planning and management for extreme weather events, e.g. heatwaves, cyclones (Geospatial) More sustainable management of soil and groundwater resources from improved knowledge of landscape evolution and soil profiles (Earth imaging and structure, Geospatial, SAM) More efficient development of online data discovery and access in environmental sector (GRID)	Medium

AuScope component	Key examples of impacts and benefits influenced by AuScope	Size of AuScope influence
Spatially sensitive industries	More accurate spatial positioning for diverse social and industrial uses (transport, environmental monitoring, agriculture, emergency services) (Geospatial) More accurate real-time spatial positioning for precision users (e.g. agriculture, surveyors, mining, pipeline) (Geospatial)	Medium
Other	Contribution to international data or analytical infrastructure (SAM, Geospatial) Possibly, time synchronisation for communications and finance (Geospatial)	Medium

Note: AuScope component in brackets

Qualitative and quantitative assessments of impact are complementary – each provide different kinds of insight. While economic assessments help to make impacts tangible and comparable, they are only one way of understanding the impact pathways of complex, multi-faceted and long-term science research infrastructure like AuScope.

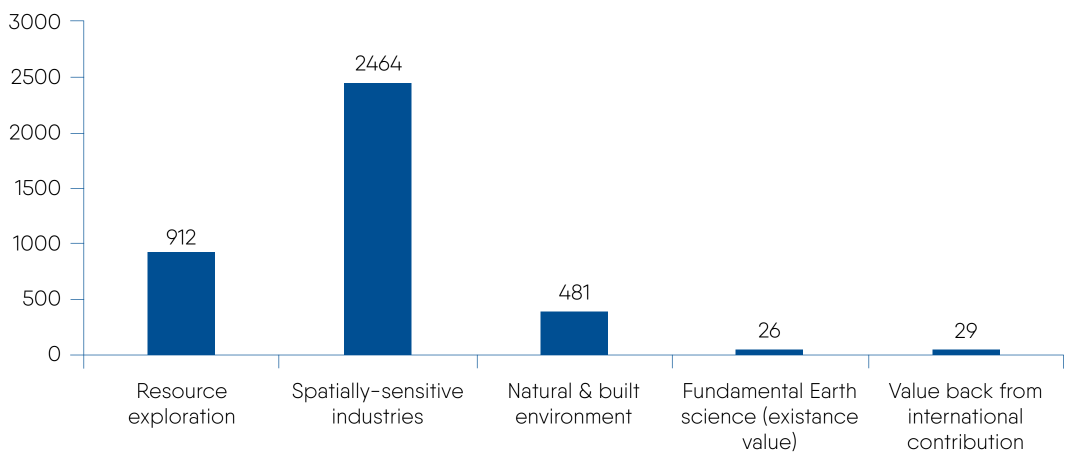
Our indicative economic assessment (see Table 2) suggests a net benefit to Australia from AuScope between $2.3 billion to $6.2 billion – with our best estimate of $3.7 billion (net present value in 2015-16 terms, over the period to 2040-41).

A net benefit of $3.7 billion is equivalent to $15 of benefit for every $1 in economic cost – a substantial return on investment. While substantial, the scale of these estimates is consistent with other economic assessments of similar initiatives, in Australia and the United States.

Table 2 – Summary of indicative economic assessment

Category	Estimated present value (2015-16)	% of gross benefit
Gross economic benefits	**$3,912 million**	
Fundamental Earth science (existence value)	$26 million	0.7%
Resource exploration	$912 million	23%
Spatially-sensitive industries	$2,464 million	63%
Natural & built environment	$481 million	12%
Value back from international contribution	$29 million	0.7%
Economic costs	**$261 million**	
Net benefit	**$3,651 million**	

Figure 1 – Gross benefit of AuScope by impact area ($m, present value)



Impacts related to infrastructure and data usage can sometimes mask potentially significant but less tangible effects. Principally, due to lack of evidence, this assessment may have considerably underestimated the value the Australian community as a whole places on the fundamental scientific knowledge of the world around us generated through AuScope. An outcome-based impact assessment also does not consider rich qualitative effects within the Earth sciences sector, such as the deepening of long-term collaborative networks, the sharing of learnings and approaches across jurisdictions, or the development of postgraduate students and early career researchers.

Realising Continued Impact

Impacts can occur today, and also over time including as resultant data is reinterpreted with newer technology, or as AuScope infrastructure continues to be used to generate new data.

Realising continued impact of AuScope's 2007-08 to 2013-14 investment over the medium to longer term substantially depends on how impact pathways develop – that is, how universities, government agencies and industry continue to make use of physical and data infrastructure generated. Wide interest in Earth science will likely continue, particularly given the challenges of greenfields exploration for valuable mineral, energy and petroleum resources, and the growing demand for increased precision of positioning in multiple industries including agriculture, transport, construction, mining and public services. Resources and technical capability will need to follow.

1.1 Context

Australia's base of geoscience and geospatial (collectively referred to in this document as Earth science) knowledge and capability is crucial to our economic, social and environmental future.

Our continent's unique geology has long been recognised as important to economic activity – Earth resources including minerals and energy drive much of the Australian economy, particularly in regional areas. The sustainable management of Australia's natural resources such as groundwater and the balancing of productive and environmental land uses is one of this century's greatest challenges. And scientific uses of spatial positioning and geodesy are increasingly finding diverse and innovative applications.

The national AuScope Infrastructure Program (AuScope), a collaboration between Australian research institutions in universities and government,[3] has developed physical and 'virtual' infrastructure for Earth science in Australia – including equipment, data and analytics. The vision has been to achieve 'a world class research infrastructure to characterise the structure and evolution of the Australian continent in a global context from surface to core in space and time'.

AuScope has been principally funded under the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS)[4]. NCRIS funding of $43.3 million over the period 2007-08 to 2013-14 was complemented by cash and in-kind contributions from university and government partners.[5] Some operational activities continue under current NCRIS funding and partner contributions.

1.2 Purpose of this document

AuScope Limited has commissioned Lateral Economics to develop an impact assessment of the AuScope programs supported by NCRIS over the period 2007 to 2014. The assessment includes articulating the impact that NCRIS-related AuScope has delivered to its participants, its key stakeholders and broader beneficiaries, and expectations of future impact and benefit.

This document:

- summarises each of the six AuScope components, including their objectives, inputs, key themes and outputs produced;
- identifies the main users of research and other AuScope outputs by research groups, government agencies and industry;
- examines how and why these users utilise the outputs, and the impacts achieved, in various ways including through illustrative case studies; and
- provides a quantitative-based economic analysis of the benefits and costs of AuScope.

The analysis was developed over the period December 2015 to June 2016, through synthesising extant documentation, reviewing economic and industry literature, and seeking feedback from research, government and industry stakeholders.

This document is structured in the following way:

- Section 2 highlights AuScope as an Earth science infrastructure program and sets out a framework for conceptualising the impact pathways of AuScope and assessing impacts;
- Section 3 illustrates and summarises the outcomes and impacts arising from AuScope in descriptive and qualitative terms, including identifying areas of cumulative AuScope impact;
- Section 4 furthers this by assessing current and future impacts in economic terms;
- Sections 5 to 10 provide a detailed characterisation for each AuScope component, incorporating its scope and outputs, the nature and scale of usage, and resultant impacts and benefits;
- An Appendix (section 11) provides further technical description of the indicative economic modelling, including methodology, data sources and assumptions.

3 AuScope partners are – universities: the Australian National University (ANU), Curtin University of Technology, Macquarie University, Monash University, University of Adelaide, University of Melbourne, University of Queensland, University of Sydney, University of Tasmania and University of WA; federal government agencies: Commonwealth Science and Industrial Research Organisation (CSIRO) and Geoscience Australia; state and territory geoscience agencies in NSW, the NT, Queensland, SA, Tasmania, Victoria and WA.

4 NCRIS funded 27 research infrastructure projects (of which AuScope was one) with the aim to provide Australian researchers with access to major research facilities, supporting infrastructure and networks necessary for world-class research.

5 Detailed financial information can be found in AuScope's AuScope NCRIS Program 2007-2014 publication. Total cash and in-kind investment from all sources was reported as $121.5 million for the period 2007-08 to 2013-14

2.1 AuScope as Earth science infrastructure

Defining Earth science infrastructure

Geoscience infrastructure enables research that records and interprets the structure and evolution of geology, and connects geoscience data of various kinds. Geoscience research can be undertaken at various complementary lenses – from basic research helping to understand Earth processes, through to applied research regarding particular matters of local geological concern.

There is still much that is unknown about the past and present of the Australian continent. And various barriers constrain some geoscience data being applied by researchers or end-users for maximum impact. For example, data can be difficult to access from individual agencies or repositories, it may not be set up in a manner than aids interoperability, or there may be a lack of accessible interpretation. Moreover, increasing data volumes is a challenge to data delivery.

Useful geoscience infrastructure can include highly specialised laboratory equipment or field equipment to acquire and manage data, through to 'virtual' infrastructure (software for analysis and visualisation) to promulgate and interpret large data sets on continental scales and geological timeframes.

Geospatial infrastructure involves improving the quality and precision of spatial and geodesy data. Physical infrastructure such as radio telescopes and gravimeters enable continuous calibration of the geodetic reference framework which underpins positioning services on Earth based on signals received from satellites.[6] Calibration avoids 'drift' that negatively affects accuracy of positioning systems. Other infrastructure improves one or more qualities of positioning, such as precision, robustness, or signal availability in local areas which can be critical in some specialised applications of real-time spatial data.

These calibration and data augmentation services employ spatial data capture, validation, representation, extrapolation, simulation, sharing, visualisation, operations, tools and platforms to, in turn, deliver applications and services across a wide range of sectors. Increasingly geospatial infrastructure includes some of elements of managing and delivering spatial and geodesy data to the spatial data industry through accessible online tools.

Strategic purpose of AuScope

AuScope has been a major Australia-wide infrastructure investment to drive Earth science research and support scientific investigations in government, universities and industry. Building on previous programs, AuScope has intended to provide Australia with a better capability to monitor and understand the structure and evolution of our continent. It also sought for interested parties to be able to more easily access useful data produced across Australia in a seamless, cost effective manner – essentially better enabling discovery, access and use.

AuScope has included the development of both physical infrastructure (and related data acquisition) and 'virtual' infrastructure through six major programs, implemented in different ways and across various locations in Australia. In summary:

1. three programs of infrastructure development (and/or greater utilisation) resulting in data of various kinds:
   - geochemical data – for Earth composition and evolution
   - hyperspectral core logging data – 'national virtual core library' (NVCL)
   - seismic and magnetotelluric data – for Earth imaging and structure
2. an enhanced National Geospatial Reference Framework for geospatial and Earth dynamics
3. tools for advanced data mining and computational modelling and simulation (referred to as simulation, analysis and modelling, SAM)
4. a geoinformatics 'AuScope grid' and interoperability to assist data delivery

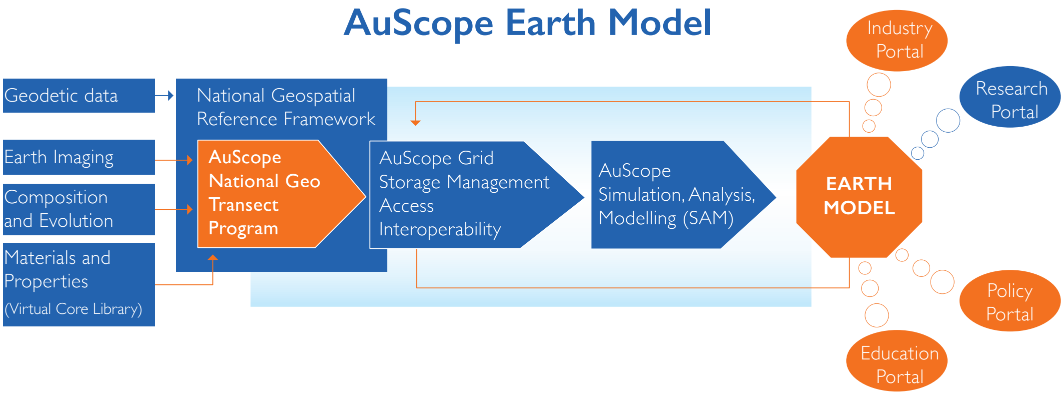
The concept was that various elements could come together, over time, as part of an integrated Earth Model (see Figure 2).

For some components, such as seismic reflection data under Earth imaging and structure, AuScope has allowed for extension of existing government geoscience activities to collect data beyond what would be normally funded in order to better achieve scientific objectives. For others, the availability of AuScope funding has influenced partners to undertake major infrastructure improvements that would not usually be feasible under standard resources. Examples include the geospatial array and the UWA Circon imaging ion probe – providing a resource that Australia would not have had access to otherwise (or least, not within the same timeframe).

AuScope has also allowed for development of the skills and capabilities of the Australian Earth science research community and broader user groups through new research opportunities or interaction with new technologies. This could be characterised as human capital development.

6 Global Navigation Satellite Systems (GNSS) rely on continuous calibration measurements that update the relationship of framework components: as a system of parts independently on the move, the accuracy of positioning in three dimensions can drift significantly over time without this. GNSS includes the familiar American Global Positioning System (GPS) although there are now also European (Galileo), Russian (GLONASS), China (Compass/ Beidou), India (IRNSS), Japanese (QZSS), India (IRNSS) and other positioning satellite systems.

Figure 2 – AuScope Earth Model concept



2.2 Framework for achieving and assessing impact

Pathways to impact – maximising value through enabling maximum use

Recognising the inter-relationships between AuScope and other activities to build Earth science knowledge in Australia, we can examine two core questions:

1 What positive impacts and associated benefit do Earth science data and knowledge have for (Australian) society?

2 To what extent can we isolate or attribute the impacts of Earth science data and knowledge to AuScope?

Earth science infrastructure such as AuScope is not usually a final product in itself, but an input into potentially diverse research and other processes.[7] Therefore, to understand its impact, we need to determine how that infrastructure is used to generate data and processed information, and how that data and processed information is applied (or is likely to be applied) for impact in various contexts. In essence, value is driven by how information is generated, processed and used.[8]

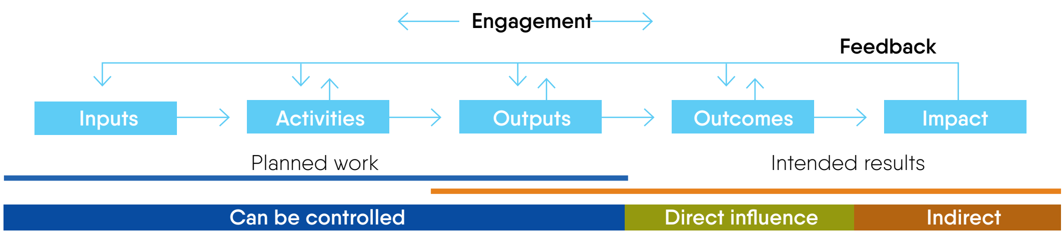
Linking AuScope activities to impact and benefits

Potential ways in which Earth science infrastructure and data is used can span from:

- generating or accelerating the discovery of new fundamental knowledge about the Australian continent through underpinning research in a variety of scientific and related contexts such as geology, geophysics, and environmental, atmospheric and marine science
  - the 'end-use' of which might not always be immediately apparent;
- important applications for:
  - productivity improvements for various significant industries or sectors, particularly mineral or energy exploration[9] and mining resulting from geoscience, and agriculture, mining, civil construction and public services resulting from positioning in general and precise positioning in particular
  - sustainable management of natural resources and hazards, for example, understanding large-scale risks to the economy, society and the environment arising from Earth structure, stresses and movements, or risks to effective management of groundwater.[10]

A conceptual framework to draw out what AuScope has delivered and resultant effects is outlined in Figure 3 and Table 3. Essentially, this charts relationships from activities to uptake and adoption, through to ultimate impacts. This generic framework is well-established (for example, within CSIRO's Impact Evaluation Guide).

Figure 3 – Conceptual framework for impact pathways



Source: CSIRO, Impact Evaluation Guide, November 2015, p.9

7 Scott, M., Dimitrakopoulos, R. and Brown, R.P.C. 2002, "Valuing regional geoscientific data acquisition programmes: addressing issues of quantification, uncertainty and risk", Natural Resources Forum, vol 26, pp.55-68

8 Haggquist, E. and Soderhom, P. 2015, "The economic value of geological information: Synthesis and directions for future research", Resources Policy, vol. 43, March, pp.93

9 Exploration is where a company or organisation searches for mineral or energy resources by carrying out geological and geophysical surveys, followed up by drilling and other evaluation of the most prospective sites.

10 For instance, how the crust will respond to natural or man-made events such as Earthquake hazards, gas extraction, groundwater extraction, or hazardous waste storage, or understanding past climate patterns.

Table 3 – Applied framework for moving from inputs to impact for AuScope

Type of infrastructure	Inputs	Activities / Output	Outcomes	Impacts (industry, society)
Physical infrastructure	Financial and human resources	Provision of infrastructure (e.g. construction, installation)	Immediate – direct usage of physical infrastructure to develop data or analytics (e.g. data generation) Intermediate – Direct or indirect usage of data or analytics for specific purposes (e.g. answering research question)	More efficient or effective outcomes for productivity, the environment, etc.
Data and analytics infrastructure	Financial and human resources	Provision of data and analytics (e.g. data generation, software development)	Direct or indirect usage of data or analytics for specific purposes (e.g. interpretation)	More efficient or effective outcomes for productivity, the environment, etc.

2.3 Complexities in describing pathways to impact for AuScope

AuScope's inputs and activities are clear and upfront. But outcomes, impacts and benefits of Earth science and AuScope specifically, which may occur over a long time period, are much less certain.

There are a number of reasons for this.

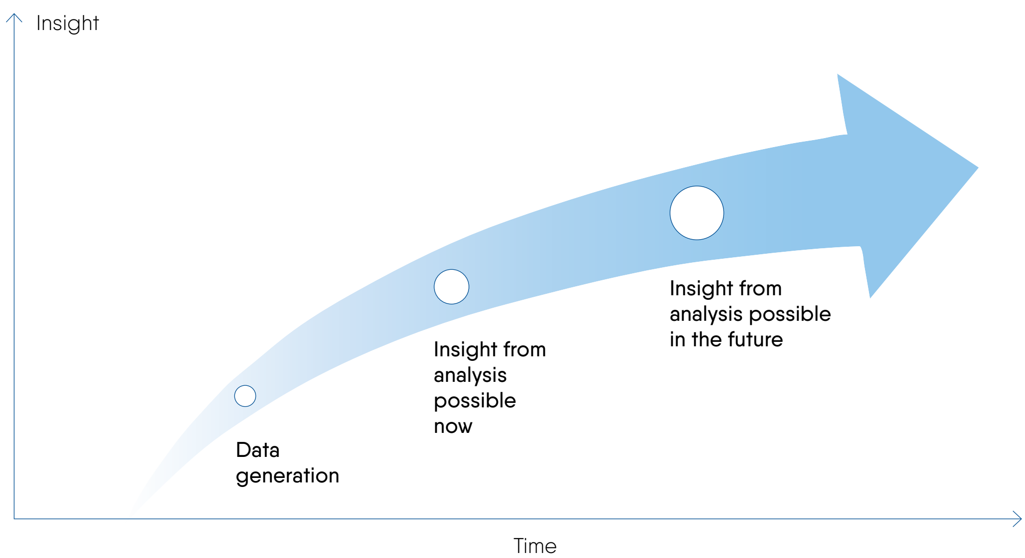
Information life-cycle

Pathways to impact do not always follow a simple, linear pattern. Notably, as Earth science data has a long shelf life, usage of information generated by infrastructure and research can occur over a long time period, in ways we cannot always expect today (illustrated in Figure 4):

> *"geological and geospatial data has a long life-cycle, primarily because of the requirement for time series continuity in certain fields but also because the development of new[9] techniques and technology for data analysis and interpretation mean that existing data can be continuously reinterpreted to provide new insights".[11]*

Similarly, the focus of parts of AuScope in facilitating interoperability between different data and data sources can help make existing data more usable, by itself or in combination, so it can be of greater potential value over time.

Figure 4 – Conceptual representation of 'data reuse' and reinterpretation over time



9 Exploration is where a company or organisation searches for mineral or energy resources by carrying out geological and geophysical surveys, followed up by drilling and other evaluation of the most prospective sites.

11 Productivity Commission 2013, Mineral and Energy Resource Exploration, Inquiry Report No. 65, pp. 252-253

Integration with other Earth science and cumulative effect

AuScope is not being pursued in isolation of other activities building geoscience and geospatial infrastructure and influencing Earth science knowledge in Australia. A range of research collaborations, cooperative research centre, specialist research groups or facilities, and government initiatives – with funding from various sources – exist to further this general purpose. Many are involved as part of AuScope programs or as users of the outputs. There are judgements to be made as to the extent that impacts can be attributed to AuScope relative to other Earth science development activities (particularly when AuScope is one contribution to a broader activity, such as Earth imaging or simulation tools).

Also, given AuScope's diverse activities and distributed implementation across the many AuScope partners, comprehensive information is not in all cases available as to how each element has been utilised, by whom, and for what purpose – particularly when utilisation is a number of steps away from project implementers. A micro-level analysis of every individual use is unsuited because in many cases the outputs are research activities that do not have a specific, immediate and measureable impact on industry, the environment or other outcomes. The impacts are more subtle and part of a longer-term progression of knowledge or techniques – and it is the cumulative effect with a field that is probably most insightful. In addition, some utilisation is expected to occur in the future and, therefore, is not yet demonstrated.

In summary, statements on outcomes and impact will inevitably be indicative and based on partial information. However, this report draws out useful evidence to inform conclusions about AuScope's current and expected future impact.

A further type of value – existence value of basic Earth science

The focus of this report is 'use value' – the value derived by research, government or commercial parties from utilising (or expecting to utilise) the outputs of AuScope, often in combination with other data or infrastructure. However, information and knowledge associated with AuScope can have economic value separate from direct use. Some basic Earth science may not have a tangible application for private or public industries (or the possible impact is so far into the future as to be too uncertain). But discoveries are still being made and knowledge generated. Some people would place value on knowing this basic Earth science exists – and would be willing to give up other uses of resources to generate the associated knowledge (i.e. have a willingness-to-pay).[12] This social preference forms a kind of existence value', or in more general terms the 'pure value of discovery'.[13] Existence value as a type of 'passive use' value is increasingly prominent in economic assessments of non-market matters. [14]

12 Across society, different people will have different preferences – some may not value basic Earth science at all, others may value it highly.

13 Florio M and Sirtori E 2015, "Social benefits and costs of large scale research infrastructures", Technological Forecasting & Social Change, pp.11

14 Examples of such matters include a healthy environment, saving endangered species or maintaining cultural heritage.

Building the Public Goods of the Information Age

Role of information

Information has played a critical, and yet somehow underappreciated role in economics in the twentieth century. In the 1930s Hayek developed Adam Smith's ideas on prices as an emergent system of distributed information in the economy

Friedrich Hayek CH, born in Austria-Hungary as Friedrich August von Hayek and frequently referred to as F. A. Hayek, was an Austrian and British economist and philosopher best known for his defense of classical liberalism.

It is more than a metaphor to describe the price system as a kind of ...system of telecommunications ... The marvel is that in a case like that of a scarcity of one raw material, without an order being issued, without more than perhaps a handful of people knowing the cause, tens of thousands of people whose identity could not be ascertained by months of investigation, are made to use the material or its products more sparingly.

Hayek argued that this informational role of prices was so critical that not to have such a system would hugely degrade economic efficiency – an insight eventually born out with the abandonment and/or collapse of the centrally planned economies in the late 1980s and early 1990s.

In the 1950s the American economist Robert Solow demonstrated that nearly all of the productivity growth in history was a result not of increasing capital investment, but of people finding better ways of working and playing, and then being copied. The coming of the Internet has delivered the decentralised generation and distribution of information to an enormous extent.

Information and public goods

The standard economist's 'take' is that 'free rider' problems or the challenges of asymmetric information put a brake on certain types of information generation and distribution. Thus, the Productivity Commission has stated that the partial public good characteristics of pre-competitive geoscientific information mean that private provision alone may not be socially optimal.

Still this somehow doesn't fully capture the fundamental nature of information in an economy, nor of the opportunity it presents for new public goods. So much so that today some of the most transformative new public goods are 'platforms' like Wikipedia, Google and Facebook. Each of these platforms was privately built and each had the choice to overcome the free rider problem by operating behind a paywall. But each understood that doing this would so degrade the amount of value they generated that they chose instead to operate as a free public good and find indirect ways of funding their operations – Wikipedia through philanthropy and Google and Facebook through advertising.

There is a particular vacuum around that class of public goods that would add substantial value but which private endeavour struggles to bring into existence without help from collective institutions such as governments. Gruen (2015) has speculated about what public goods like Wikipedia, Google and Facebook might exist that cannot be funded from indirect sources. He suggests by way of example a public private partnership in genomic data: a public health system like Medicare could fund genomic analyses and the cost of the infrastructure for hosting the information for any patients that wished to opt into the system, which would then make that information available to patients as consumers as well as curating the information as a an asset for the health system more generally in diagnosis, pharmaco-vigilance and research.

Infrastructure, AuScope and new public goods

AuScope fits this model of informational public goods and it is also worth expanding the definition of infrastructure to claim its rightful place as information infrastructure. In this regard, Brett Frishmann's recent book Infrastructure: The Social Value of Shared Resources is instructive, defining infrastructure according to the following criteria:

1) The resource may be consumed non-rivalrously for some appreciable range of demand.

2) Social demand for the resource is driven primarily by downstream productive activities that require the resource as an input.

3) The resource may be used as an input into a wide range of goods and services, which may include private goods, public goods and social goods.

This describes both the public goods specified by Gruen but also projects such as AuScope as information infrastructure. Potential roles for government in accelerating, facilitating and, where necessary, funding the emergence of such public goods include:

- Innovation partner: New products can help governments and other entities better achieve their missions. Where additional R&D is necessary to incubate the innovation, governments can undertake targeted partnering with the relevant enterprises.
- Benevolent wholesaler for life: Often governments find themselves providing a 'wholesale nudge' or a default standard to champion optimal technology, helping to transmit innovations and cost savings from production through to consumers. Ideally the standard can emerge with usage or open collaboration on standards – as it does in many standards such as the internet- with government being a large and possibly unusually influential user, rather than the dictator of the standard for all others.
- Promoter of information platforms: Where new knowledge services or products are emerging – or even mature – the market often remains uninformed as to the respective merits of alternative offerings. Where helpful, governments can assist by seeking recommendations from an independent expert group reflecting the interests of users.
- Sponsor of standards formation: Standards are a public good. Governments can and do help set standards in all manner of situations, or help facilitate some needed but as yet missing standard to emerge, or otherwise help optimise emerging standards.
- Collective purchasers: There's always been a 'textbook' case for governments to help subsidise their own or even other service providers' fixed costs from general revenue to make marginal cost pricing financially viable. Web 2.0 platforms provide an opportunity to trial these ideas, and in doing so develop additional public goods from rich data regarding usage.

While not necessarily using this language, AuScope could be seen as taking a forward role in 'orchestrating the emergence of public goods' – both traditional and emergent – in Earth science for the benefit of Australian society.

While not necessarily using this language, AuScope could be seen as taking a forward role in 'orchestrating the emergence of public goods' – both traditional and emergent – in Earth science for the benefit of Australian society.

Sources: Gruen N 2015, Government as Impresario: Emergent Public Goods and Public-Private Partnerships 2.0, Nesta, January; Gruen N, "The Ecology of Information and the Significance of Reputation", prepared for the Queensland Information Commissioner and the Australia and New Zealand School of Government. Productivity Commission 2013, Mineral and Energy Resource Exploration, inquiry report, September, p.28. Frishmann B 2012, Infrastructure: The Social Value of Shared Resources, Oxford and New York.

3.1 Outcomes – an overview

The research and other direct and indirect use resulting from AuScope-related physical and data infrastructure is tremendously diverse. It spans from basic or fundamental research aiming to generate new knowledge without a specifically envisaged or immediate practical application (e.g. use of computer modelling to understand basic Earth processes) through to highly applied activities for a specific commercial purpose (e.g. a firm utilising a HyLogger to assess the composition of a drillhole in a specific location) – and all uses in between.

In that context, direct and indirect user groups vary from:

- individual researchers in universities or structured research collaborations (e.g. cooperative research centres, specialist research groups or facilities)
  - with clear examples across the breadth of AuScope's ten partner universities and beyond
- State and Territory geological surveys (geoscience agencies) and Geoscience Australia
  - with relative activity and usage skewed towards those jurisdictions with greater size and scope of geological survey work, notably Western Australia and Queensland
- individuals or firms that utilise data or analysis and interpretation produced by the above groups (e.g. mineral or energy exploration firms, natural resource managers)

Key themes associated with AuScope outcomes include:

- a broad and deep range of knowledge generation in a range of fields
  - demonstrated by just under one thousand (984) research publications listed as being associated with AuScope over the period 2007 to 2014, across multiple research areas[15]
- a contribution to better management of emerging 'big data'
  - where applied researchers are becoming more adept at utilising detailed data, in line with general moves towards quantitative analysis and computer simulation of geological systems
- integration of AuScope infrastructure with the service offers of geological surveys as a foundation for industry uptake – although variable across the different components of AuScope
  - with much analysis and interpretation drawing on different types of AuScope-related data, for example combining seismic data with other geophysical measurements such as magnetism and gravity data, as well as geochemistry, isotope analysis, geochronology and structural analysis[16]

Table 4 summarises key outcomes for each of the AuScope components (see subsequent chapters for more detail). Sections 5 to 10 draw out the specific uses of individual AuScope programs including in case studies and qualitative stories.

15 Count of research publications listed in AuScope NCRIS Program 2007-2014 report.

16 See Geological Survey of WA 2015, Geological Survey work program for 2015–16 and beyond: Geological Survey of Western Australia, Record 2015/1, for examples of how multiple types of data are drawn on, for instance towards understanding the 3D character of the Albany–Fraser Orogen in WA. In general, emerging technology such as the HyLogger and uptake of GRID has had less uptake by geological surveys than established technology such as Earth imaging equipment.

Table 4 – Key Outcomes for AuScope component

AuScope component	Inputs	Key outcomes
Earth Imaging and Structure	$7.7 million NCRIS funding (total investment $10.9 million, i.e. incorporating additional cash and in-kind contributions from AuScope partners) • improved knowledge of large-scale Earth processes/ geodynamics (SAM) • improved knowledge of Earth structure, composition, continental deformation, geochronology and early life (Earth composition and evolution, Earth imaging and structure, geospatial, GRID) • better accuracy of geodetic analyses (geospatial)	• AuScope has contributed to the major national effort in seismic reflection profiling since the mid-2000s – about 6-7% of the total transect lengths profiled. – This has helped provide new insights into crustal structure, architecture and evolution across key parts of the Australian continent. • There has also been strong researcher demand for the seismic andmagnetotelluric infrastructure acquired through AuScope – with the effect of reducing previous capacity constraints that limited or delayed research and generating new data and insights. • Data acquisition and associated research has typically occurred in regions that have mineral, geothermal or petroleum potential – most resultant data has had a major role in geological survey publications and services and that generate exploration industry interest and engagement. • The Earth imaging data also has or will inform Earthquake investigations which, ultimately, influence actions to mitigate the negative economic effects of Earthquakes. • The value of AuScope-generated data is being extended by complementary initiatives such as the Australian Seismological Reference Model (AuSREM).
Earth Composition and Evolution (geochemistry)	$2.8 million NCRIS funding (total investment $16.0 million)	• AuScope, together with other funders, made it possible for UWA to acquire and operate a uniqu-in-Australia capability in Australia to measure in situ stable isotopes at the microscale. • AuScope-related technical staffing and maintenance also contributed to at least 10% greater utilisation of three geochemistry facilities across Australia, from 2008-09 onwards. – This arguably allowed research activities to take precedence over fee-for-service activities, leading to greater common knowledge. • At least 20 organisations are using the facilities, principally researchers in universities (mostly local, some international) and government, with applications for exploration, environmental and biological sciences. • For data re-use beyond its initial purpose, some geochemistry data is being made available via the AuScope portal. There may be further opportunities to achieve more accessible geochemistry data, nationally. • Three of the four research centres funded through this AuScope component formed the ARC Centre of Excellence for Core to Crust Fluid Systems in 2011 (led by Macquarie), and the AuScope support likely assisted this.

AuScope component	Inputs	Key outcomes
NVCL/ HyLogger	$2.7 million NCRIS funding (total investment $12.1 million)	• To end 2013-14, State and Territory geological surveys have cumulatively scanned 687 km of drill core (over 2,340 cores). – This represents at most 10% of total length currently held in state core libraries, nationally. Cores continue to be generated, needing further and ongoing scanning to keep pace. – A key use of HyLogger scanning has been for major collaborative research projects, and the scanning of core newly ingested from exploration co-funding programs (as opposed to historical core) is becoming increasingly prominent – There appears to be some under-utilised capacity on the HyLoggers, in aggregate – which is driven by interest and operational resources in each jurisdiction. • Understanding and adoption varies across the geoscience community. – Through projects, researchers in university and government are becoming more familiar with the technology, what it can tell us about the crust, and what greater meaning can be generated through interaction with other technologies (e.g. soil geochemistry), and the resultant value. – Academic research utilisation of HyLogger and NVCL includes, in 2014-15, 86 refereed publications/ conference papers/abstracts, and in 2016 a special issue of the Australian Journal of Earth Sciences devoted to NVCL outputs and findings. – The exploration industry is in the initial stages of adopting the technique into their 'toolkit', in part due to the low density of scanned boreholes allowing regional interpretation. In contrast, there are already commercial competitors for onsite scanning of core from new boreholes. • Scanning core and making the data web-accessible are two different actions. Greater web-based access to data is only now starting to become available to any significant degree. As more becomes online, and as hyperspectral data becomes understood, usage would be expected to grow.
Simulation, Analysis and Modelling (SAM)	$7.4 million NCRIS funding (total investment $20.7 million)	• Many researchers in Australia and overseas are using AuScope-related Simulation Analysis and Modelling (SAM) tools – particularly GPlates and Escript, for applications across a range of Earth science including across (variously) geodynamics, minerals and energy exploration, sustainable management of energy resources, and natural hazards, across both fundamental and applied research. – some of these applications have industry involvement, or involvement of industry-focussed researchers (e.g. in CSIRO, geological surveys, ARC Linkage Projects). – there do not appear to be commercial alternatives that fulfil all the uses of the SAM tools. • Specific uses are not tracked comprehensively and many are not visible to AuScope if they do not directly involve personnel involved in AuScope.

AuScope component	Inputs	Key outcomes
Geospatial Framework and Earth Dynamics	$15.4 million NCRIS funding (total investment $50.4 million)	• Spatially-based sciences are a growth area with applications in a broad range of fields. • The technology for positioning is evolving rapidly, and the span and reach of geospatial applications are becoming increasingly important across a wide range of users. • There is already strong evidence that the new VLBI infrastructure funded through AuScope has contributed to a substantial improvement to positioning accuracy and repeatability in the southern hemisphere, to be now equivalent to the northern hemisphere. • AuScope infrastructure will be a key contributor to the new national reference frame in development (GDA2020), replacing GDA1994, that will support emerging societal needs. • The location and distribution of AuScope-funded CORS infrastructure does not to tend to optimise real-time precise positioning for commercial/industrial applications in all cases (as that is not its primary purpose). However, future technology achieving precise results with sparser networks may make greater use of AuScope CORS infrastructure for this purpose.

GRID and Interoperability	$5.9 million NCRIS funding (total investment $9.4 million)	• Data exchange, delivery and visualisation in a data-rich Earth science context is a major task
		• Data layers have progressively become available via the aggregating AuScope portal
		  – from various parts of CSIRO, Geoscience Australia, state and territory geological surveys, universities including Curtin University, University of Queensland and University of Melbourne
		  – but are not yet comprehensive, particularly for geological survey data
		• There is insufficient evidence on the extent to which end-users are using the AuScope Grid to access data for impact.
		  – However, the planned integration of the AuScope Grid approach into an expanded National Geoscience Portal administered by Geoscience Australia suggests that government geoscience agencies (who interact with industry end-users) see merit.
		• There appears to be effective use of the AuScope-supported Terrawulf computing facility, particularly since the Terrawulf-III upgrade in 2012, to support data-rich investigations.
		• The approach to spatial data access through the AuScope portal is being applied to other sectors, notably the current National Environmental Information Infrastructure led by the Bureau of Meteorology

Note: Funding and investment figures from AuScope NCRIS Program 2007-2014 report

3.2 Describing impacts

Impact categorisation

Earth science information is geographically specific and local – it exists and is utilised here, within Australia. At the same time some of the underlying infrastructure can have impact beyond Australia, for example in contributions to global information systems and knowledge.

We aggregate impacts to four areas of main impact, each of which are reasonably distinct (Figure 5):

- fundamental Earth science
- resource exploration
- natural and built environment
- spatially sensitive industries

The specific impacts vary by AuScope components – see Table 5 for a more detailed articulation.

Figure 5 – Summary areas of actual and expected AuScope impact

Fundamental Earth science
• cost savings/productivity in academic research processes
• enhanced knowledge across diverse areas (note: an intermediate rather than final impact)

Resource exploration
• cost savings/productivity
• resource discoveries brought forward

Natural and built environment
• improved risk management for natural and built environment, including natural disasters
• regulation of boundaries (land ownership, border enforcement, fisheries control)

Spatially-sensitive industries
• cost savings /productivity and additional activity in various sectors (e.g. agriculture, mining, construction, transport)

Other
• international contributions

As described in section 2.3, some impact pathways more certain than others. Resource exploration has a reasonably close connection to AuScope infrastructure and data directly produced. Yet, given commercial sensitivity, it is not always publicly-apparent what commercial entities are using what data for what purpose – particularly when data is 'open access'. Causality and attribution is even more challenging when end-uses are further distant from the AuScope activity. For example, it cannot be said with certainty that more effective building codes or other land use planning in Earthquake-prone regions that achieves ultimate impact have or indeed will result from AuScope-related actions – only that AuScope work provides options that makes such a pathway possible.

Table 5 – Summary – key examples of impacts and benefits influenced by AuScope

AuScope component	Key examples of impacts and benefits influenced by AuScope	Size of AuScope influence
Fundamental Earth science	Through allowing greater access to and use of rich geoscience and geospatial data: • improved knowledge of large-scale Earth processes/geodynamics (SAM) • improved knowledge of Earth structure, composition, continental deformation, geochronology and early life (Earth composition and evolution, Earth imaging and structure, geospatial, GRID) • better accuracy of geodetic analyses (geospatial)	Major
Resource exploration	Reduced exploration cost for a given discovery through more efficient acquisition of Earth structure data and related targeting (Earth imaging and structure, Earth composition and evolution, NVCL, SAM, GRID) Discovery and/or resource extraction brought forward through reduced uncertainty for locations with uncertain mineral or energy prospectivity (Earth imaging and structure, Earth composition and evolution, NVCL, SAM, GRID) – e.g. increase probability of discovery, decrease uncertainty of exploration cost	Major
Natural and built environment	Better land use planning and other natural hazard risk management resulting from improved knowledge of tectonic stress and seismic risk (SAM, Earth imaging and structure, Geospatial) Better coastal management informed by improved sea level estimates (Geospatial) Better meteorological products and improved knowledge of weather/climate patterns through air moisture data, resulting in better disaster planning and management for extreme weather events, e.g. heatwaves, cyclones (Geospatial) More sustainable management of soil and groundwater resources from improved knowledge of landscape evolution and soil profiles (Earth imaging and structure, Geospatial, SAM) More efficient development of online data discovery and access in environmental sector (GRID)	Medium
Spatially-sensitive industries	More accurate spatial positioning for diverse social and industrial uses (transport, environmental monitoring, agriculture, emergency services) (Geospatial) More accurate real-time spatial positioning for precision users (e.g. agriculture, surveyors, mining, pipeline) (Geospatial)	Medium
Other	Contribution to international data or analytical infrastructure (SAM, Geospatial) Possibly, time synchronisation for communications and finance (Geospatial)	Medium

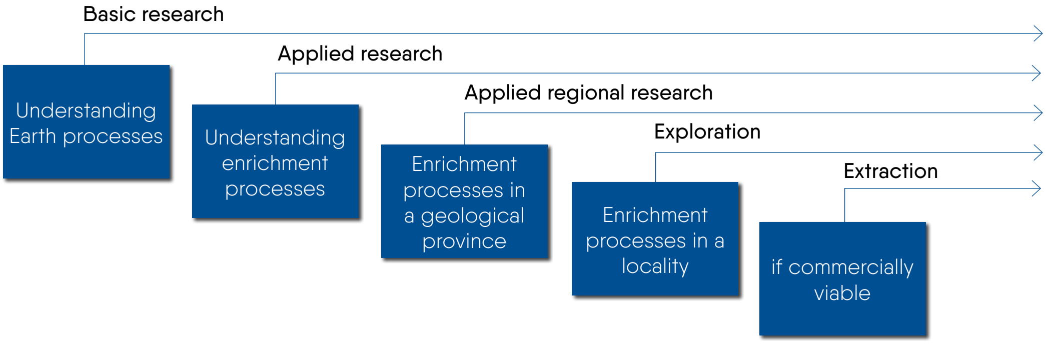
Note: AuScope component in brackets

Example of AuScope application – resource exploration

Context

Mineral and energy industries are not the only application of geoscience, but a significant one (see Figure 6). Essentially, information regarding Earth structure and composition and ready access to that geoscience knowledge helps to reduce the time, cost and risk of resource discovery by assisting the targeting of exploration effort.[17] The general availability of geoscience information can also positively influence industry views about the exploration potential of a location relative to alternatives.

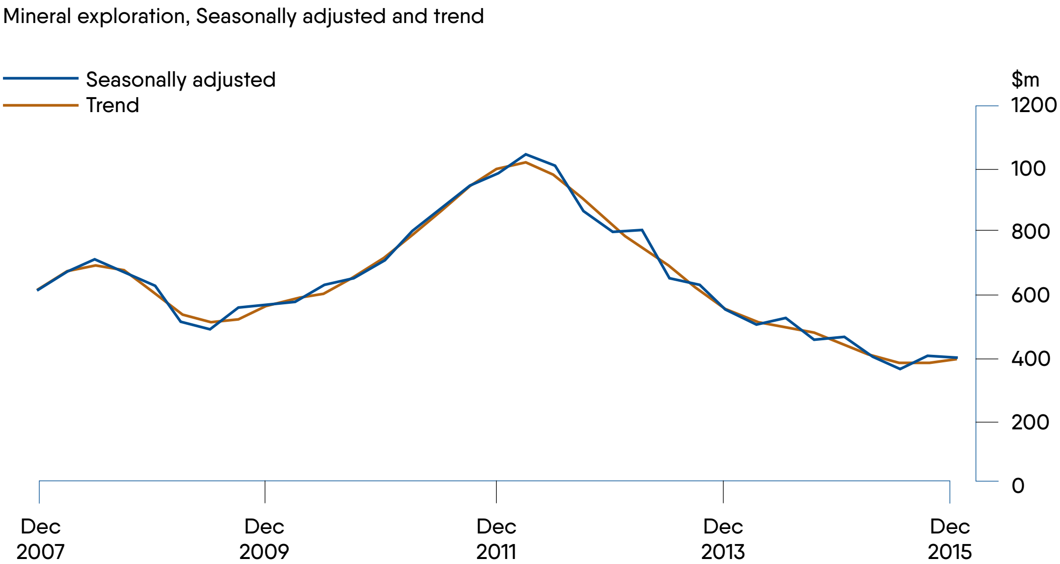
Figure 6 – Pathways of geoscience understanding



Based on presentation by Geoscience Victoria, "Implementing spatial information services at Geoscience Victoria".

The need for high quality and accessible geoscience that assists the targeting of exploration is arguably more important than ever. Australian exploration is facing higher costs and lower rates of discoveries. Annual expenditure on private mineral exploration in Australia in 2014-15 totalled $1.6 billion ($1,579 million) in 2014-15, a substantial reduction from over $3 billion ($3,055 million) two years earlier in 2012-13 and nearly $4 billion ($3,953 million) in 2011-12.[18] The substantially reduced expenditure on exploration– particularly greenfields exploration – over recent years may impair Australia's long term ability to generate a pipeline of new stocks of resources.

Figure 7 – Quarterly mineral exploration (other than for petroleum), expenditure, Australia



Source: ABS 8412.0, Mineral and Petroleum Exploration, Dec 2015 (released 29 February 2016). Note: This figure shows quarterly figures (i.e. for three months) and the previous paragraph refers to annual figures (i.e. four quarters combined).

17 In economic terms, to lower the long-run marginal cost curve of exploration and extraction.

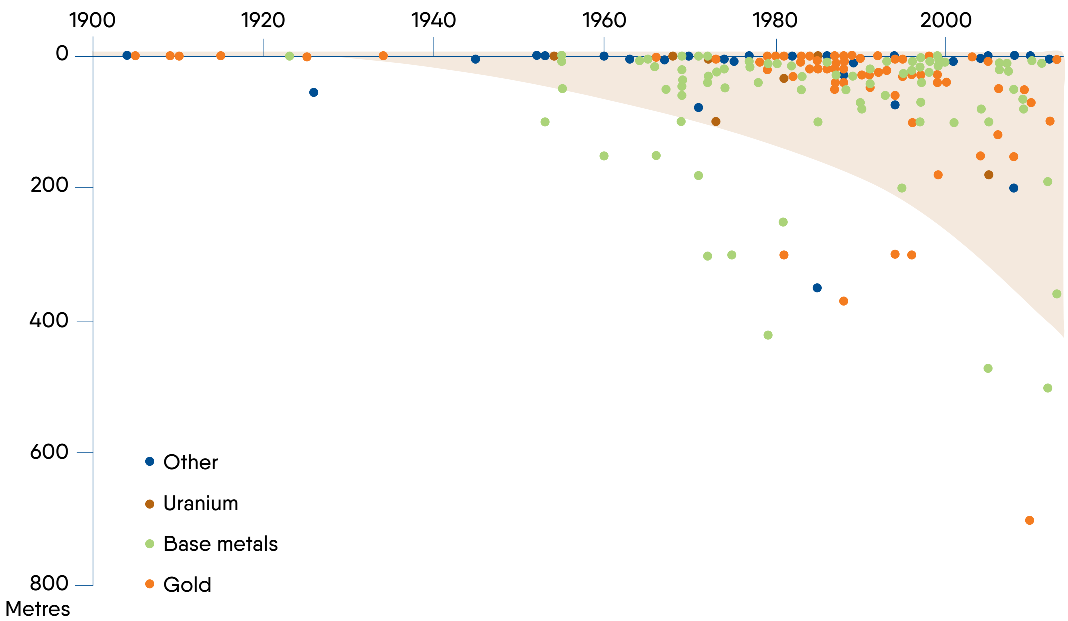
18 ABS 2016, Mineral and Petroleum Exploration, Australia, December Quarter 2015, cat. no. 8412.0, released 29 February 2016.

In Australia's mature exploration environment, resource extraction will increasingly rely on deposits of deeper in the ground or of lower grade.[19] For example, Figure 8 highlights the growing depth of larger mineral discoveries in Australia. Deposits deeper in the ground are typically harder (and more costly) to discover, which highlights the importance of basic geoscience data and interpretation (typically openly available) – called 'pre-competitive information' – for greenfield exploration frontiers.

In recognition of these challenges, since 2010 the Australian Academy of Science has been promoting the UNCOVER initiative to generate a sustained national conversation on the geoscience knowledge, data and technology needs of the minerals exploration industry to underpin Australia's future mining industry. UNCOVER's focus for geoscience research to address the challenges of developing pre-competitive information about ore deposits buried hundreds of metres below 'featureless' cover includes:

- upgrading individual geoscience disciplines such as physical and chemical 'imaging' of the subsurface and 3D/4D computational simulation predicting the development of deposits hidden by later cover;
- interdisciplinary approaches that integrate the data generated by individual disciplines into comprehensive visualisation of the prospectively to geographical regions; and
- capabilities and capacities to harvest, clean, organise and combine, interpret, communicate and publish big data sets resulting from these approaches. [20]

Figure 8 – Depth of cover on Major and Giant mineral discoveries, Australia, 1900-2014



Source: MinEx Consulting (Richard Schodde) 2015, "Exploration trends, finds and issues in Australia", presentation to International Mining and Resources Conference, Melbourne, 10 November, p.29. Note: Excludes satellite deposits within existing camps. Also excludes bulk mineral discoveries. Shaded envelope refers to depth of cover for 95% of all deposits in given decade. Analysis based on >= major sized deposits only.

Contribution of AuScope

Much of AuScope's focus is on research that can enhance geological understanding and, over time, underpin greenfield exploration and discovery (as well as having other impacts) – such as identifying a geophysical or geochemical anomaly or more fundamental aspects of Earth structure. For example, UNCOVER work to prioritise research and data acquisition actions to realise the UNCOVER vision included, inter alia, developing comprehensive maps of the characteristics of the Australian continental cover, underpinned by the data from increasingly detailed targeted and national surveys using the physical and chemical imaging infrastructure supported by AuScope.[21] Geoscience is a catalyst for finding deeper deposits and increasing overall exploration return through two main effects:

- reduced exploration cost for a given discovery through more efficient acquisition of Earth structure data and related targeting– e.g. avoided drilling, shorter exploration period
- discovery and/or resource extraction brought forward through reduced uncertainty for locations with uncertain mineral or energy prospectivity – e.g. increase the probability of discovery or decrease uncertainty (variance) of exploration cost[22]

19 Productivity Commission 2013, Mineral and Energy Resource Exploration, inquiry report, September, p.41

20 Australian Academy of Science, Searching the deep Earth - A vision for exploration geoscience in Australia, 2012

21 AMIRA International, Unlocking Australia's hidden mineral potential, An Industry Roadmap – STAGE 1, 2015

22 For deeply-hidden-resources, even if with full information the expected return would be positive, it is possible that firms lack incentive to explore because the variance/ uncertainty is too large.

Either together or in combination, aspects of AuScope's Earth imaging and structure, Earth composition and evolution, NVCL, SAM and GRID all contribute to targeted geoscience information for this purpose, often mediated through geological survey outputs. Increasingly this is through multiple method approaches that draw together a range of geoscience information to assist effectively and efficiently exploring prospective covered regions on a large scale.

As a limitation, the specifics of how geoscience information (including AuScope-related information) is used by industry is often anecdotal, unless reported. For example, companies holding exploration licenses or claims in a given area are likely to be key users, but other firms may have also reviewed this same information in the planning or reconnaissance stages of exploration. Similarly, the contribution of public geoscience information to the quality of day-to-day decision-making in exploration that led to a discovery is rarely documented.[23]

It should also be acknowledged that while geoscience can have an enabling or catalytic role, it is not the only factor affecting the extent of new exploration activity. Other factors include the skill base within firms, institutions and governance that support exploration, and market conditions.[24]

23 Duke, J.M. 2010, Government geoscience to support mineral exploration: public policy rationale and impact, prepared for the Prospectors and Developers Association of Canada, March

24 ACIL Allen Consulting 2015, Exploration Incentive Scheme Economic Impact Study, report for Geological Survey of WA (Department of Mines and Petroleum), January, p.47

4.1 Applying cost-benefit analysis to AuScope

This economic assessment places a value on cumulative effect of AuScope across key impacts, building on the framework and evidence in the previous sections.

We use a cost benefit analysis (CBA) approach to quantify, to the extent feasible, the economic value to Australian society arising from AuScope and its utilisation, relative to counterfactuals of what would have been expected if AuScope (or a similar ongoing initiative) did not occur. This includes identifying and valuing the varying impacts of the various AuScope programs – typically productivity improvements and cost savings relative to the counterfactual.

CBA is the standard approach in Australia for assessing the *ex ante* or *ex post* net benefit of activities with public funding. It involves a systematic evaluation of the impacts of an activity, accounting for all the effects (to the extent possible) on the community and economy. It provides an objective basis for comparing different impacts and impacts that occur in different periods, and converting impacts into present value dollar terms. The approach can incorporate non-market benefits, i.e. those impacts that do not have an effect on GDP as it is measured but do affect society. Overall, CBA provides a simple indicator of an activity's net contribution to society. [25]

Applying CBA techniques to a complex, distributed science initiative like AuScope is, at best, indicative. Also, due to lack of data and uncertainty about the future, there is risk of inaccuracy. Given this, we have sought to make conservative assumptions that err towards under- than over- estimation of benefit. Given these limitations, we consider that analyses like this CBA should be only one of a number of inputs including the scientific case itself that should influence future directions.

4.2 Key results

Our indicative economic assessment (see Table 6) suggests an overall net benefit to Australia from AuScope of between $2.3 billion to $6.2 billion – with a best estimate of $3.7 billion (net present value in 2015-16 terms, over the period to 2040-41).

The base case or best estimate incorporates gross benefits of $3,912 million ($3.9 billion) and economic costs of $261 million ($0.3 billion).[26] (Subsequent content refers to this base case, unless otherwise stated.)

A net benefit of $3.7 billion is equivalent to $15 of benefit for every $1 in economic cost – a substantial return on investment.

The largest impact areas are:

* spatially-sensitive industries, with gross benefit of $2,464 million or 63% of total gross benefit;
* resource exploration, with gross benefit of $912 million or 23% of total gross benefit.

Table 6 – Summary of indicative economic assessment – base case, high case, low case

Category	Estimated present value (2015-16)
Base case (best estimate) – gross economic benefits	$3,912 million
Base case (best estimate)– economic costs	$261 million
Base case (best estimate) – net benefits	**$3,651 million**
High case – economic benefits	$6,506 million
High case – economic costs	$261 million
High case – net benefits	$6,246 million
Low case – economic benefits	$2,604 million
Low case – economic costs	$261 million
Low case – net benefits	$2,344 million

25 Australian Government Department of the Prime Minister and Cabinet 2016, Guidance Note – Cost–benefit analysis, Office of Best Practice Regulation, February, p.2

26 High and low cases are sensitivity tests that bundle higher and lower assumptions on a number of key variables including social discount rate, sector growth rates, and the influence of AuScope on unit cost reduction and adoption rates within resource exploration and spatially-sensitive industries.

Figure 9 – Summary of indicative economic assessment – net benefit – base case, high case, low case ($m, present value)

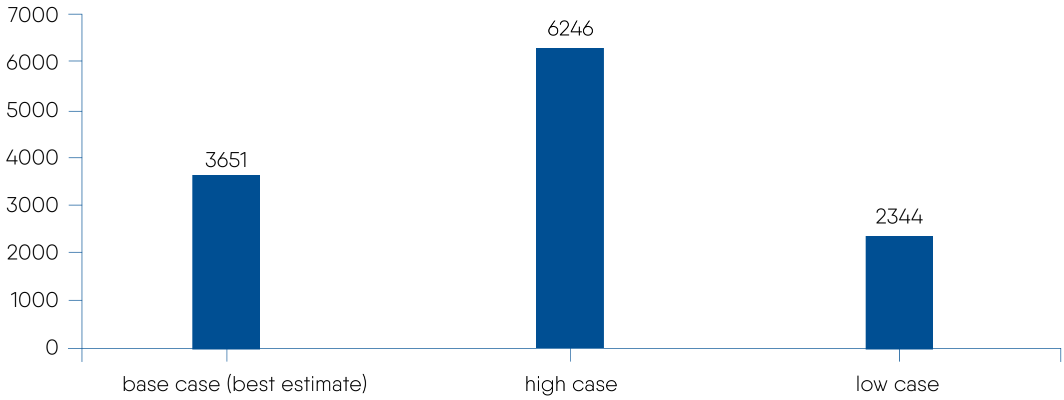
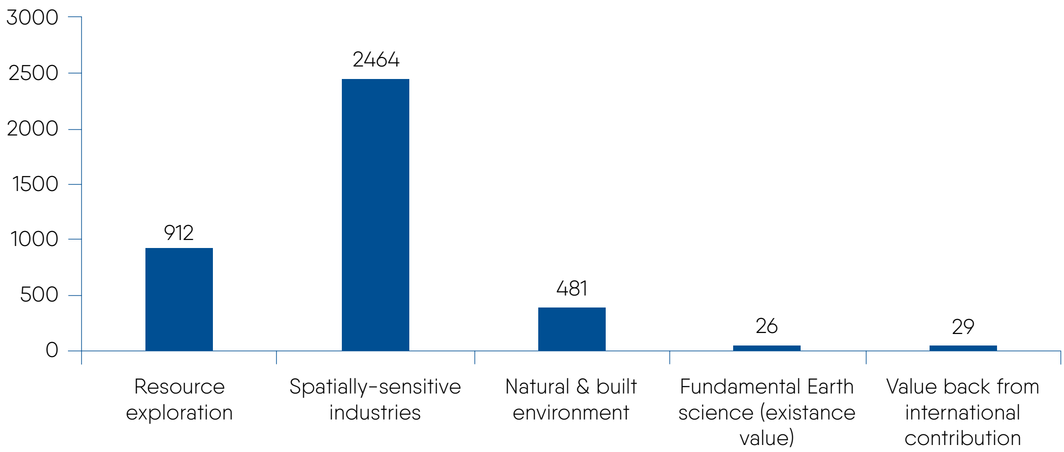


Table 7 – Summary of indicative economic assessment – composition of gross economic benefits

Category	Estimated present value (2015-16)	% of gross benefit
Gross economic benefits	**$3,912 million**	
Fundamental Earth science (existence value)	$26 million	0.7%
Resource exploration	$912 million	23%
Spatially-sensitive industries	$2,464 million	63%
Natural & built environment	$481 million	12%
Value back from international contribution	$29 million	0.7%
Economic costs	**$261 million**	
Net benefit	**$3,651 million**	

Figure 10 – Gross benefit of AuScope by impact area ($m, present value)



4.3 Summary results by impact area

Below are summary results by each of the key impact areas. All figures are in present value terms for 2015-16 unless otherwise specified. An Appendix provides detailed description of method and data sources.

Resource exploration

We assess the benefit of AuScope for Australian resource exploration through two complementary effects.

The first is reduced exploration cost for a given discovery. Explorers can utilise AuScope-related data to build knowledge of exploration areas in a less costly manner and target their physical exploration effect (e.g. avoided drilling or a shorter exploration period). Key drivers of results are assumed longterm trends on two matters relating to AuScope, for each of existing mineral deposits, new mineral deposits (greenfields) and onshore petroleum:

- the proportion of exploration activity in Australia influenced by AuScope data/research ('adoption')
- the (average) reduction in exploration expenditure when adopting AuScope data/research ('productivity')

We assess the reduced exploration cost is $257 million for greenfields minerals (new deposits), $114 million for existing mineral deposits and $80 million for onshore petroleum.

The second impact is the value of discovery brought forward. This assumes that AuScope data/research contributes to reduced uncertainty about Earth composition and structure which leads to a higher chance of economic discoveries which can be extracted at a lower cost than existing mines. In short, if more is discovered, if gives miners more options about where to mine – and some of those options will be more commercial in the production phase than existing locations.

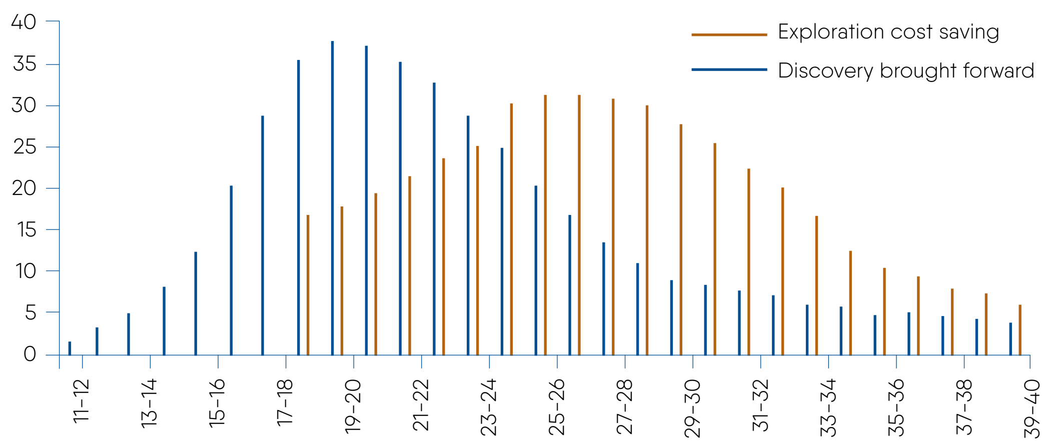
The relevant impact is calculated as the difference between the value-added to the Australian economy from the minerals sector under a scenario where AuScope has contributed to economic discoveries, and an alternative scenario without AuScope. Similar to resource exploration, key drivers are long-term trends on two variables relating to AuScope impact:

- the average difference in production cost from less costly per-unit extraction where AuScope data/research is utilised to find more economic discoveries – ('productivity')
- the proportion of mineral extraction in Australia that has been affected in this manner ('adoption'), and the extent of time delay between discovery and extraction

Combined, the overall present value is $114 million for gold, $192 million for iron ore, $84 million for copper, and $72 million for other minerals, totalling $462 million. There is substantial uncertainty in this estimation, because if we do not know what is going to be discovered, it is difficult to estimate the 'productivity' effect (i.e. extraction cost reduction). Our estimates are conservative – a major discovery with cost-effective extraction could substantially increase the overall impact.

Figure 11 illustrates the phasing of the two separate effects over time.

Figure 11 – Resource exploration gross benefit of AuScope ($m, present value)



Spatially-sensitive industries

AuScope's geospatial infrastructure and data can contribute to operational efficiencies in various industries and parts of the public sector that utilise, or have the potential to utilise, spatial information.

In order to assess AuScope's contribution, we firstly estimate the current and future economic benefit of geospatial technology in general (i.e. not just AuScope) across various sectors of the Australian economy.[27] We then use this as a basis to isolate AuScope's relative contribution over time. Without AuScope, precision or automation would be less precise and/or available in fewer parts of Australia than the above scenario (particularly in regional areas that may not have otherwise achieved augmentation technology). That is, unit cost savings and adoption levels could each be smaller. As such, to estimate AuScope's relative contribution, we assume AuScope can have two effects (which can be multiplied for an overall effect):

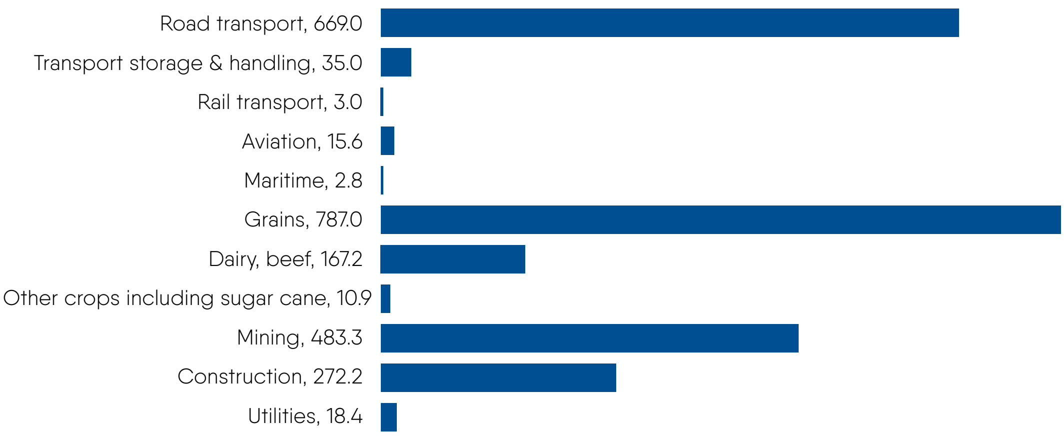
- positive change in the unit cost reduction rate (e.g. from greater accuracy, or maintaining accuracy over time) ('productivity')
- positive change in adoption rate (e.g. from greater availability of precise applications, or maintaining availability, in particular locations)

We assume that AuScope's impact is negligible in 2012, but that it increases over time as legacy infrastructure becomes less fit-for-purpose. However, the counterfactual also conservatively assumes that infrastructure equivalent to (or better than) that under AuScope would eventually have been resourced (by the early-2030s), and from this point AuScope has effectively no economic impact (even if in reality the actual physical infrastructure built under AuScope would still be in use).

There are varying effects by sector, based on their location, precision applications, and use of substitutes for augmentation. For example, construction is predominantly located in major urban centres that do not particularly benefit from CORS augmentation which occurred mainly in rural areas, but construction does benefit from the AuScope system's contribution to maintaining the reference system's accuracy over time. The assumed pattern and scale of AuScope's incremental effect by sector is based on input by sector from geospatial stakeholders. It is highly indicative, as it is not common practice within geospatial fields to isolate the impact of one part of the geospatial system on geospatial applications, let alone assess that impact in quantitative terms. No literature was identified that could further validate the assumptions made.

The overall AuScope gross benefit in spatially-sensitive industries of $2,464 million is composed of $787 million from the grains industry (32%), $669 million from road transport (27%), $483 million from mining (20%), $272 million from construction including land management and surveying (11%), $167 million from dairy and beef (7%) and the remaining 3% from various other industries. Figure 12 over the page illustrates this.

Figure 12 – Spatially-sensitive industries gross benefit of AuScope ($m, present value)



27 This draws on 2013 research by ACIL Allen with Sinclair Knight Merz (SKM) and Lester Franks Surveyors and Planners for the then Australian Government Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (Space Coordination Office). These are the most contemporary and comprehensive available studies of cost savings and industry adoption in the Australian context.

Natural and built environment

AuScope is one contributor to better prediction and land use planning for natural hazards such as floods, storms and Earthquakes. This includes data infrastructure utilised for understanding of tectonic stress and seismic risk, water level estimates relevant to flood studies and long-term sea level rise, and knowledge of weather/climate patterns through air moisture data.

Better prediction and land use planning can reduce the economic costs of natural hazards. Totaleconomic costs of natural hazards include not only tangible damage costs but also indirect tangible costs such as business interruption and emergency relief and recovery and intangible 'social costs' such as human injury and death and impacts of wellbeing.

The total present value of AuScope's impact on storm (including cyclone and hail), flood and Earthquake are estimated to be $305 million, $166 million and $10 million respectively – or $481 million combined.

Existence value

Existence value (i.e. the value the community places on basic scientific knowledge that does not necessarily result in downstream usage) is challenging to quantify, and there is no relevant data available that can be used to directly infer a value. Our literature review indicated only one major study exploring what it calls "for the first time, an empirical estimation of the willingness to pay for discoveries in basic research by the general public", focusing on existence value (for Europe) of Large Hadron Collider participle accelerate at CERN in Switzerland. The existence value was assessed as €3.2 billion, equivalent to 24% of the Large Hadron Collider's substantial economic costs.[28] AuScope is of a much smaller scale to the Large Hadron Collider and not directly analogous. However, in order to recognise the likely presence of existence value, we adopt a conservative assumption that AuScope existence value is equivalent to 10% of AuScope's economic costs, or $26 million.

International contribution

Overseas usage can be observed in many aspects of AuScope (for example, in international research collaborations or in the utilisation of SAM-software in international contexts). However, in this analysis, the economic benefit of international users utilise AuScope outputs/knowledge is targeted to how Australians benefit from such international usage, given the standing is limited to Australia. Benefits to Australia arising from international usage might include, for example, further technical development which Australians can adopt and overseas reciprocity of open-data. Our conservative assumptions suggest a total value of $29 million.

Costs

We assessed the economic costs associated with AuScope to have a present value of $261 million, consisting of $210 million for AuScope costs (including costs financed by NCRIS funding as well as cash and in-kind contributions by AuScope partners) and $50 million for marginal excess tax burden (i.e. the cost to society from raising revenue through taxation to pay for AuScope). (Note that present value economic costs are different to nominal financial costs which is usually how AuScope investment is described. See Appendix for more detail.)

4.4 Comparisons with other assessments of Earth science infrastructure

The results of Lateral Economics' economic analysis are broadly consistent with the few other studies of the economic benefit or impact of Earth science infrastructure in Australia and internationally.

Pre-competitive information for resources exploration has been assessed in various studies as having a strong net benefit to society.[29] For example:

- a 2015 study found benefit-cost ratios of between 5.2 to 1 to 9.0 to 1 for WA Government geoscience investment to support exploration;[30]
- a similar study in Queensland in 2002 on actions to improve data quality found benefit-cost ratios of between 3.8 to 1 and 7.4 to 1.[31]

We estimate an approximate ratio of 6.4 to 1 for AuScope benefits and costs attributable to resource exploration.[32] The scale of WA and Queensland study results are comparable to the effects in this study.

Recent analysis of the United States' geospatial system commissioned by the US National Geodetic Survey suggests (gross) present value upwards of $US55 billion over 15 years. This incorporates (gross) present values for the spatial reference system as used for private and public surveying and mapping ($US36 billion), CORS data ($US18.5 billion), and gravity/vertical datum as used for long line levelling and floodplain management ($US4.8 billion).[33]

A (gross) present value of $US55 billion is of comparable scale to (or possibly higher than) the results in this study (gross geospatial value of $2.5 billion), given the Australian economy is roughly 10% the size of the US economy or Australia's population is around 7.5% of the US population.

28 For more detail on the method used in the Large Hadron Collider assessment, see Florio M, Forte S, Sirtoro E 2016, "Forecasting the socio-economic impact of the Large Hadron Collider: A cost-benefit analysis to 2025 and beyond", Technological Forecasting & Social Change, in press and Catalnao G, Florio M, Giffoni 2016, "Contingent valuation of social preference for science as a pure public good: the LHR case", DEMM working paper, University of Milan

29 While not an exact match for AuScope, these studies point to the strong value of geoscience in general – and, indeed, are limited only to exploration-related benefits.

30 Fogarty, J.J. and Sagerer, S. 2016, "Exploration externalities and government subsidies: the return to government", Resources Policy, vol 47, pp.78-86

31 Scott, M. et al 2002, op cit

32 Non-geospatial elements account for 55% of AuScope costs. (We applied this proportion to the total economic costs for an approximate figure on resource exploration-related AuScope costs given all nongeospatial elements have strong resource exploration-related utilisation).

33 Leveson 2009, 'Socio-Economic Benefits Study: Scoping the Value of CORS and GRAV-D', for the US National Geodetic Survey: http://www.ngs.noaa.gov/PUBS_LIB/Socio-EconomicBenefitsofCORSandGRAV-D.pdf

Key points

- AuScope has contributed to the major national effort in seismic reflection profiling since the mid-2000s – about 6-7% of the total transect lengths profiled.
  - This has helped provide new insights into crustal structure, architecture and evolution across key parts of the Australian continent.
- There has also been strong researcher demand for the seismic and magnetotelluric infrastructure acquired through AuScope
  - with the effect of reducing previous capacity constraints that limited or delayed research and generating new data and insights.
- Data acquisition and associated research has typically occurred in regions that have mineral, geothermal or petroleum potential
  - most resultant data has had a major role in geological survey publications and services and that generate exploration industry interest and engagement.
- The Earth imaging data also has or will inform Earthquake investigations which, ultimately, influence actions to mitigate the negative economic effects of Earthquakes.
- The value of AuScope-generated data is being extended by complementary initiatives such as the Australian Seismological Reference Model (AuSREM).

5.1 Scope and outputs

Scope

The Earth Imaging and Structure component of AuScope involved generating images of the subsurface along sections through the Australian continent. It aimed "to build an increasingly clear and rich picture of the subsurface"[34] through high resolution imaging of the Australian crust and mantle. Seismic reflection is used to acquire images of the Earth's crust at depth which provides insight into its structure and its resources, particularly when combined with magnetotelluric (MT) data to measure electrical resistivity of the sub-surface and other geophysical measurement.

Specifically, NCRIS funding was utilised to:

1 keep passive seismic and MT equipment (physical infrastructure) contemporary by replacing obsolete equipment no longer supported by the manufacturer and improving capability (e.g. greater dynamic range, able to probe greater depth)
  - this equipment, which forms part of a national pool, is portable and able to be deployed to the location of an experiment[35]

2 generate more and better data (i.e. data infrastructure) on various areas of Australia by cofunding large-scale seismic and MT imaging of certain geotransects (i.e. strips of land)
  - providing full crustal reflection profiles spanning the depth of the Earth's crust in areas where crustal structure was poorly known and considered to be of high scientific importance, and not being provided by geoscience agencies[36]

3 process data from current and previous experiments into broadly accessible and usable forms (including summary information through the AuScope portal).

Key inputs have included AuScope expenditure of around $7.7 million (with approximately 62% for geotransects).

Outputs

Seismic and MT equipment (approaching 200 instruments) was purchased and become operational and available for use in tranches over the period to 2010-11. [37] The equipment remains available for use.

Data from the three main geotransects (plus a trial transect) was acquired over the period 2008-09 to 2010-11, typically as additional distance on existing geoscience agency projects[38]

- in 2008, additional 200 kilometres in the Gawler-Officer-Musgrave-Amadeus (GOMA) transect near the South Australia-Northern Territory border – with results made available by November 2010[39]
- in 2009, additional 180 kilometre in the Southern Delamerian transect in western Victoria and South Australia – with results made available by March 2011

34 AuScope 2006, "NCRIS Investment Plan for Structure & Evolution of the Australian Continent", p.21

35 The specific equipment includes around 200 broadband seismic recorder systems (ANU), MT broadband systems (University of Adelaide and ANU) and 15-20 MT low frequency recorder systems (University of Adelaide). The seismic equipment replaced legacy equipment of a consortium of universities and Geoscience Australia, the Australian National Facility for Earth Sounding (ANSIR).

36 AuScope 2014, NCRIS Australian Continent FY2014, p.14

37 MT instrumentation has been available since 2010-11; seismic equipment earlier.

38 It is assumed the focus of geoscience agencies is locations of importance for the resources sector.

39 The interpreted processed data was released at the GOMA seismic and MT workshop, November 2010, in Adelaide.

- in 2010, additional 290 kilometres in the Capricorn transect in Western Australia (Pilbara region) – with results made available by April 2011[40]
- as well as additional reflection work for 200 kilometres in the Isa-Coast transect in north Queensland in 2007, as a trial.[41]

The AuScope-funded effort has been only one part of an ongoing effort, principally by geoscience agencies, to map survey lines across Australia.[42] AuScope has funded a distance of about 6-7% of seismic reflection profiling achieved nationally since the mid-2000s.[43]

5.2 Nature and scale of usage

Types of usage

Usage of the AuScope-funded physical and data infrastructure incorporates a number of different activities:

- usage of the passive seismic and MT equipment for research to understand continental rock mass at a range of scales, typically by research institutions
- usage of data resulting from such research, and the specific geotransects funded under AuScope, by universities, government agencies and exploration companies for varied purposes
  - which might range from calibration of models of the Earth's crust and upper mantle, to specific exploration applications

Figure 13 – Pathways to impact Earth imaging for equipment

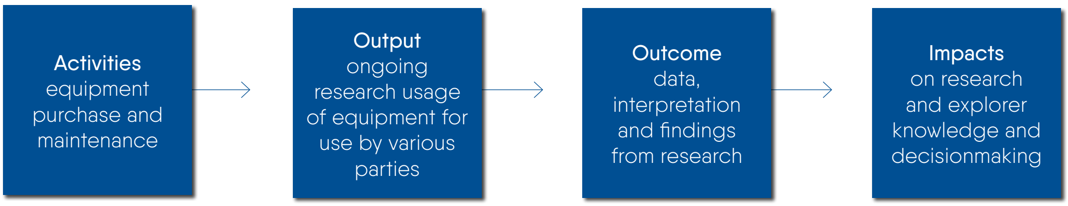
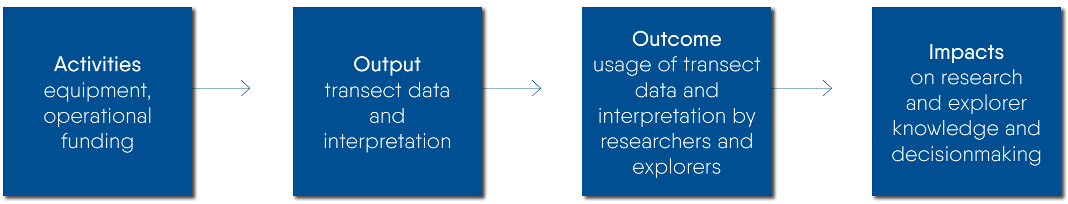


Figure 14 – Pathway to impact for transects



Demonstrated usage

Portable seismic and MT equipment

The AuScope-related equipment has effectively been fully utilised since becoming available, and continues to be (e.g. in 2014-15). This utilisation includes field usage (~85-90% of time) plus maintenance/servicing time (~10%).

Usage has been, as expected, by university researchers and government agencies, typically part of collaborative research projects (some with exploration industry involvement).[44] Deployments have been in locations across Australia.

A recent case study using AuScope seismic and MT infrastructure in 2013 (page33) reveals what lies beneath the western Gawler Craton in SA and WA, and related exploration. Similar examples include a deep crustal seismic reflection survey in 2012 of the Albany Fraser Orogen in WA, a collaborative project between Geoscience Australia, the Geological Survey of WA, the National Research Facility for Earth Sounding (ANSIR), AngloGold Ashanti Limited (AGA) and Independence Group, and the Centre for Exploration Targeting (CET) at the University of WA.

40 A collaborative project between Geoscience Australia, the Geological Survey of WA and AuScope.

41 The interpreted processed data was released at the North Queensland Seismic and MT Workshop, Townsville, June 2009.

42 For example, since 1980, Geoscience Australia has acquired in excess of 15,000 kilometres of onshore deep crustal seismic reflection data and numerous 2D seismic refraction profiles. (http://www.ga.gov.au/about/what-we-do/projects/minerals/current/seismic, accessed 20 January 2016)

43 Based on the statement that over 14,000km of full crustal reflection profiles acquired with recording to 20 s or more have been acquired across Australia since 2004 in Kennett B.L.N & Saygin, E. 2015 "The nature of the Moho in Australia from reflection profiling: A review", GeoResJ, volume 5, March, pp.74–91

44 Access is based on scientific merit is coordinated and scheduled through a national committee attached to a pre-existing group incorporating Geoscience Australia and ten universities (Research Facilities for Earth Sounding, ANSIR). In 2013-14, KPI summary reports the instrument pool had the following users: seismic 14 users (ANU, UWA, Macquarie, GSWA, Geoscience Australia, Victoria University of Wellington (NZ), MT 6 users (Adelaide, GA, UWA); 6 Australian research collaborations involving use of AuScope infrastructure, 1 collaborative experiment with NZ.

Similarly, MT deployments have been made as part of projects in WA, Queensland, Victoria, South Australia and other locations.[45] Notably, a national collaboration led by Geoscience Australia, AusLAMP[46], is currently undertaking a multi-year national survey to acquire long-period MT data across Australia to map the electrical conductivity of the continent in three dimensions. AuScope-funded portable MT equipment is being deployed for a one-month period at approximately 2,800 sites spaced at a distance of around 55 km. Outputs (e.g. metadata records, processed data, inversion products and reports) will be freely available to scientific research organisations and industry.[47]

With respect to data generated from portable seismic and MT equipment, the AuScope portal currently provides summary information, and detailed data is available from specialised interfaces of the University of Adelaide (for MT data) and the ANU (for seismic data).[48] The ANU in 2014 reported a steady increase in users to about 100 for its seismic interface (AuSREM and AusMoho)[49] – no further information is available as to their composition or interest or extent of usage.

Open data access is expected to continue. For example, Geoscience Australia has stated its intent to provide free access to AusLAMP data and products including metadata records, processed data, inversion products and reports, for research organisations, industry and the general public.[50]

Geotransects

As described above, interpreted and processed data for the three main geotransects were made available over the period November 2010 (for GOMA transect) to April 2011 (for Capricorn transects). The relevant state geological survey(s) and Geoscience Australia held workshops/presentations outlining relating data and interpretations, together with other geological datasets and geophysical modelling, which were published. These had a high profile with industry: for example the GOMA transect workshop was held at the Adelaide Convention Centre as an affiliate event to the SA Explorers' Conference.[51] The content included interpretation of geodynamic implications and implications for regional energy and mineral systems, for example, identification of major crustal boundaries, favourable regions for uranium resources which share for of the key architectural ingredients of iron oxide-copper-gold (IOCG) systems, and for areas of high heat-producing granites of potential interest for geothermal resources.

Processed data and images from the transects are available via various websites/portals, and in geological survey publications. Geological surveys described the material as useful inputs to their ongoing work to assess prospectivity in different regions. No comprehensive information is available on specific usage of the information generated by researchers or industry.

5.3 Impacts and benefits – qualitative assessment

Counterfactual

AuScope-funded equipment and data has potentially brought forward experiments that would otherwise occurred at a later date or not at all, given a counterfactual of fewer financial resources for geotransects and a smaller, older and in some cases ad hoc stock of field equipment with long lead-times for equipment use.[52]

Actual

The range of projects fully utilising AuScope-related Earth imaging equipment, and the high profile of AuScope Earth imaging-related data in state geological survey work, suggests strong value from this AuScope component, summarised in Table 8.

The direct impact is providing fundamental data and interpretation to contribute to an understanding of Australia's geology, including:

- near surface targets such as groundwater channels, regolith profiles, palaeochannel mineralenergy resources and mine structure,
- deeper targets such as hydrocarbon reservoirs, carbon capture and geological storage sites and geothermal deposits, and
- crustal scale targets such as crustal structure, whole-of-mineral-system, and major fault systems.[53]

45 As an example of diversity, the main experiments for the MT equipment in 2014 have been a MT grid over the Flinders Ranges (University of Adelaide and DMITRE SA), AusLAMP program across Victoria (GSVic and Geoscience Australia); a MT transect across Olympic Dam (University of Adelaide and DMITRE SA); a MT transect across western Victoria (University of Adelaide and GSVic); an MT transect across the Perth Basin (UWA and GSWA); a MT transect in the Capricorn Orogen (UWA and GSWA); a MT monitoring array in Queensland for Coal Seam Gas (UA and industry). Various data has resulted from these projects.

46 The Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) – 'Illuminating Australia's Deep Earth',

47 http://www.ga.gov.au/about/what-we-do/projects/minerals/current/auslamp

48 AuScope FY2014, p.12

49 Quarterly reporting from ANU, Q4 2014

50 http://www.ga.gov.au/about/what-we-do/projects/minerals/current/auslamp

51 See https://d28rz98at9flks.cloudfront.net/71141/Rec2010_039.pdf and http://www.ga.gov.au/metadatagateway/ metadata/record/71344/

52 For example, most international pools of portable seismic and MT Earth imaging equipment are oversubscribed, so lead times for experiments may be several years before recorders and sensors become available.

53 http://www.ga.gov.au/scientific-topics/disciplines/geophysics/seismic

Using AuScope seismic and MT infrastructure to reveal what lies beneath the western Gawler Craton and related exploration

The Nullarbor Plain is famous for being flat and featureless. Despite this, its subsurface structure and history is complex, with potentially mineral bearing structures beneath hundreds of metres of sedimentary rock coverage hinted at by the few drill holes, but largely unknown. The region lies between two of the most prospective geological regions in the world, the Yilgarn Craton to the west (featuring the Super Pit open cut gold mine at Kalgoorlie) and the Gawler Craton to the east (featuring the Olympic Dam iron oxide copper gold ore deposits (IOCG) province), so its potential is high. But, as typical of regions in Australia where the surface coverage obscures what lies beneath, the area has been typically 'under-explored' – we don't know what is there.

"The striking orange-red colored southern Australian coast contrasts against the deep sapphire-blue waters of the Southern Ocean in this true-color Moderate Resolution Imaging Spectroradiometer (MODIS) image acquired by the Terra satellite on August 19, 2002. In the northern portion of the image, a handful of fires (marked in red) were detected burning in the Great Victoria Desert by the MODIS instrument. South of the desert is the lighter-orange Nullarbor Plain, which stretches for over 1000 kilometers (about 600 miles) from end to end. Finally, just off the coast in the Southern Ocean is the Great Australian Bight, home to Australian Sea Lions, Southern Right Whales, and various fish species."

Credit Jacques Descloitres, MODIS Rapid Response Team, NASA/GSFC

Employing AuScope-related seismic and MT infrastructure, in 2013-14 Geoscience Australia, the Geological Survey of WA and the Geological Survey of SA undertook a 'Eucla-Gawler transect' project involving a deep crustal seismic reflection line and magnetotelluric surveys along 870 kilometres across the Nullarbor Plain from Haig in southeastern WA to Tarcoola in SA. This transect linked previous surveys in each State in otherwise unknown territory.

In December 2015, the first results of analysis and interpretation of the Eucla–Gawler transect data were released. There was evidence for a number of major crustal discontinuities and structures from both seismic and MT data. This includes the Tallacootra, Karari and Coorabie shear zones, prospective for transported metals mineralisation such as gold, nickel, copper and platinum group elements, and the Hiltaba-aged magmatism in the eastern Wilgena Domain as highly prospective for potential IOCG or gold only type mineralisation. The final survey results are due for release in mid- 2016.

Entities showing interest through attending the data and interpretation workshop included:

- Universities and government: SA Department of State Development, SA Department of Environment, Water and Natural Resources, Geological Survey of WA, Geoscience Australia, University of Adelaide, University of South Australia, Deep Exploration Technologies Cooperative Research Centre (DET CRC)
- Industry: AngloGold Ashanti, Argonaut Resources, Cartwheel Minerals, CGG, Emmerson Resources, Greenfieldexplorer.com, Iluka Resources , Investigator Resources, Fortescue Metals Group, Minotaur Exploration, Monax Mining, MWH Global, Southern Geoscience Consultants, Terramin, Petra Search, Western Areas, Woomera Exploration, Vector Research

Given the deep sedimentary coverage, the prospectivity of these areas was relatively unknown before this survey. Even now the economic potential of some domains is difficult to assess in the absence of drill hole data. However already Iluka Resources and Western Areas are drilling in areas re-rated by the new transect as a region of potential mineral discovery, and have pegged ground on arguably the even more prospective hotspot above the Karari shear zone.

Sources: What lies beneath the western Gawler Craton? 13GA-EG1E Seismic and Magnetotelluric Workshop 2015, Extended Abstracts, p70-71, Department of State Development, Government of South Australia http://minerals.statedevelopment.sa.gov.au/geoscience/geological_survey/gssa_projects/western_craton_margins/western_gawler_craton_workshop; personal communication with Rian Dutch, Geological Survey of SA, 4 March 2016

Table 8 – Qualitative summary of key uses and impacts of Earth Imaging and Structure

Impact area	Contribution	Nature of impact and benefit
Fundamental Earth science	Major	Improved knowledge of Earth structure and geodynamics (e.g. crustal boundaries, changes in character)
Resource exploration	Major	Reduced cost of acquiring Earth structure data compared to less efficient methods (e.g. drilling) Shorter period of exploration and discovery through better targeting (e.g. shorter experiment time, bringing forward experiments)
Natural and built environment	Medium	Improved understanding of natural hazard potential informing risk management
Spatially-sensitive industries	-	-
Other	-	-

The ongoing knowledge created in regions where crustal structure was poorly known is a demonstrated change. For example, the Capricorn Orogen survey changed some of the basic thinking about tectonics in regions of colliding crust, and identified a number of mantle-scale structures that were previously unrecognised because they had little or no expression at the surface.[54]

Complementary initiatives mean AuScope-generated data is likely to have ongoing impact beyond direct research projects. This is not only through ongoing development of newer and more advanced processing techniques (e.g. to improve seismic images), but in user-focused research activities such as the Australian Seismological Reference Model (AuSREM)[55] which brings together existing information (including data from AuScope-supported work) to synthesise a 3D seismological model from the surface to 300-kilometres depth.

Data acquisition and associated research has typically occurred in regions that have mineral, geothermal or petroleum potential – and have had a major role in geological survey publications and services. Industry involvement and interest (for example AngloGold Ashanti Australia in Albany-Fraser projects) is a strong signal of efficiencies for exploration prioritisation: "seismic data at any scale, has the ability to compress the timeframe of discovery and significantly reduce the cost and number of drill holes to achieve this when combined with robust 4D geology models."[56]

The other major area of impact from AuScope Earth imaging work is an enhanced understanding of natural hazards. Seismic refraction methods are a fundamental component of most geohazard research, particularly Earthquake investigations.[57] For example, Geoscience Australia found that using the AuSREM 3D model resulted in improved or comparable location estimates of various recent Earthquake events when compared to those from the local Australian 1D models. [58] While not a direct impact, ultimately geohazard research informs vulnerability analysis and resultant land use planning, building costs or other actions to mitigate the negative economic effects of Earthquakes.

54 See http://www.auscope.org.au/portfolio_category/Earth-imaging-Earth-sounding/

55 See http://rses.anu.edu.au/seismology/AuSREM/index.php

56 "Multi-scale seismic exploration for minerals" by Brendan Hardwick (AngloGold Ashanti Australia & Geoconferences WA), http://www.explorationconnect.com.au/news/article/20042015-160/multi-scaleseismic- exploration-for-minerals.aspx

57 http://www.ga.gov.au/scientific-topics/disciplines/geophysics/seismic

58 De Kool M, Jepsen D, Spiliopoulos S, Glanville H 2013, "Locating Australian Earthquakes Using the Australian Seismological Reference Model (AuSREM)", Geoscience Australia, paper to the Australian Earthquake Engineering Society 2013 Conference, Nov 15-17, Hobart, http://www.aees.org.au/wpcontent/uploads/2015/06/66-Spiliopoulos-Spiro-Locating.pdf

Key points

- AuScope, together with other funders, made it possible for UWA to acquire and operate a unique-in-Australia capability in Australia to measure in situ stable isotopes at the microscale.
- AuScope-related technical staffing and maintenance also contributed to at least 10% greater utilisation of three geochemistry facilities across Australia, from 2008-09 onwards.
  - This arguably allowed research activities to take precedence over fee-for-service activities, leading to greater common knowledge.
- At least 20 organisations are using the facilities, principally researchers in universities (mostly local, some international) and government, with applications for exploration, environmental and biological sciences.
- For data re-use beyond its initial purpose, some geochemistry data is being made available via the AuScope portal. There may be further opportunities to achieve more accessible geochemistry data, nationally.
- Three of the four research centres funded through this AuScope component formed the ARC Centre of Excellence for Core to Crust Fluid Systems in 2011 (led by Macquarie), and the AuScope support likely assisted this.

6.1 Scope and outputs

Scope

Geochemistry is the basis for understanding the formation mechanisms and history of the geology of the Australian continent. The purpose of the AuScope geochemistry program was to address three identified areas of deficiency:[59]

- no access within Australia to capabilities of new-generation Ion Probes;
- under-utilisation of existing infrastructure at various Australian universities due to lack of enabling technical support; and
- inadequate management of geochemical data, resulting in it being inaccessible (to a degree even within individual labs) except via eventual publication.

Outputs

Specifically the program has involved:

- co-funding with UWA and WA Government the acquisition of a Cameca 1280 Ion Probe at the UWA's Centre for Microscopy, Characterisation and Analysis – a unique capability in Australia to measure in situ stable isotopes at the microscale
- supporting employment of technical staff and minor equipment and maintenance items to facilitate the use of (and guarantee access to[60]) three existing geochemical facilities:
  - TerraneChron facilities at Macquarie University's GEMOC[61] Geochemical Analysis Unit
  - thermochonology facilities at the University of Melbourne
  - SHRIMP[62] and the Western Australian Argon Isotope Facility (WAAIF) at the John De Laeter Centre of Mass Spectrometry involving Curtin University, UWA, CSIRO and the Geological Survey of WA

Key inputs have included AuScope funding of $1.5 million for the Ion Probe and $1.3 million for the existing facilities.

The Cameca 1280 Ion Probe was fully commissioned by 2009-10. Additional technical staff for the existing geochemical facilities commenced in 2007-08 and 2008-09, variously.

6.2 Nature and scale of usage

Types of usage

University and government researchers primarily directly use the AuScope-related geochemistry infrastructure, given the sophisticated type of analysis. (Some analysis is part of collaborative projects involving industry participants).

Understanding the geochemistry of landscapes, and the history of their evolution, ultimately assists in the identification of mineral deposits and other materials that share geological history. This has applications

59 AuScope 2006, "NCRIS Investment Plan for Structure & Evolution of the Australian Continent"

60 These facilities were expected to make at least 10% of available time to AuScope projects

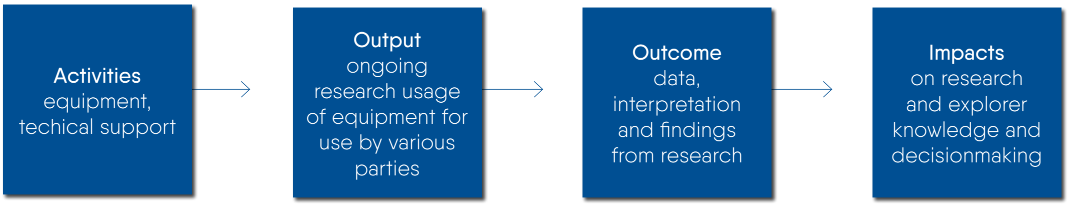
61 ARC National Key Centre for Geochemical Evolution and Metallogeny of Continents (GEMOC)

62 SHRIMP: Sensitive high resolution ion micro probe for explorers to prioritise targets (albeit a number of steps removed from basic research) – for example, determining the chronology of geological and mineralisation events in various resource regions (e.g. Pilbara Craton, Yilgarn Craton, Capricorn Orogen, Musgrave Complex).

The infrastructure and techniques also have applications in environmental and biological sciences. For example, the IMS 1280 can be used for in situ stable isotope ratio analyses in diverse applications such as:

- oxygen isotope analyses in minerals to provide information concerning provenance or formation environment;
- depth profiling of semiconductors to reveal trace element distributions;
- sulphur isotope analyses of sulphide minerals to provide information about age or biological activity; and
- carbon isotope analyses to provide clues to the nature of early life on Earth. [63]

Figure 15 – Pathways to impact geochemistry equipment and technical support



Demonstrated usage

Cameca 1280 Ion Probe at UWA

The Cameca 1280 Ion Probe at UWA approached full utilisation in 2012 and was oversubscribed in 2013, which demonstrates strong user demand principally by universities.[64] As examples of usage, fourteen research projects that commenced in 2008-09 concerned:

- oxygen isotopes in quartz (Geological Survey of WA)
- boron isotopes in serpentine (Curtin University)
- early life signatures (Curtin University)
- heavy metals in chiton teeth (UWA)
- isotopic signatures of ore stage minerals (CSIRO)
- migration patterns of Diprotodon (Curtin University)
- oxygen isotopes in garnets - fluid flows (Curtin University/University of Adelaide)
- provenance of zircons using oxygen isotopes (UWA)
- early life (UWA)
- water on early moon (Curtin University/UWA)
- uranium isotope signatures (Institute of Transuranium Elements, Germany)
- microbial forensics (Pacific North West National Laboratory, USA)
- oxygen isotopes in garnets (James Cook University)
- oxygen isotopes in meteorites (UWA)[65]

Existing facilities

With respect to AuScope funded technical staff at existing facilities, the additional value of AuScope support is greater (although still finite) capacity and more efficient use of capacity, resulting from:

- faster maintenance of equipment, so more equipment up time
- support in instrument use, so collaborating researchers do not need to extensively train in its use, increasing the productivity of available time.

There is some evidence that these productivity improvements have resulted. For example, the John De Laeter Centre of Mass Spectrometry (Curtin) facility reported that SHRIMP availability lifted from 70% to over 80% in 2011.[66] This is consistent with an estimate that without AuScope support, there might be 25% less activity in relevant parts of the John De Laeter Centre.[67] However, in general, change in facility utilisation resulting from AuScope funding was not consistently recorded.

63 http://www.cmca.uwa.edu.au/facilities/sims/cameca-ims-1280

64 AuScope 2014, AuScope NCRIS Program 2007-2014, pp.35-36

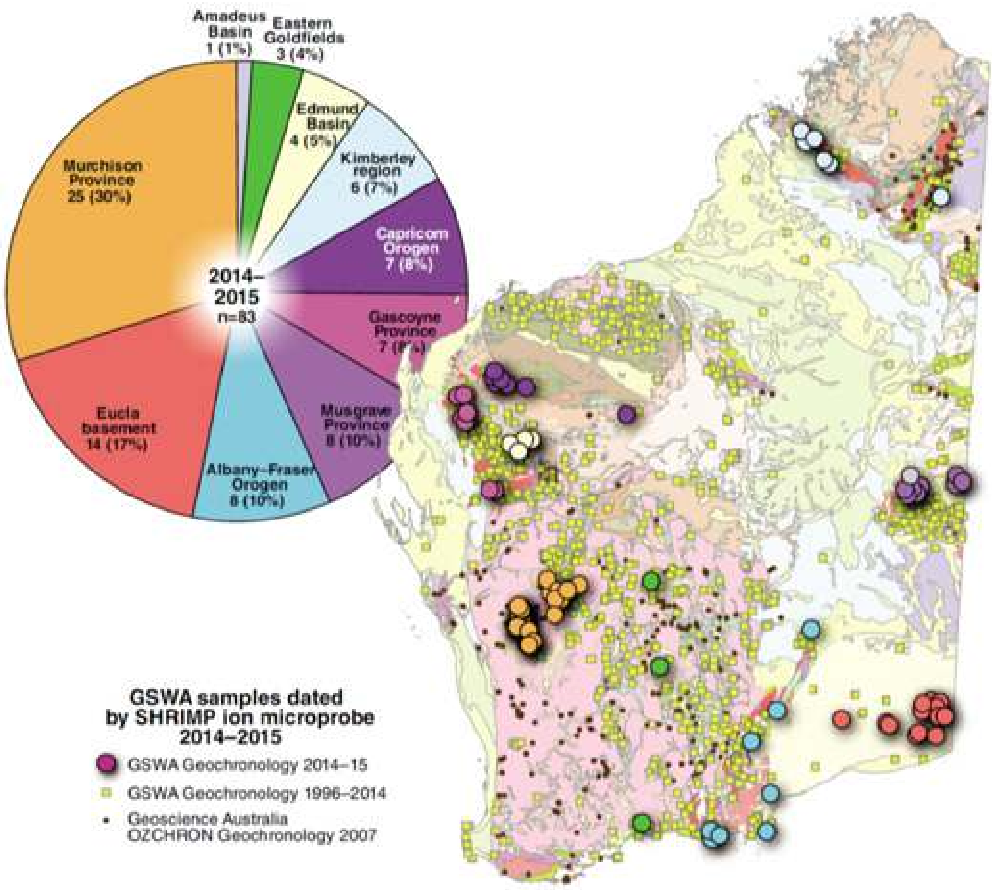
65 NCRIS 2 progress reports

66 NCRIS 2 progress reports, ECE program, Curtin University Q4 2011

67 Discussion with Professor Brent McInnes, Curtin University, 2 February 2015

The research and analysis undertaken at these facilities is varied. The Geological Survey of WA is a major user of SHRIMP in the John De Laeter Centre – for example, in 2014-15 GSWA geochronologists analysed about 80 rock samples for uranium–lead (U–Pb) dating by using these facilities, for subsequent publishing of geochronology records by GSWA. These samples were dated in support of GSWA geoscience programs in the west Musgrave and Gascoyne Provinces, the Murchison and Eastern Goldfields regions of the Yilgarn Craton, the Albany–Fraser Orogen, the Kimberley, Edmund, and Amadeus Basins, and in basement rocks beneath the Eucla Basin (see Figure 16).[68]

Figure 16 – Distribution of Geological Survey of WA samples dated by SHRIMP ion microprobe during 2014-15



Source: GSWA 2015, Geological Survey work program for 2015-16 and beyond, Record 2015/1, p.7

There is also evidence that facilities were available to broad research networks – for example, at the Macquarie TerraneChron facility, AuScope-related projects consistently accounted for over 30% of available time, having committed to at least 10% access.[69]

As an illustration, 33 collaborative projects made use of the facility during 2009-10, and 30 publications resulted from use of the infrastructure in that year. Similar numbers of projects continued in subsequent years. Recent users of Macquarie TerraneChron (including participants in collaborative projects) include: [70]

- Australian institutional researchers from Geological Survey of WA, University of WA, Curtin University, CODES University of Tasmania (ARC Centre of Excellence in Ore Deposits), Geoscience Australia, University of Adelaide, University of Newcastle, University of New South Wales
- international institutional researchers from Okayama University (Japan), Russian Academy of Science, GNS New Zealand, Wuhan University (China), Brown University (USA), PanAust (Laos), Academia Sinica (Taiwan), Nanjing University (China), China University of Geosciences
- industry participants First Quantum Minerals Ltd, MMG Ltd, GFM Exploration, Vale Exploration, Phu Bia Mining Limited, Compania Minera Barrick Chile Ltd, Iluka Resources Limited, Geosciences Environment Toulouse.

68 GSWA 2015, Geological Survey work program for 2015-16 and beyond, Record 2015/1

69 NCRIS 2 progress reports, ECE program, Macquarie University. Use for AuScope-related projects were reported as approximately 13% of instrument time (2008, for six months), 37% (2009), 29% (2010), 29% (2011), 42% (2012, for six months).

70 NCRIS 2 progress reports, EDE program, Macquarie University. For instance, these state that resulting from use of the Macquarie TerraneChron infrastructure: for 2013-14, 35 collaborative projects, 3 conferences, 12 publications; for 2014-15, 20 collaborative projects, 9 conferences, 13 publications.

Wider outcomes

While not a direct impact, three of the four research centres[71] funded through this AuScope component formed the ARC Centre of Excellence for Core to Crust Fluid Systems (CCFS) in 2011, led by Macquarie, and the AuScope support likely indirectly assisted this (in that AuScope support has contributed to the range and quality of research and services available from these institutions). This centre has a wide range of interactions with industry and researchers across multiple projects.

6.3 Impacts and benefits – qualitative assessment

Counterfactual

The counterfactual is likely to be that individual infrastructure enhancements would not have occurred via other funding sources, so capacity would continue to be constrained and some types of analysis could not have been conducted (or, at least, not in an efficient manner or achieving the same scientific insights).

Actual

Outcomes suggest the AuScope geochemistry component made possible some new research in a number of areas, and in terms of the UWA ion probe will continue.

With respect to exploration impacts, clearly geochemistry is being used as a tool to develop precompetitive information, with multiple examples. Geoscience agency stakeholders were not able to make a specific attribution as to the relative importance of the geochemistry work in achieving their overall exploration impacts.

Table 9 – Qualitative summary of key uses and impacts of Earth Composition and Evolution

Impact area	Contribution	Nature of impact and benefit
Fundamental Earth science	Major	Enhanced knowledge of geochronology, composition early life
Resource exploration	Major	Reduced cost of comparative data Shorter period of exploration and discovery through better targeting
Natural and built environment	Medium	Improved understanding of early life on Earth and composition of organic samples
Spatially-sensitive industries	-	-
Other	-	-

71 All except the University of Melbourne facility

Using SHRIMP geochemistry infrastructure to identify geochronology of iron formations in Western Australia

A recent research project by Curtin University, the University of Western Australia, the Geological Survey of Western Australia and the University of Manitoba linked the synchronous deposition of giant iron ore deposits in WA and Canada to a 1.88 billion year superplume event. This provided a possible explanation for the reappearance of major iron formations, long after the rise in atmospheric oxygen about 2.4 billion years ago, which should have ended their deposition.

Part of the method included zircon U-Th-Pb analysis of zircon carried out using a SHRIMP at the John de Laeter Centre at Curtin University, to which AuScope contributed technical staffing support.

Banded Iron Formation (BIF)

Most iron formations were deposited before free oxygen first accumulated in Earth's atmosphere about 2.4 billion years ago (the so-called Great Oxidation Event), and are characterised by interlayering of iron and silica-rich bands. However, after a gap of about 500 million years, major iron formations re-emerged, mostly composed of iron-rich granules and silica.

The re-occurrence of major iron formations about 1.9-1.8 billion years ago in WA and Canada has been unexplained, as the build-up of oxygen after the Great Oxidation Event should have prevented iron formations from developing. It was uncertain whether the younger, post-oxidation iron formations provided information about the composition of the global ocean or conditions in restricted or closed basins.

Researchers identified centimetre-thick beds of volcanic ash in drill cores from the Frere Formation in the Earaheedy Basin, between the Archaean Pilbara and Yilgarn Cratons in Western Australia.

Using SHRIMP, they were able to date zircon crystals in the ash beds to show that the Frere Formation was deposited at the same time as the iron formations in North America. This suggested the deposition of iron formations on two different continents was synchronous 1.9 billion years ago and probably reflects the composition of the global ocean.

Precise geochronology of the chemistry of sedimentary and volcanic rocks helps to understand the relationships between the chemistry of the hydrosphere and atmosphere, and the deep Earth, which can provide insights into significant changes in the evolution of the Earth.

Sources: B. Rasmussen, I.R. Fletcher, A. Bekker, J.R. Muhling, C. J. Gregory, A.M. Thorne 2012, "What a difference a date makes: global deposition of iron formations in response to mantle superplume volcanism", published as a letter, Nature, 484, 498-501 April 26, 2012; UWA Centre for Microscopy, Characterisation and Analysis annual repot 2011 – 2012

Key points

- To end 2013-14, State and Territory geological surveys have cumulatively scanned 687 km of drill core (over 2,340 cores).
  - This represents at most 10% of total length currently held in state core libraries, nationally. Cores continue to be generated, needing further and ongoing scanning to keep pace.
  - A key use of HyLogger scanning has been for major collaborative research projects, and the scanning of core newly ingested from exploration co-funding programs (as opposed to historical core) is becoming increasingly prominent
  - There appears to be some under-utilised capacity on the HyLoggers, in aggregate – which is driven by interest and operational resources in each jurisdiction
  - Understanding and adoption is variable across the geoscience community.
  - The Geological Surveys have a strong comprehension of the strengths of the technology, evidenced by their utilisation and the Surveys' co-investment.
  - Through projects, researchers in university and government are becoming more familiar with the technology, what it can tell us about the crust, and what greater meaning can be generated through interaction with other technologies (e.g. soil geochemistry), and the resultant value.
  - Academic research utilisation of HyLogger and NVCL includes, in 2014-15, 86 refereed publications/conference papers/abstracts, and in 2016 a special issue of The Australian Journal of Earth Sciences devoted to NVCL outputs and findings
  - The exploration industry is in the initial stages of adopting the technique into their 'toolkit'. In part due to the low density of scanned boreholes allowing regional interpretation. In contrast, there are already commercial competitors for the delivery of onsite scanning of core from new boreholes.
- Scanning core and making the data web-accessible are two different actions. Greater webbased access to data is only now starting to become available to any significant degree. As more becomes online, and as hyperspectral data becomes understood, usage would be expected to grow.

7.1 Scope and outputs

Scope

The National Virtual Core Library (NVCL) component of AuScope aims "to progressively build a high resolution image of Earth materials and properties for the upper 1-2 kilometres of the Australian continent"[72]. It does this through scanning, interpreting and digitally publishing mineralogical and image scans from historical and new drill cores[73]. Specifically, the NVCL has involved:

- each of the seven State and Territory geological surveys[74] hyperspecturally scanning (a portion of) archived drill cores using a CSIRO-invented automated instrument (HyLogger) – plus scanning explorers own new drill cores where requested
- processing, analysis, visualisation and generation of interpretation products utilising TGSCore software[75] (also developed by CSIRO)
- availability of high resolution hyperspectral data and corresponding photo-logs of scanned drillcore, combined with bore hole data including GIS (including through the AuScope Discovery portal)

Key inputs have included AuScope funding for the HyLogger equipment (and some transport of cores), supported by State and Territory Government funding of their operational staffing.

Outputs

Through AuScope, the HyLogger infrastructure has been deployed across seven (currently six) locations. HyLogger-2, configured for oxide and hydrous silicate mineral characterisation, was initially rolled out to each geological survey. A subsequent upgrade to HyLogger-3 also allowed for thermal infrared sensing.[76] HyLoggers can operate at around 1 metre per minute (logging between 250 and 500 metres of core per day[77]), collecting physical and chemical data at a spatial resolution of approximately 10mm.[78] HyLogger returns voluminous whole-of-drillhole measurements, compared with individual point sampling done with hand-held devices.[79] AuScope assessed that no other system currently available could provide the high throughput, operational and integrated capability of the HyLogger.[80]

72 AuScope 2006, "NCRIS Investment Plan for Structure & Evolution of the Australian Continent", p.21

73 Drill cores are the sample of the top 1-2 kilometres of the continent produced by core drilling. These were mostly made by explorers and submitted to geological surveys as per exploration legislation requirements.

74 In NSW, Victoria, Queensland, WA, SA, Tasmania and the NT, and to a minor extent in Victoria.

75 The Spectral Geologist (TSG), see http://www.thespectralgeologist.com/

76 AuScope 2014, AuScope NCRIS Program 2007-2014, pp.38-39

77 http://www.minerals.statedevelopment.sa.gov.au/geoscience/geoscientific_data/hylogger

78 AuScope 2006, "NCRIS Investment Plan for Structure & Evolution of the Australian Continent", p.43

79 http://www.nt.gov.au/d/Minerals_Energy/Geoscience/Content/File/Docs/NVCL/AESC_02REC202_UnderstandingHyLoggerResponse.pdf

80 Particularly, that "none could be utilised to simply scan and process the volume of material in store in the harsh environments of Australian core libraries nor so rapidly produce output products suited to web delivery". AuScope document on input to Evaluation of NCRIS: Request for information from NCRIS-funded capabilities, Oct 2009, p.14-15

Table 10 –Summary of Implementation Progress/Outputs – National Virtual Core Library (NVCL)

Year	Implementation Progress/ Outputs summary
2006-07	-
2007-08	Prototype HyLogger-2 constructed at CSIRO
2008-09	HyLogger-2 instruments completed and commissioned in NSW, SA, with other five in varying stages of completeness. Draft access policy document being reviewed
2009-10	Remaining five HyLogger-2 instruments completed and commissioned. Hylogger-3 upgrade prototype being developed. Nodes have cumulatively scanned 200km of drill core
2010-11	Cumulatively scanned over 350 km of drill core (nearly 1,000 cores)
2011-12	All seven nodes upgraded to HyLogger-3
2012-13	Cumulatively scanned 565 km of drill core
2013-14	Cumulatively scanned 687 km of drill core (over 2,340 cores) with over 400 scanned holes accessible through webservices.
2014-15	Cumulatively scanned over 763 kilometres of drill core with over 1,300 scanned holes accessible through webservices

Source: AuScope NCRIS Program 2007-2014 and individual year reporting

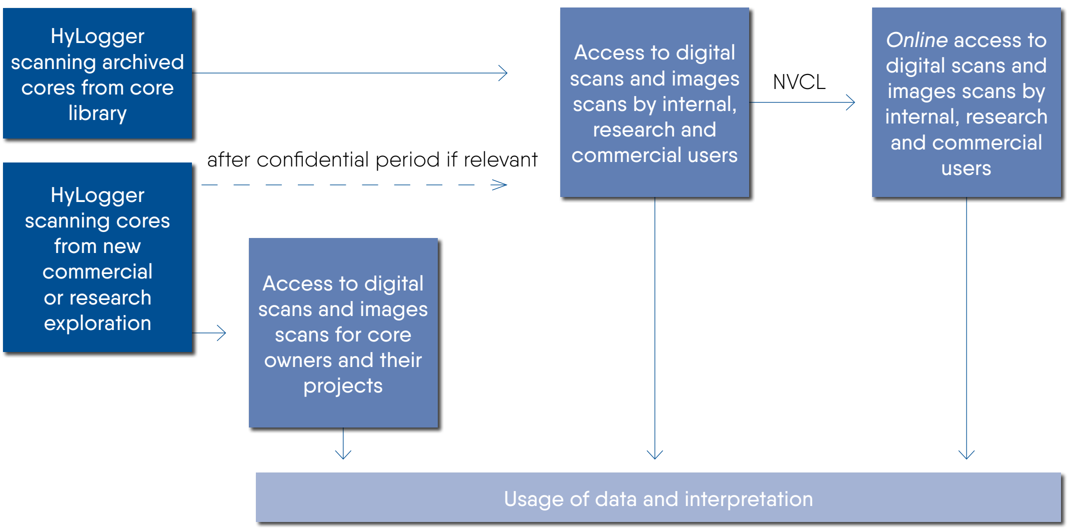
7.2 Nature and scale of usage

Types of usage

Usage of the AuScope-funded infrastructure incorporates a number of different activities – either individually or in combination (see also Figure 17):

- use of HyLoggers to scan archived cores held in geological surveys
- use of HyLoggers to scan new cores generated from research or commercial purposes (aspart of the overall scanning program) and use of resultant data
- use of open-access NVCL scans by internal, research and commercial users

Figure 17 – Ingest of information from HyLoggers and pathway to usage



The specific purposes of usage (e.g. minerals, coal seam gas, geothermal, non-exploration) have varied by location, usually depending on the sort of resource endowments that are more typical in a jurisdiction. The Northern Territory reported NVCL has been particularly useful for correlating stratigraphy for petroleum, however its use for minerals has been variable.[81 82] Queensland considers the use is currently more relevant for minerals than petroleum.

81 Discussion with Ian Scrimgeour, NT, 10 February 2016.

82 http://www.nt.gov.au/d/Minerals_Energy/Geoscience/index.cfm?header=National%20Virtual%20Core%20Library

Demonstrated usage

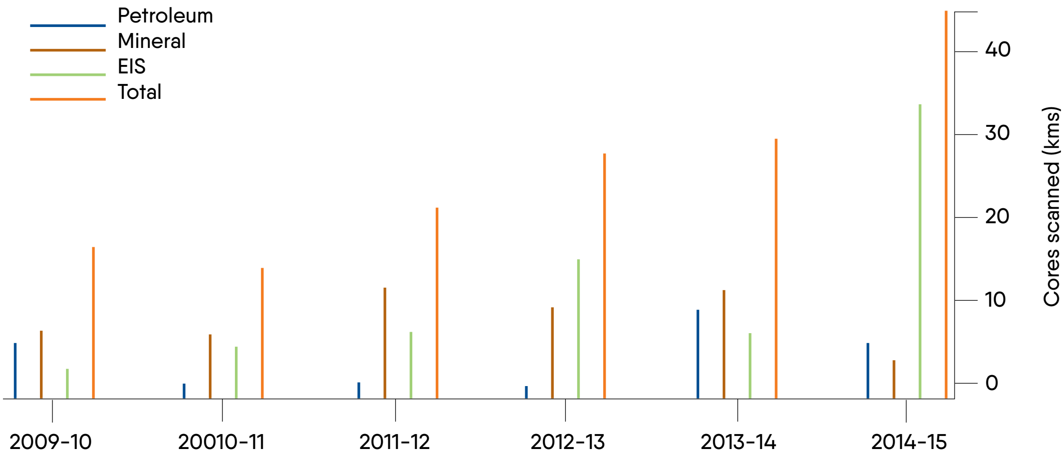
Use of HyLoggers to scan archived cores

The HyLoggers themselves are being routinely utilised. As a rough estimate, the 690 kilometres (690,000 metres) from 2,340 cores scanned to end 2013-14 reflects only around **a tenth** of total length held in state core libraries, nationally (on the basis of one rough estimate in 2009 of total length held being, at that time, of around 8 million metres[83]). (Note that the content of core libraries continues to grow, and probably at a rate faster than cores are being scanned).

There may be spare capacity, in aggregate – KPIs for 2014-15 report 35,345 machine hours of usage and at least 70,000 machine hours available across 6 surveys. The extent of usage is likely driven by allocation of operational resources for each geological survey.

Most of the drill cores scanned to date have been from archived cores, although cores from research projects or derived from state-subsidised exploration (discussed below) are becoming more prominent (see for example, the recent shift in WA to scanning core funded through its exploration funding program, as shown in Figure 18).

Figure 18 – Spectral scanning of core through GWSA HyLogger (Perth), 2009-10 to 2014-15



Source: GSWA 2015, Geological Survey work program for 2015-16 and beyond: Geological Survey of Western Australia, Record 2015/1

Use of HyLoggers to scan cores as part of new exploration or research

Using HyLogger hyperspectral data and image scans as part of new exploration or research has been a conscious strategy by geological surveys to introduce their stakeholders to the insights and precision achievable – to seed projects with "early adopters" and to assist them to understand how this differs from physical logs or other techniques.

This has taken a number of forms:

- major collaborative research projects with government or university funding, or other statesponsored exploration[84], with scanning for a specific purpose (and any new cores and resultant scans also forming part of the NVCL, after a period of confidentiality)[85]
- to a lesser extent, companies and researchers testing their own core (not as part of collaborative projects).

HyLogger data from new and sometimes historical cores have also been used as part of major collaborative projects, many involving industry and being used to test technology integration – possibly as many as 100 projects.[86]

Effectively, researchers can request particular cores to have priority. [87] For example, in 2014-15, drill cores were sourced from various remote sites across Australia, including Broken Hill, Mount Isa Inlier, Pilbara, Centralian Basins, Tennant Creek and the Tasmanian West Coast Mines, tying in with research projects conducted by universities, geological surveys and/or CSIRO, such as the Capricorn Distal Footprints Project or the Broken Hill Exploration Initiative. The HyLogged drill cores served as reference drill holes for detailed geochemical, isotopic and hyperspectral analysis or were used for integration with geophysical and remote sensing data. [88]

83 Estimate of 8 million metres (8,000 km) of drill core held by surveys in AuScope Investment Plan, p.42 and referred to in Brace M 2009, "Australia's minerals go on", Earthmatters, March/April, p.7

84 For example, the WA Government's EIS (Exploration Incentive Scheme) or South Australia's PACE (Plan for Accelerating Exploration) or Queensland's Greenfields 2020.

85 http://www.dmp.wa.gov.au/Geological-Survey/HyLogger-spectral-scanner-396.aspx

86 Under NVCL Operations, FY2015 KPIs indicate '102 project so far' with respect to the number of collaborative projects involving industry.

87 http://www.dmp.wa.gov.au/Geological-Survey/HyLogger-spectral-scanner-1396.aspx

88 Quarterly reports Q4 2015 NVCL

For example:

- GWSA, Minerals Research Institute of WA, and CSIRO undertaking over 2013-2015 a prospectivity study of Volcanic Hosted Massive Sulphide (VHMS) potential in the Yilgarn Craton in WA to establish vectors to mineralization
  - involving a deposit-scale study of Nimbus Zn-Ag(-Au) deposit, deposit- to camp-scale study of VHMS mineralisation at Erayinia, and a regional-scale study of the SE Gum Creek greenstone belt.
  - making use of drillcore acquired through state funding support, HyLogger data, petrography, scanning electron microscope (SEM) work, soil geochemistry, U-Pb zircon geochronology, geology and geophysics to establish vectors to mineralization.[89]
- CSIRO and GWSA undertaking integrated spectral mapping of Au-hosted mineralization at the Nanjilgardy Fault in WA
  - through processing and cross-calibrating HyLogger-3 visible, shortwave infrared and thermal infrared spectral data (from 24 drill holes, most donated by Sipa Resources) and remote sensed ASTER[90] data to develop a 3D mineral map of the Mount Olympus area, Turee Creek/Ashburton Basin.
  - Comparison of HyLogger-3 data with ASTER surficial data for Mount Olympus suggests that potential gold-related alteration or structural indicators might be identifiable.
  - In general this project concluded that the HyLogger-3 and remote sensing data such as ASTER provides a strong platform to develop a spectrally-derived, 3D-mineral mapping approach to add value to precompetitive spectral data.[91]

Actions to broaden familiarity with the HyLoggers and the resultant data are generally seen as useful for their own purposes, and also a stepping stone to greater industry and researcher utilisation of NVCL historical scans. Geological surveys have encouraged interested parties to utilise the HyLogger technology.[92] Demonstrated commercial use of HyLoggers (with purposes varying) includes, as examples:

- in Queensland, QGC, Buka, Anglo American Coal, Santos, Origin Energy, Arrow Energy, Central Petroleum, Evolution Mining, Cuesta Coal and Active Ex.[93]
- in Tasmania, Macquarie Harbour Mining, Metalstocks Australia, Shree Minerals, Venture Minerals, Copper Mines of Tasmania, MMG (Minerals and Metals Group), Metals X, Bass Metals and Unity Mining.[94]

The HyLogger capability has also been applied to other sectors. Although uses are minimal compared to exploration, some 'proof of concept' examples are below:

- analysing soil profiles in an agricultural context, in a manner that is faster and more comprehensive than traditional soil analyses.[95]
- analysing Aboriginal cultural heritage materials to differentiate types of mineral pigments used and contribute to knowledge about historical Aboriginal life pigments[96]
- efficiently analysing drill cores from different areas of the Launceston area prone to landslides, to correlate rock layers and layering (stratigraphy) – with the aim to ultimately input to assessment of landslide susceptibility used by town planners to avoid unstable areas when new subdivisions are being proposed (Minerals Resources Tasmania)[97]

Access to archive NVCL scans for research and commercial purposes

In concept, NVCL provides easier access for researchers and explorers to data on the mineral composition of drill cores held by State and Territories Geological Surveys, when compared to physical access to raw (i.e. unanalysed) core material scattered in warehouses around Australia.

Currently, full datasets are typically available off-line by application by users to the relevant survey agency. Some datasets and interpretation have been made available in relational databases on geological survey websites and/or through the AuScope portal. Scanned data is only now starting to become accessible online – for example, holes accessible through web services increased substantially from 400 in 2013-14 to 1,300 in 2014-15. (This may not include full HyLogger data, which is typically currently available via an approach to geological surveys). Online availability is not uniform across states, influenced in part by operational resources that have been available for this purpose.[98]

Anecdotal feedback is that there is some nascent use of online material, although this has not been tracked systematically.[99] It is unclear how to interpret the measures under the KPIs related to requests for access to infrastructure or access, and they may not be reliable.[100]

89 'GSWA collaborative research' internal document, June 2015, p.6 (document pages unnumbered)

90 ASTER (Advanced Spaceborne Thermal Emission and Reflection radiometer) is a high efficiency optical sensor which covers a wide spectral region from the visible to the thermal infrared by 14 spectral bands.

91 GSWA 2016, 'Integrated Spectral Mapping of Precious and Base Metal Related Mineral Footprints, Nanjilgardy Fault, Western Australia', report 156

92 For example, in 2012 Shree Minerals used the HyLogger in Tasmania to prioritise its drilling in the Sulphide Creek area as part of a mineralogy study, with spectral logging via the HyLogger to establish hydrothermal alteration halos in the tenement of 1,075 metres of core from 6 drill holes. A spatial association was observed between the gold assays and spectroscopic signatures of an alteration mineral assemblage comprising dickite plus hematite, minus white mica and kaolin, occurring at a boundary (gradient) in mica chemistry composition, which was poorly tested by much of the previous drilling. See http://www.shreeminerals.com/downloads/ifrhy31dec2012.pdf

93 Discussion with Mark Thornton, Queensland, 10 February 2016

94 Discussion with Andrew McNeill, Mineral Resources Tasmania, 12 February 2016

95 http://www.adelaide.edu.au/environment/lfp/research/aglandsproj2.html

96 Popelka-Filcoff RS, Mauger A, Lenehan CE, Walshed K and Pringe A 2014, "HyLogger™ near-infrared spectral analysis: a non-destructive mineral analysis of Aboriginal Australian objects", Analytical Methods, 2014,6, pp. 1309-1316

97 Discussion with Andrew McNeill, Mineral Resources Tasmania, 12 February 2016

98 For example, Queensland has made around 6 holes online of the approximately 600 scanned.

99 Mid-term Review report 2009, p.18: "The VCL group needs to track who is using the VCL database, and how it is being used. Educational use is valid and valuable and should be monitored. Examples of industry or state governments using the data would also be helpful." We are not aware of consolidated information on who is using the database and how they are using it is available.

100 For example, the 2013-14 KPIs report 238 industry users of HyLoggers (across 6 nodes) and the 2014-15

Summary usage metrics

This new technology is still in the uptake stage – we are not yet at maturity with researcher and industry use of hyperspectral data and imaging, nor with availability of digital NVCL information across the breath core libraries. Currently, due to the outputs to date and the nature of usage, impacts are mainly arising from new core or archived core in the content of research projects. One jurisdiction called the rate of uptake "slow but steady", noting that industry can be conservative with technology.

The scale of NVCL content is expected to continue to grow over time, to the extent that geological surveys continue to allocate resources to scanning archived cores and cores drilled by private operators are ingested into the NVCL. The quantity of data in the NVCL – and particularly the quantity available to be interrogated via the web – will likely increase over time as geological surveys continue to scan and process material.

While the exact form of usage is not always clear[101], some key usage metrics reported through AuScope include for 2014-15:[102]

- 64 or more collaborations across 6 geological surveys (p.2)
- 176 direct requests for data [access to infrastructure] from 10 or more Australian agencies and 3 overseas agencies. (p.3), and multiple requests for data from 67 industry users. (p.3)
- 35,345 machine hours of usage and at least 70,000 machine hours available across 6 surveys to the end of Q4 FY2015 (p.1)
- 102 'collaborative projects involving industry' listed so far (pp.3-4)

7.3 Impacts and benefits – qualitative assessment

Counterfactual

The assumed counter-factual is use of other techniques to analyse some aspects of core samples, although in a manner not necessarily conducive to ongoing data discovery. Possibly alternative technology could be further developed that achieves some of the capability of HyLoggers.

Actual

The impacts and benefits arising from use of the HyLoggers and the NVCL described above are various, summarised in Table 11.

Fundamental Earth science

Academic research utilisation of HyLogger and NVCL includes, in 2014-15, 86 refereed publications/ conference papers/abstracts,[103] and in June 2016 a special issue of The Australian Journal of Earth Sciences published at the Australian Earth Sciences Convention devoted to NVCL outputs and findings. [104] There is early evidence that new research never previously able to be done is arising through having access to continuous spectral logging data, particularly thermal infrared spectral data.[105]

Table 11 – Qualitative summary of key uses and impacts of NVCL/HyLogger

Impact area	Contribution	Nature of impact and benefit
Fundamental Earth science	Major	Enhanced knowledge of upper crust
Resource exploration	Major	Reduced cost of acquiring upper crust data (e.g. avoided costs of manual logging, avoided costs of physical interrogation of existing core, less drilling) Shorter period of exploration and discovery through better targeting
Natural and built environment	Minor	Efficiencies in assessing soil profiles and groundwater for agriculture or environment, or climate change analysis
Spatially-sensitive industries	-	-
Other	Minor	Other purposes such as understanding Aboriginal cultural heritage Avoided storage costs (possibly, not certain)

101 Mid-term Review report 2009, p.18: "The VCL group needs to track who is using the VCL database, and how it is being used. Educational use is valid and valuable and should be monitored. Examples of industry or state governments using the data would also be helpful." No consolidated information on who is using the database and how they are using it is available.

102 NCRIS2 KPIs Summary, FY2015, p.3

103 NCRIS2 KPIs Summary, FY2015, p.3

104 http://www.minerals.statedevelopment.sa.gov.au/geoscience/geoscientific_data/hylogger

105 AuScope document on input to Evaluation of NCRIS: Request for information from NCRIS-funded capabilities, Oct 2009, p.2

Resource exploration

The main tangible area of benefit – as with the other areas of AuScope focussed on pre-competitive exploration data – is reduction of exploration risk of a given exploration process. It does this through increasing the productivity of exploration through more efficient (less labourintensive and therefore less costly) mechanisms for researchers and explorers to access mineral composition data to influence their decisions on targeting subsequent exploration activities. This relates to either or both:

- new core samples via directly using the HyLogger – compared to manual logging[106] or other less efficient or effective techniques; and
- extant core via NVCL online metadata or data – when compared to only physical access to raw (i.e. unanalysed) core material scattered in warehouses around Australia, allowing an overall reduction in cost to identify and access information of interest.[107]

As both more NVCL data is available (in digital form and, additionally, online)[108] providing a more comprehensive picture of Australia's shallow crust, and as the user community becomes more familiar with interpreting and using HyLogger information, it can be expected that the impacts arising from extant core (by itself or in combination with new core) will grow.

Some strong potential for substitution and efficiencies through digital access into the future is demonstrated by current demand for core itself. For example, GSWA Perth core library laid out about 100 kilometres (100,000 metres) of core in 2014-15 or 2,000 pallets[109]. With respect to minerals, there has been an approximate doubling of pallets viewed inside the library to about 500 per year over the five years to 2014-15. However, under existing resources there will continue to be a large backlog of archived drill core, and the backlog will grow over time if (as is currently the case) the amount of core newly acquired (and not yet scanned) each year exceeds the amount of core scanned each year.

There is a general view across the geological surveys that the HyLogger and NVCL are best considered one part of the package of exploration tools. Attribution of impact is challenging – is not necessarily feasible to isolate the impact of HyLogger/NVCL from other geoscience information. The multiplicity of contingent factors and confidentiality of commercial decision-making also means that the relative importance of HyLogger/NVCL may never be known.

Other

As described in section 3.2, there are already some small examples of usage and associated benefit of HyLoggers or NVCL or both outside of geoscience (e.g. salinity and soil investigations, Indigenous cultural use of minerals). Possible other uses include for research in paleoclimate and early life, climate change (Earth-history studies) and geobiology (astrobiology).[110] Future usage in these sectors would depend on understanding of the NVCL and accessibility of information for the purposes they seek.

A potential future impact is the scanned core data replacing the physical cores, such that there is no longer a need to store the actual drill cores. The avoided cost of physical storage would be a benefit to geological surveys (and potentially private companies if they also store cores). We understand there is no change along these lines envisaged at this stage, but it may emerge as the technology matures.

106 Note that manual logging, assumed at 8 metres per day, is not a direct substitute (e.g. does not involve spectroscopy).

107 Some physical access may still be needed or desired, but digital access can substantially reduce the extent of this.

108 There is somewhat of a network effect involved in the NVCL – the more core material is scanned and becomes accessible, the more useful the NVCL library as a whole will be.

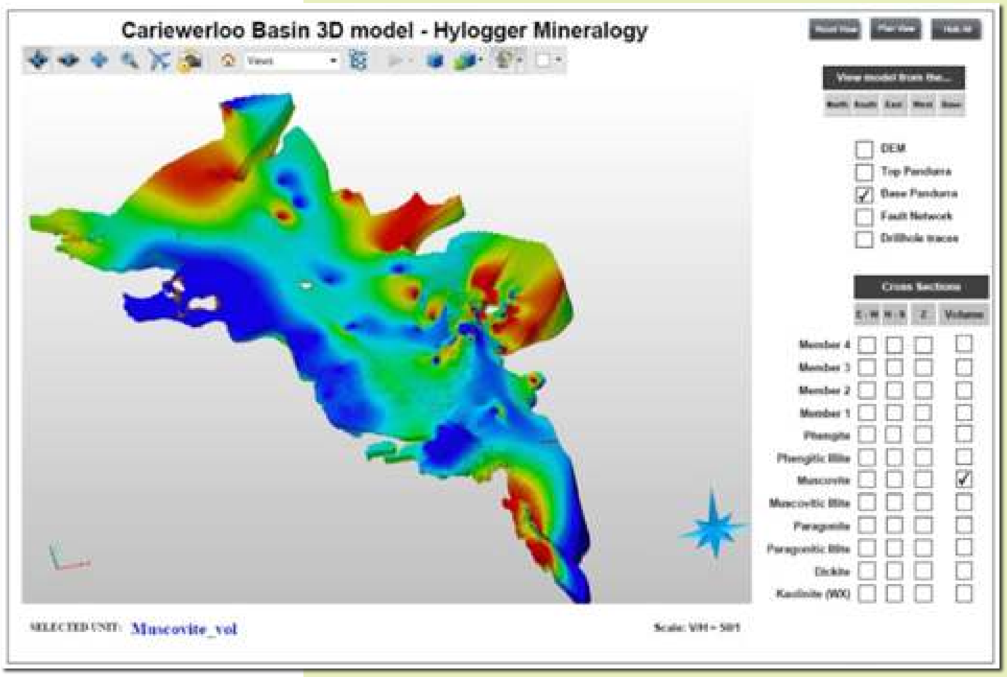
109 GSWA 2015, Geological Survey work program for 2015-16 and beyond: Geological Survey of Western Australia, Record 2015/1

110 Mid-term Review report 2009

Using HyLogger to develop unconformity-related uranium exploration

Australia is the world's third largest supplier of Uranium after Canada and Kazakhstan. South Australia hosts four of Australia's six uranium mines, which in the decade 2004-2014 contributed more than $3 billion in export revenue to the South Australian economy. The Olympic Dam mine in SA is the world's largest known Uranium deposit. The Olympic Dam province is hematite-rich granite breccia complex in the Gawler Craton containing iron, silver, copper, gold and uranium. Following the success of the Olympic Dam province, Uranium exploration in South Australia is typically focused on similar formations.

Historically, however, 80% of Australia's Uranium production since 1980 originated in unconformityrelated ore-bodies such as Ranger #1 and Nabarlek. Unconformity-related deposits constitute approximately a third world production, with Canada's production from unconformity-related deposits from the Athabasca Basin in Saskatchewan.



Source: Wilson T., Uranium and uranium mineral systems in South Australia Report Book 2015/00011, Geological Survey of South Australia, 2015; T Wilson et al 2010, "Uranium: The search for unconformity-related uranium mineralisation in the Pandurra Formation, South Australia: an international multidisciplinary collaboration", MESA 9 Journal 58 September 2010; Aden D. McKay & Yanis Miezitis 2007, "Australia's Uranium Resources, Geology and Development of Deposits", Geoscience Australia. http://www.minerals.statedevelopment.sa.gov.au/invest/mineral_commodities/uranium#uranium http://www.minerals.statedevelopment.sa.gov.au/geoscience/geoscientific_data/3d_geological_models/cariewerloo_basin

The Cariewerloo Basin in SA is analogous to the Athabasca Basin, with potential unconformity-style uranium mineralisation. Geological Survey of South Australia (GSSA) geologists have promoted the uranium potential of the Cariewerloo Basin since similarities were proposed first in the 1990s. Numerous possible sources of uranium exist within the Basin and recent exploratory drilling has found signals of deposits such that the region is considered highly prospective. However the precise locations of the unconformity surface and associated deposit forming processes are unknown.

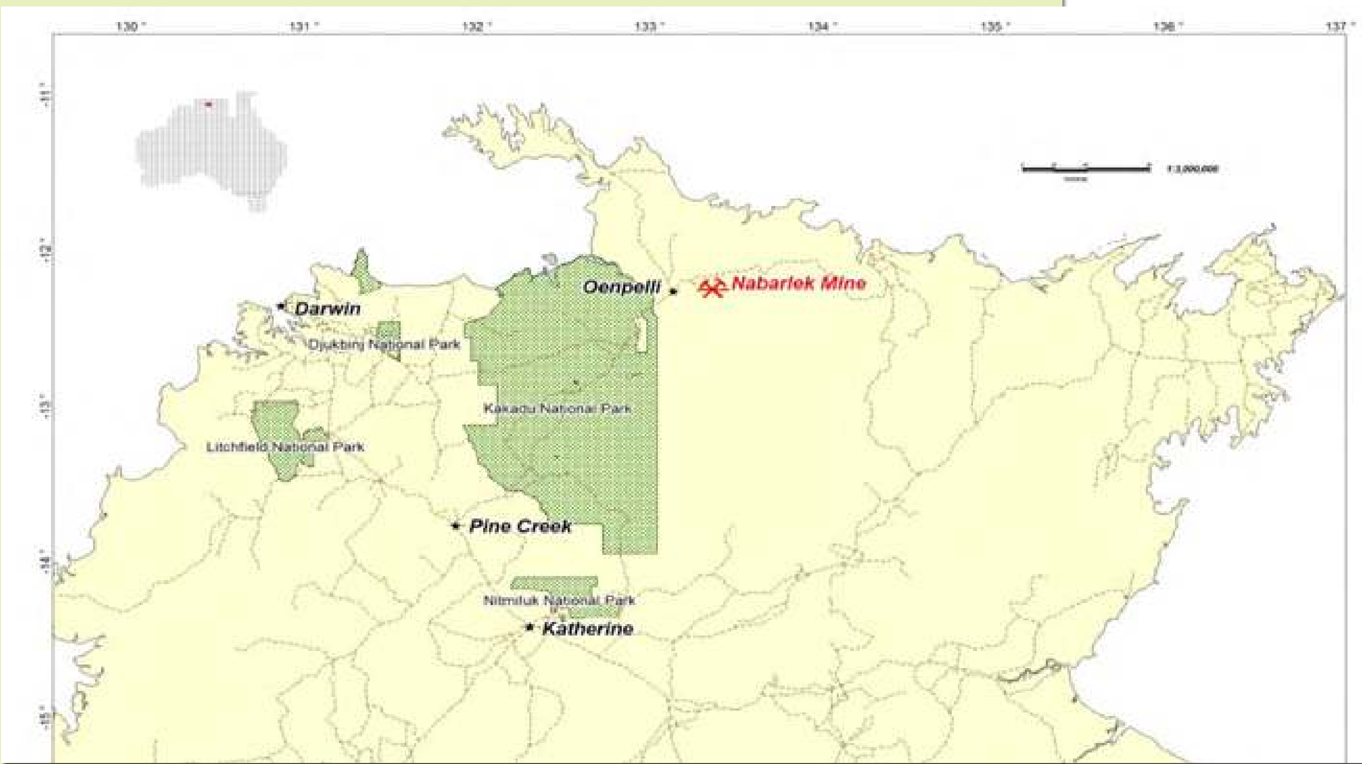
Since 2009 GSSA geologists and the Canadian Saskatchewan Geological Survey of the Saskatchewan Ministry of Energy and Resources have been collaborating to develop mutual understanding of these resources. Geologists have been seconded from each agency to exchange technical capabilities on aspects of geophysics and 3D modelling of these Basins.

A team of geologists from both agencies undertook a multidisciplinary investigation of the in unconformity-related uranium potential of the Pandurra Formation in the Cariewerloo Basin. The project included logging of drill holes using lithostratigraphic techniques from Saskatchewan and hyperspectral techniques available from AuScope's NVCL HyLoggers. Correlation of the lithostratigraphic and hyperspectal data was studied to differentiate subtle variations in secondary alteration mineralisation versus the stratigraphic variation throughout the Pandurra Formation. This stratigraphy and mineralogy data is fundamental to the detailed 3D model developed by the team to provide a robust model of the potential for unconformity-related uranium.

The development of a robust predictive modelling that can delineate areas of interest for uranium exploration is a mainstay of the Geological Survey's program of pre-competitive knowledge development to promote a rewarding resource for South Australia.

Using HyLogger and historical and new cores to identify uranium exploration targets (extensions to mineralisation) in the Northern Territory

Uranium Equities in May 2015 announced that it had identified a rare, near-mine uranium exploration opportunity surrounding the historic Nabarlek Uranium Deposit in the Northern Territory. It identified a 'drill ready' offset target by new analytical data and reassessing existing data, including through short-wave infrared spectral data generated through the HyLogger in the Northern Territory and associated multi-element geochemical data.



Uranium Equities used HyLogger-generated scans of ten historical diamond core holes, including original drilling from the Nabarlek mine site completed by QML between 1970 and 1973, and most recent exploration drilling by Uranium Equities. This data was interrogated to determine whether structurally controlled Nabarlek-style alteration existed under the old Nabarlek pit and if this supported the concept of an 'offset' of the Nabarlek orebody beneath the Oenpelli Dolerite intrusion. The analysis provided a clear vector for the company to target offset mineralisation beneath the dolerite.

Subsequent drilling in August and September 2015 found that the intense alteration and pathfinder anomalism surrounding the silver anomaly are consistent with footwall alteration to the Nabarlek deposit. This suggests the Nabarlek structure extends at depth and north along strike below the Oenpelli Dolerite.

Source: Uranium Equities ASX announcements: "UEQ Identifies Significant New Exploration Target Beneath High-Grade Nabarlek Uranium Mine, NT", ASX announcement by Uranium Equities, 7 May 2015, http://www.asx.com.au/asxpdf/20150507/pdf/42yfh2khl6f62d.pdf; http://www.uel.com.au/wp-content/uploads/2015/03/20150803-UEQ-Nabarlek-Project-Drilling-to-Commence.pdf; http://www.uel.com.au/wp-content/uploads/2015/03/20151007-Drill-Results_JMc_final.pdf

Key points

- Many researchers in Australia and overseas are using AuScope-related Simulation Analysis and Modelling (SAM) tools
  - particularly GPlates and Escript, for applications across a range of Earth science including across (variously) geodynamics, minerals and energy exploration, sustainable management of energy resources, and natural hazards, across both fundamental and applied research
  - some of these applications have industry involvement, or involvement of industryfocussed researchers (e.g. in CSIRO, geological surveys, ARC Linkage Projects)
  - there do not appear to be commercial alternatives that fulfil all the uses of the SAM tools
- Specific uses are not tracked comprehensively and many are not visible to AuScope if they do not directly involve personnel involved in AuScope

8.1 Scope and outputs

Scope

The Simulation Analysis and Modelling (SAM) component of AuScope has been to generate high quality tools for computer simulation, modelling, inversion and data mining[111], and improve accessibility to the processed data, models and other outputs from them. The focus for tools has been geological-related functions that were not well served by 'off the shelf' commercial applications.

AuScope supported further development, documentation and promulgation of various software tools that were, at the commencement of AuScope, in various stages of development or being utilised by small groups of specialists. AuScope also funded powerful computing hardware to use in development.[112]

Outputs

For each of the various SAM tools (see below), outputs involved CSIRO and universities:

- developing a range of updates over time for new features and bug fixes, typically up to 2010-11 (noting that some have continued further development with other sources of funding)
- now collaborating with researchers to integrate the software packages into workflows for various research applications (e.g. geodynamics, exploration, energy, natural hazards)

The software and computational tools in scope included:

- Underworld, a suite of tools to simulate large scale Earth processes such as plate/mantl interaction and basin development – delivered by Monash University.
- ESyS-Particle – for particle modelling, a specialised area with particular application to materials and Earth science – delivered by University of Queensland
- ESyS-Crustal, to model crustal dynamics, with applications including for Earthquake and tsunami prediction modelling, and the modelling of interactions of fracture and heat transfer of geothermal power from hot fractured rocks – delivered by the University of Queensland
- ESyS-Geodynamics, to model large scale geodynamics – delivered by the University of Queensland
- Escript, a programming tool for dealing with complex physical and mathematical problems with applications across a range of sciences and underpinning many of the ESyS elements – delivered by CSIRO and the University of Queensland
- Pplates, a tectonic reconstruction tool for linking plate motion histories with geodynamic, tectonic and surface elevation outcomes – delivered by the Australian National University
- GPlates, a plate-tectonics visualisation package – delivered by the University of Sydney
- Reactive Transport – modelling coupled fluid-flow, heat and mass transport and chemical reactions within the Earth – delivered by CSIRO Inputs from AuScope funding totalled $5.9 million.

8.2 Nature and scale of usage

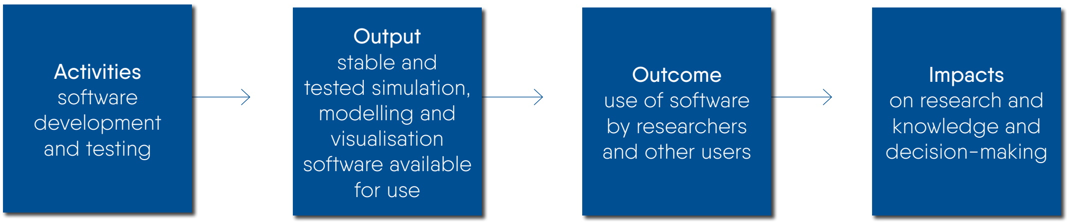
Types of usage

The SAM tools are free and open source. The different tools vary in their direct user communities: for example, GPlates is intended to be relatively accessible desktop software for the interactive visualisation of plate-tectonics, whereas the direct user community for E-sys software is those working with the code itself and therefore smaller and more specialised.[113]

*111 Previous funding initiatives under which software was initially developed include the Australian Computational Earth Systems Simulator Major National Research Facility (ACcESS MNRF) and Predictive Mineral Discovery (pmd*CRC) activities.*

112 For example, to achieve a consistent code base and the development of code with a view to integration and compatibility, rather than optimisation for individual projects.

Figure 19 – Pathways to impact for Simulation, Analysis and Modelling



Demonstrated usage

Stakeholder feedback is that researchers in Australia and internationally are utilising the various SAM products, in applications across (variously) geodynamics, minerals and energy exploration, sustainable management of energy resources, and natural hazards. The universities involved in SAM report also report collaboration with CSIRO, Geoscience Victoria, Geoscience Australia, Geological Survey of NSW and Geological Survey of WA. Table 12 highlights various metrics.

Table 12 – Summary evidence on usage of SAM software

SAM component	Summary evidence on usage
Underworld	Around 30 Underworld users in 2014-15 (by location: 10 international, 20 Australian; by professional status: 15 researchers/government, 15 students)
	6 Australian and 5 international research collaborations in 2014-15 (including 1 industry project via CSIRO)
	10 publications in 2014-15 (as an annual example)
Escript	Around 1,000 software downloads in 2013-14
	2 Australian research collaborations in 2013-14
	7 publications in 2013-14 (as an annual example)
	About 125 results in Google Scholar since 2012 for "escript" and "Earth"
ESys-Particle	Around 700 downloads in 2013-14
	About 84 results in Google Scholar since 2012 for "ESys-Particle"
Pplates	About 12 results in Google Scholar since 2012 for "Pplates"
GPlates	Over 400 subscribers to GPlates newsletter in 2014-15, growing from over 200 in 2013-14[114]
	About 1,530 results in Google Scholar since 2012 for "GPlates"
	About 30 Australian and 15 research collaborations in 2014-15 (including 2 major collaborations with energy industry)
	12 publications in 2013-14 (as an annual example)

Sedimentary basins house energy resources and groundwater, and can be a location for carbon dioxide storage. As well as testing new concepts for understanding basin structures and new digital basin models to improve understanding of geological processes, the Hub has a focus on data delivery, software and visualisation for industry uses – particularly in identifying energy exploration targets in deep basins in remote regions of Australia.[115] Basin GENESIS Hub partners include the University of Melbourne, Curtin University, Geoscience Australia and California University of Technology, as well as industry participants Chevron USA (multinational oil, gas and geothermal company), Statoil (multinational oil and gas company), Oil Search (oil and gas exploration and development company), 3D-GEO (a seismic and structural modelling consultancy) and Intrepid Geophysics (geophysics software and services).[116]

Another example of how SAM outputs have been utilised is a major project assessing non-seismic geophysics for reservoir monitoring of coal seam gas, conducted by the University of Queensland's Centre for Coal Seam Gas and the Centre for Geoscience Computing (in 2014-15 and 2015-16). Industry partners in the project include Santos, QGC, Arrow Energy and Origin.

The coal seam gas industry currently uses various techniques to monitor gas production, pressure and water quality, including by drilling monitoring wells. Wells have drawbacks including cost, land access and that they

114 KPI reporting indicates 49,000 downloads of GPlates to 2014-15, however this appears to be aggregate downloads across all versions so it unlikely to be unique users. Data on downloads suggests the bulk of users are from North America and Europe rather than Australia, which is likely a function of the size of relevant researcher communities.

115 Particularly, the north-west shelf of Australia, PNG and the Atlantic Ocean continental margins.

116 See http://www.Earthbyte.org/the-basin-genesis-hub/.

only provide information for a single location. The project utilised a 3D gravity Escript module, as well as other modelling software based on Escript, to test reservoir performance, shallow groundwater system integrity and reservoir stimulation effectiveness for alternative nonseismic geophysical methods that would be more cost effective, provide more geographic coverage and are less disruptive for landholders. Computer modelling indicated that certain combinations of non-seismic methods, in certain geological conditions, can work effectively and with lower cost, and field trials are now being developed. [117]

8.3 Impacts and benefits – qualitative assessment

Counterfactual

The assumed counter-factual is, with fewer resources, the various SAM tools not being further matured and documented (or on a slower development path), and consequently not being as useful to research users and others.

Actual

Upfront certainty of resources and collaboration across institutions provided through AuScope likely also positively influenced pooling of knowledge and demand across groups and sectors that assisted SAM development. Stakeholders view that this period of development and use, although not solely attributable to AuScope, has led to being able to achieve analysis and knowledge that was not possible a decade ago.

Table 13 – Qualitative summary of key uses and impacts of SAM

Impact area	Contribution	Nature of impact and benefit
Fundamental Earth science	Major	Greater knowledge of large scale Earth processes and geodynamics
Resource exploration	Major	Shorter period of exploration and discovery Reducing uncertainty for areas with unknown or insufficiently known mineral or energy prospectivity
Natural and built environment	Medium	Greater knowledge of natural hazard dynamics informing mitigation
Spatially-sensitive industries	-	-
Other	-	Uptake of SAM tools globally, not just in Australia

As highlighted above the areas of actual and expected future impact arising from geoscientific modelling assisted by SAM cover a broad range of areas, including but not limited to:

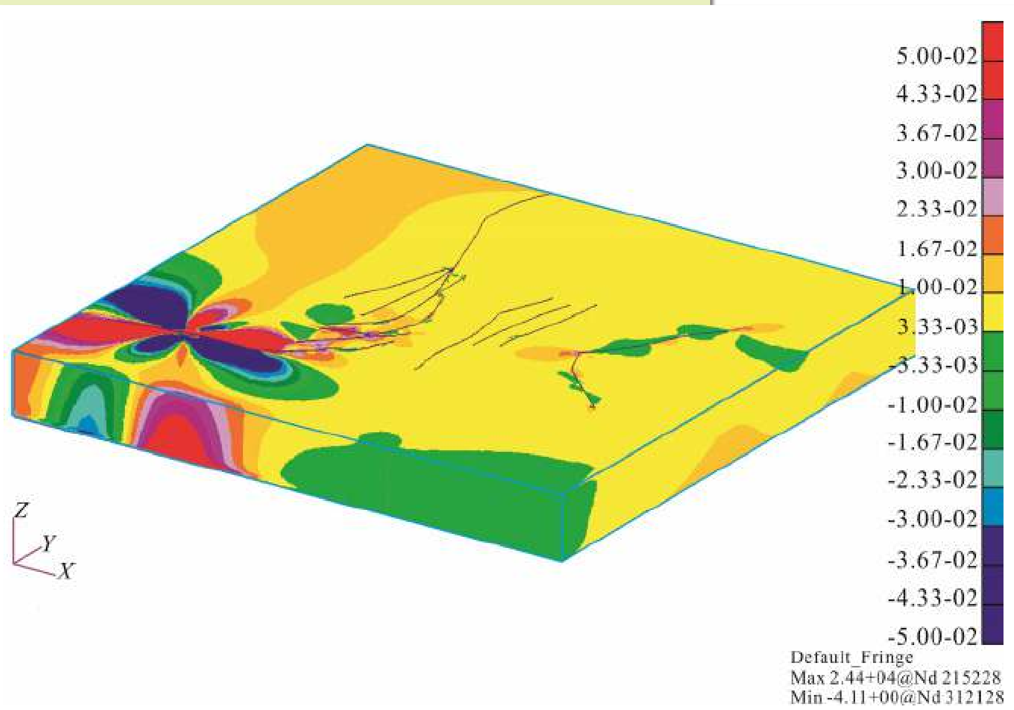
- minerals, oil and gas and geothermal exploration and sustainable management – through understanding of Earth processes and their influence on the spatial location and formation of all Earth resources, as well as thermal, mechanical and fluid transport modelling for energy resources
- natural hazards – assisting risk management and community wellbeing through building a better understanding of Earthquakes and tsunami generation, hazardous waste storage, natural variations relevant to climate change, salination causes, soil development, etc.

117 See http://www.ccsg.uq.edu.au/Research/Geoscience/Modellingnonseismicgeophysics.aspx and http://www.ccsg.uq.edu.au/Portals/0/docs/2014-poster-non-seismic-geophysics.pdf

Assessing geotechnical risk in geothermal areas using ESys computation

A recent research project by Curtin University, the University of Western Australia, the Safety is obviously a key consideration in mining development. Geotechnical risk assessments in mining and other contexts often use numerical models as predicative tools. However calculating the risk of steam outbursts, release of harmful gases, boiling or geysering water in production blastholes resulting from heat and mass flow in geothermal systems is beyond most software systems.

Hydrogeologists from Coffey Geotechnics Pty Ltd partnered with academics from the Earth System Science Computational Centre, University of Queensland, to deploy the finite element methods of ESyS_Crustal to solve the large system of coupled, nonlinear differential equations describing heat and mass flow in a geothermal system taking into account phase transition of condensable fluids as well as for transient boundary conditions of an open-cut mine pit.



A snapshot of the equivalent stress rate distribution simulated by using PANDAS/ESyS_Crustal (the black lines inside are the faults) (Xing and Mora, 2006)

The resulting code was demonstrated for risk analysis of geothermal hazards during mining in hot ground at the Kapit Pit extension of the Lihir Gold Limited open-cut gold mine. The mine is located in a geothermal active caldera on Lihir Island, in the New Ireland province of Papua New Guinea. The region is geothermally active with surface manifestations including acid sulfate hot springs, neutral chlorite springs, mud pools and low temperature fumaroles.

The model found that steam did not develop after deepening the pit by 90m despite computed temperatures exceeding 100 degrees Celsius due to high hydrostatic pressures, and demonstrated the practical utility of the method for assessing geotechnical risks such as pit wall stability, the likelihood of geysering water from blasts and the efficiency of steam release wells.

The partnership between Coffey Geotechnics and University of Queensland developed into an ARC Linkage project to employ ESyS_Crustal to model geomechanical-fluid flow-thermal systems in fractured geomaterials to support facility design, construction, risk assessment and production of Hot Fractured Rock (HFR) geothermal energy technology.

This case study exemplifies how geoscience software developed with academic applications in mind can be adapted and developed to unforeseen but (by definition for industry) valuable applications that lead to ongoing collaborations.

Sources: Bringemeier D., Wang, X, Xing, H. L. and Zhang, J (2010). Modelling of Multiphase Fluid Flow for an Open Pit Development within a Geothermal Active Caldera, Proceedings of the 11th International Association for Engineering Geology and the Environment (IAEG) Congress, Auckland; http://www.auscope.org.au/geothermal-demonstrators/

Key points

- Spatially based sciences are a growth area with applications in a broad range of fields
- The technology for positioning is evolving rapidly, and the span and reach of geospatial applications are becoming increasingly important across a wide range of industrial users and, with the proliferation of smart phones, nearly every person.
- There is already strong evidence that the new VLBI infrastructure funded through AuScope has contributed to a substantial improvement to positioning accuracy and repeatability in the southern hemisphere, to be now equivalent to the northern hemisphere.
- AuScope infrastructure will be a key contributor to the new national reference frame in development (GDA2020), replacing GDA1994, that will support emerging societal and geospatial needs.
- The location and distribution of AuScope-funded CORS infrastructure does not to tend to optimise real-time precise positioning for commercial/industrial applications in all cases (as that is not its primary purpose). However, future technology achieving precise results with sparser networks may make greater use of AuScope CORS infrastructure for this purpose.

9.1 Scope and outputs

Scope

The AuScope Geospatial and Earth Dynamics component ($15.5 million NCRIS funding, plus partner contributions) aimed to establish and operate national geodetic infrastructure to a substantially greater level of accuracy and time resolution.[118] (See section 2.4 for discussion of intent and purpose). Essentially the scope is to provide the means to better capture changes in the Earth system at current timeframes.

It included four complementary infrastructure elements that, collectively, enhance the geospatial system:

- three elements to calibrate the geodetic framework:
  - Very Long Baseline Interferometer (VLBI) to calibrate the terrestrial reference frame to the celestial reference frame;[119]
  - Satellite Laser Ranging (SLR) to recalibrate the terrestrial reference frame due to the variation of Earth orbiting satellites from their predicted orbit, and coordinating different positioning (GNSS[120]) networks;[121]
  - Gravity Measurement (GM) linking the Cartesian coordinate framework with the dynamic height system, enabling satellite height measurements of the geoid (hypothetical level water surface).[122]
- one GNSS augmentation system:
  - expanding the network of Continuous Operating Reference Stations (CORS) across parts of Australia – in part, intended to improve the local accuracy, robustness, and signal availability of spatial positioning through acquiring, processes and distributing real-time positioning information across a geographic region.

Calibration of the reference frame is important in its own right, and local positioning techniques also rely on the calibration.

Outputs

The outputs delivered from this component, over time, are summarised below.

Calibration

Very Long Baseline Interferometer (VLBI)

Outputs included construction of two new radio telescopes at Yarragadee (WA) and Katherine (NT) and a replacement for the existing but ageing Hobart system (Figure 20), as well as software correlation[123] to process data from the array. Operational observations commenced in 2011-12, and by 2014-15 the regular observation program included 235 days. All data from the AuScope VLBI array is publically available via the International VLBI Service.

118 AuScope 2006, "NCRIS Investment Plan for Structure & Evolution of the Australian Continent"

119 http://www.cpi.com/projects/vlbi.html

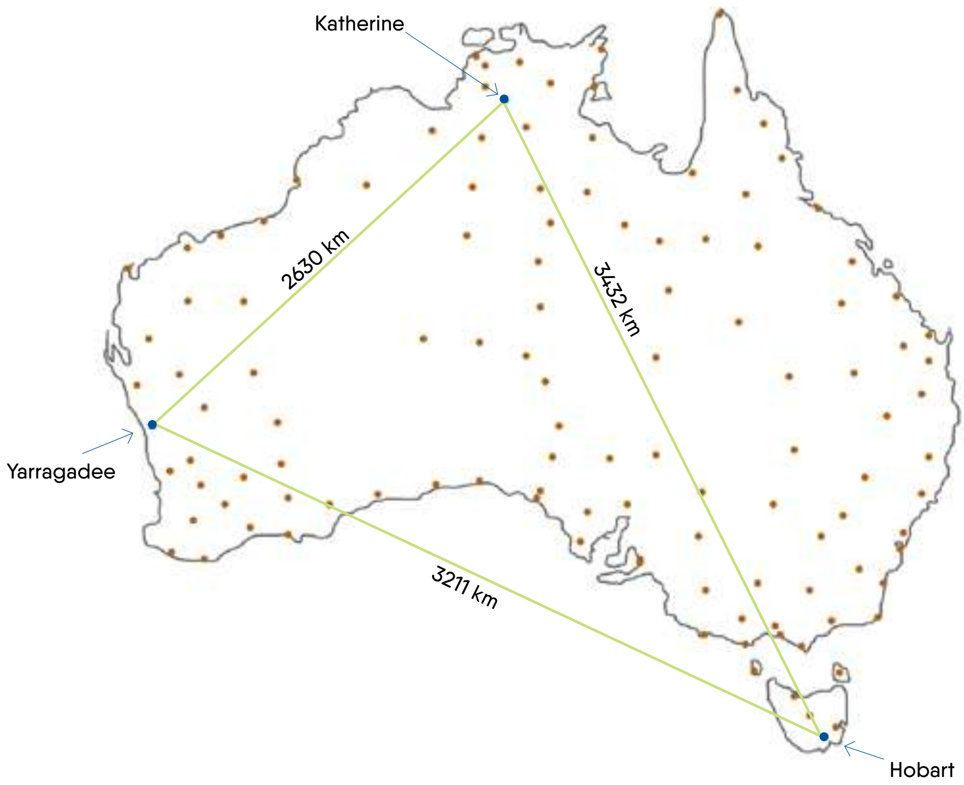
120 GNSS (Global Navigation Satellite System) is a satellite system used to pinpoint the geographic location of a user's receiver anywhere in the world.

121 http://www.ga.gov.au/scientific topics/positioning-navigation/geodesy/geodetic-techniques/satellite-laserranging-slr

122 http://auscope.org.au/site/framework.php

123 The Curtin University Parallel Processor for Astronomy (CUPPA)

Figure 20 – Locations of the VBLI infrastructure



Source: Lovell, J.E.J. et al 2013, "The AuScope geodetic VLBI array", Journal of Geodesy, vol. 87, pp.527-538. Note: dots also represent new GNSS sites directly funded through NCRIS.

Table 14 - Summary of Implementation Progress/Outputs – Geospatial and Earth Dynamics

Year	Implementation Progress/ Outputs summary
2008-09	Construction Hobart 12m radio telescope completed
2009-10	Construction Yarragadee and Katherine telescopes completed
2010-11	Commenced observations to calibrate array
2011-12	Commenced operational observations
2012-13	-
2013-14	178 observation days
2014-15	235 observation days, with 100 dedicated to the southern hemisphere AUSTRAL program together with antennas in South Africa and New Zealand

Satellite Laser Ranging (SLR)

An upgrade of components at the Mt Stromlo SLR site enhancing the ability of the system to range to high-orbit satellites was achieved in 2007-08.

Gravity Measurement (GM)

Various capital improvements including acquiring one FG5 absolute gravimeter and various relative gravimeters over the period 2007-08 to 2009-10, enabling regular gravity measurements to be made at strategic sites across the country. Data from the core program is freely available. The program also funded seven gravity observation huts, operated by the states and territories, and completed in 2013-14.

Summary of effects

Table 15 – Effect of AuScope activities – Geospatial framework and Earth Dynamics (VBLI, SLR, GM)

Situation without AuScope	Situation with AuScope
Very Long Baseline Interferometry (VBLI)	
Construction of three dedicated VLBI radio antennae within Australia (including replacement of Hobart facility) and hardware for data correlation.	
Legacy radio telescopes performed 20-30 per annum VLBI observing days on an ad hoc basis in conjunction with observatories in South Africa and Chile.	Array now conducting observations for 140-210 observing days per annum (contingent on operational funding), remotely controlled from Hobart
	Self-sufficient calibration of Australian terrestrial reference frame and improved Southern Hemisphere measurements
	Higher profile in designing international research program
Satellite Laser Ranging (SLR)	
Power upgrade to the SLR facility at Mt Stromlo (distance and precision)	
SLR systems at Yarragadee (WA) and Mt Stromlo (ACT)	Substantially increased volume of southern Hemisphere ranges (approximately 20% of global data) Improved science of cross-validation GNSS networks Calibration of radar altimeter satellites
Gravity Measurement (GM)	
FG5 absolute gravimeter, three relative gravimeters and construction of a calibration facility at Mt Stromlo and 7 gravity observation huts	
Ad hoc use of international instruments when available	Own national observing program with dedicated national control points
	More accurate altitude reference measurement for other gravimeter applications (e.g. private prospecting, construction)

Augmentation

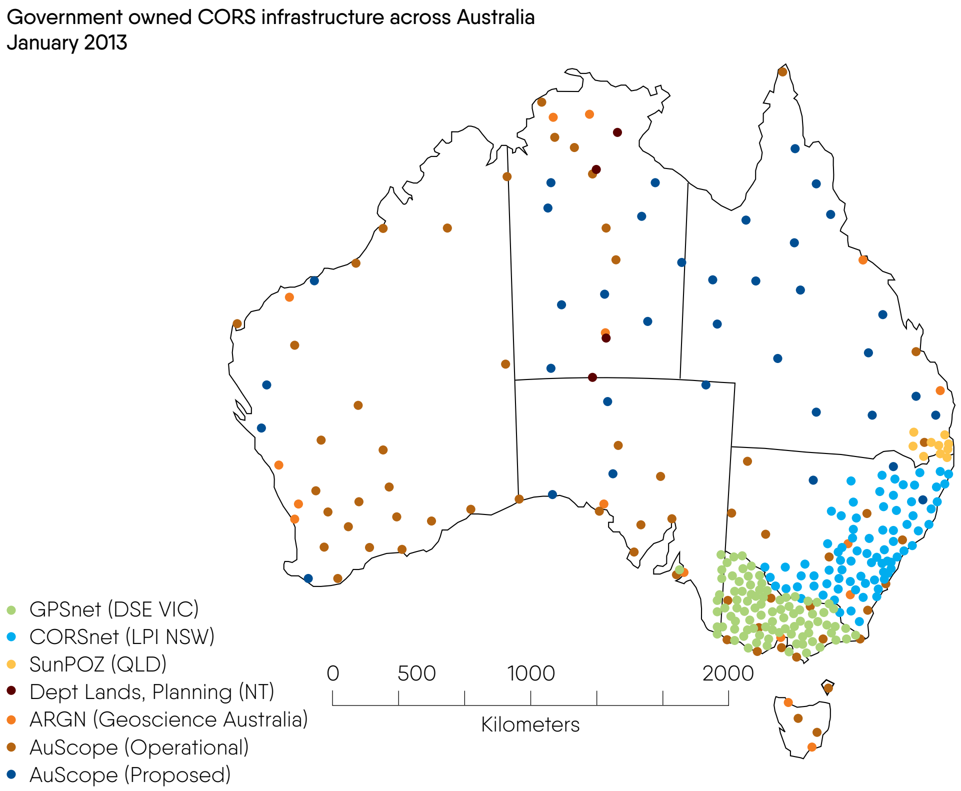
AuScope funding has accelerated the recent development of CORS sites across Australia by funding an expansion in national CORS infrastructure. NCRIS funds were used for around 55 Geoscience Australia sites deployed at distances of about 200 kilometres from each other. Some sites commenced in 2008-09 and others were progressively constructed and become operational over the period to 2014-15.

As seen in the Figure 21 the 55 AuScope-funded CORS sites, which are mostly rural, represent roughly 10 per cent of national CORS infrastructure.[124] The focus of locations, as with other Geoscience Australia sties, is the integrity of the nation's geodetic framework. States and territories also have continued to expand their own CORS networks during this period, somewhat connected to AuScope.[125] State government-funded CORS infrastructure or private infrastructure tends to focus on further facilitating precise or real time positioning through CORS densification (i.e. closer together) in areas of economic importance.

124 ORIMA Questionnaire for Data Collection, NCRIS review, 2011, p4 – Q3 relative scale in sector. There are approximately 650 CORS sites established by government and some private operators in various locations across Australia.

125 While some states and territories may have undertaken CORS expansions in the absence of AuScope, it is reasonable to suggest that the existence of federal NCRIS funding assisted justifying the level and nature of 'matched' state and territory investments.

Figure 21 – CORS augmentation



Original figure supplied by Grant Hausler, Cooperative Research Centre for Spatial Information & The University of Melbourne.
Source: NCRIS 2 progress reports, VLBI program, Q4 2014

9.2 Nature and scale of usage and impacts

Types of usage

As mentioned in section 2.1, the span and reach of geospatial data is becoming increasingly important across a wide range of users, and technology is rapidly evolving. Though invisible, geospatial infrastructure is arguably as important as any other major infrastructure – potentially more so, given the vast and diverse number of scientific, industrial and social applications that already exist or are evolving. Figure 22 positions AuScope's geospatial infrastructure at the peak of the value chain for GNS systems in maintaining the calibration of these systems.Usage comes in three main forms:

- direct usage of the AuScope infrastructure to improve geodetic calibration including through contribution to global arrangements[126] and local positioning
- indirect research users utilising high precision geodetic observations to better measure and understand various interactions within or across solid Earth, oceans and atmosphere
  - in fields such as geophysics, geology, and environmental, atmospheric, marine and climate science
- indirect end users of GNSS positioning services – who, without being conscious of it, utilise the improved spatial accuracy to which AuScope geospatial activities contribute.[128]

126 Primary direct user is the International Earth Rotation and Reference Systems Service that maintains the International Terrestrial Reference Frame (ITRF), the international celestial reference frame (ICRF), and Earth orientation parameters (EOP). As the most significant contribution to geospatial instrumentation in the southern hemisphere, the AuScope Geospatial component also helps to increasing the access of Australia to global data sets and influence on global research priorities. AuScope GNSS array is also one of the few infrastructure in the world to see all the new and emerging navigation satellite systems including Galileo (Europe), GPS III (USA), GLONASS (Russia), Beidou (China), QZSS (Japan) and IRNSS (India).

128 Indirect usage is usually through institutional or commercial intermediaries. All end-users of GNSS services are dependent on the continuous calibration of GNSS to improve the precision of their positions, both horizontally and vertically. Over time the accuracy of GNSS will drift, that is the same coordinates do not bring back to the same position within the standard precision – the AuScope geospatial activities contribute to calibration to avoid this 'drift'.

Figure 22 – Value chain for Global Navigation Satellite Systems[127]

GNS System

Satellites, ground stations, user equipment

Signals, calibration and co-ordination

Timing - enabling the enablers by synchronising systems

GNS Systems, computer and telephony systems, electric power systems management

Positioning, Navigation and Timing

Transport (air/surface/ marine navigation, automated control and guidance)

Timing (international time standartd, communications, power, financial transactions)

Land data (surveying and mapping, construction, GIS)

Location based sercvices (navigation, asset traking, locating people)

Emergency and safety (defence and emergency services, search and rescue, tracking patients and children, tracking criminals)

Scientific and environmental (weather forecasting and extreme weather risk management, environmental monitoring and ecological risk management, measuring Earth's shape , crustal movement and seismic risk management,

Legal and regulatory (boundary determination, land rights management, border enforcement, managing extra-territorial resources eg fishing limits)

Potential Benefits

Saving time, improved management of business and personal activities

Facilitating commerce, increased productivity and cost savings, security of transactions, innovation, product and market development

Increased safety, health, improved warning and emergency management, reduced loss of life, injury and disability, medcal costs, damage and loss of income

Scientific research, exploration, legal and educational aspects

Improved built and natual environmental monitoring and management

127 Leveson I., The Economic Value of GPS: Preliminary Assessment, National Space-Based Positioning, Navigation and Timing Advisory Board Meeting, June 11, 2015

Figure 23 – Pathways to impact for geospatial infrastructure – research

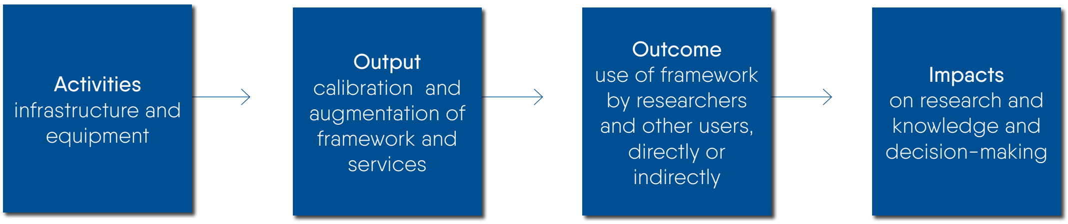
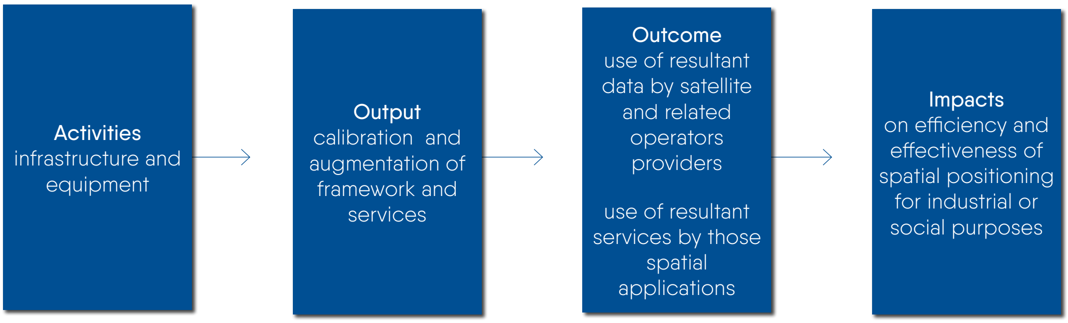


Figure 24 – Pathways to impact for geospatial infrastructure – industrial and social applications



Demonstrated usage

Direct usage

Preliminary results are positive that the AuScope infrastructure is achieving its direct technical purpose of improving the reference frame. This is a pre-condition for AuScope's impact on research or other indirect uses.

For example, the AuScope VLBI array was built in order to increase the number of stations and observations in the southern hemisphere and, in doing so, strengthen the celestial reference frame in the south. There is strong evidence that this new infrastructure has resulted in a dramatic improvement to positioning accuracy and repeatability:

- baseline length repeatabilities – a standard quality measure of geodetic VLBI data – are since mid-2013 the same in the southern hemisphere than in the north.
- this demonstrates that the increased observing effort of southern stations including the AuScope VLBI array since mid-2013 has helped to overcome a previously significant difference in the results of the two hemispheres where southern baselines had significantly less precision.[129]

Research applications

VLBI or GNSS researchers in Australian universities and government agencies (and to some extent internationally) can exploit the AuScope array for research in geodesy, geophysics and measurement technique improvement – for example, generating data on the dynamism of the Earth's surface crust (i.e. how the Australian continent moves and distorts in three dimensions) or the operation of tides.[130] Core areas of scientific research include:[131 132]

- defining an accurate height datum and assessing sea-level variation from land or sea changing and its effect on the Australian coastline;
- estimating the deformation and strain field of the Australian continent including estimates resulting from plate tectonics stresses and anthropogenic causes;
- understanding the Australian water cycle and improved weather forecasting thorough monitoring atmospheric water vapour and ionospheric electron density mapping.

No consolidated information is available for the extent or impact of this research, since researchers are not necessarily directly involved in AuScope activities.

The case study on page 60 involving atmospheric modelling and research highlights using GNSS meteorology to better predict severe storms in Victoria. This is related to broader work between the CRC for Spatial

129 Plank, L., Lovell, J.E.J., Stanislav, S.S., Bohm, J. Titov, O. 2015, "Challenges for geodetic VLBI in the southern hemisphere", Advances in Space Research, volume 55, pp. 304-313

130 NCRIS 2 progress reports, VLBI program and Gravity program, Q4 2014, Q42015

131 http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/gnss-networks

132 Tregoning, P. / The University Component of the AuScope Geospatial Team 2008, "New geodetic infrastructure for Australia", Journal of Spatial Science, vol 53 no 2, December

Information, Geoscience Australia and the Australian Bureau of Meteorology to integrate the AuScope GNSS data on atmospheric water vapour estimates into the national weather forecast model in near real-time, in order to improve weather forecasting. Overall technical design and user requirement specifications have been completed and work has commenced on GNSS data quality control components and implementation of an orbit determination capability.[133]

Non-research applications

The number of indirect end users of AuScope-related GNSS positioning services is in the thousands.[134] This is because every user of a global positioning receiver such as GPS in mobile phones is affected by AuScope calibration, even if only marginally. In addition, many spatial data users experience greater localised positioning accuracy when utilising data from AuScope-funded CORS in otherwise non-covered locations. This industrial and social usage is not the AuScope geospatial component's direct purpose but it is a co-benefit.

The variety and number of users of real time positioning services (as a GNSS application) is growing, across a range of fields and industries. Most end-users of positioning systems are satisfied with standard levels of precision and accuracy (e.g. to within 5 metres). For example:

- by local government for asset management;
- by transport and logistics for tracking freight movements and network optimisation
- by environmental monitoring of water quality or salinity
- by emergency managers to manage disaster relief and firefighting.[135]

Beyond that, some users require precise positioning to achieve real-time or near real-time accuracy to better than 10cm horizontal accuracy – with the majority of precise positioning users seeking the highly precise positioning within 2cm.[136] Potential end-users with respect to precise positioning, depending on their uptake of relevant equipment and competency, can include:

- surveyors and builders, such as for locating components of buildings on sites, building true vertical lines, assessing true heights etc.
- pipeline builders seeking to build to precise heights to keep flow "downhill", will want to use high precision satellite height measurements enabled with gravity monitoring
- agricultural users utilising an automated high precision navigation method[137], for example to keep tractors on the same path reducing soil compaction to one path and maximising productive land
- miners also using automated high precision navigation, for example for automated mining trucks with associated safety and efficiency benefits

Uptake of high precision applications is growing across the country. For example, a 2012 survey of Australian grain growers found 39 per cent of growers use controlled traffic (which requires high precision), compared to 22 per cent in 2010 – usage almost doubling in two years.[138]

AuScope is not specifically designed to facilitate precise positioning, but the combination of AuScope-related CORS infrastructure and other close non-AuScope CORS infrastructure and data exchange could achieve this.[139] Effects would be largely limited to users based in rural areas (including along major transport routes) rather than metropolitan areas, as that is where AuScope CORS are typically located.

However, future positioning technology being developed – including through the CRC for Spatial Infrastructure's Analysis Centre Software project[140] – which may enable precise positioning accuracies to be derived in real-time using a sparser network of CORS.[141] This could enable the AuScope/Geoscience Australia CORS network to play a greater role in precise positioning.

9.3 Impacts and benefits – qualitative assessment

Counterfactual

The assumed counterfactual is an incremental evolution of the existing infrastructure, which was developed in a somewhat piecemeal manner given available funding over time, and which also varied in quality and ability to undertake different applications. [142] This counterfactual includes modest investment in satellite laser ranging, continued ad hoc gravity measurement, and limited CORS observation sites outside of state and private networks and less integration between all CORS sites across the nation.[143]

Actual

Relative to this counterfactual, through AuScope Australia's geospatial infrastructure is now substantially more developed which provides a platform for multiple scientific investigations and productivity-improving industrial and social applications (see Table 16).

133 NCRIS 2 progress reports, CORS program Q2 2015

134 NCRIS2 KPIs Summary, FY2015

135 Roberts, C., Ozdemir, S. and McElroy S. 2009, "Where is positional uncertainty?" in: Ostendorf ,B., Baldock, P., Bruce, D., Burdett, M. and Corcoran, P. (eds.), Proceedings of the Surveying & Spatial Sciences Institute Biennial International Conference, Adelaide 2009, Surveying & Spatial Sciences Institute, pp. 559-575.

136 Lorimer R 2009, "A User Needs Analysis for Precise Positioning Services in Australia", Journal of Global Positioning Systems, vol 8 no 1, pp.113-114.

137 Such as Near Real Time Kinematics (NRTK)

138 ACIL Allen Consulting 2013, Precise positioning in the agricultural sector – an estimate of the economic and social benefits of the use of augmented GNSS services in the agricultural sector, report for the Department of Industry, Innovation, Climate Change, Research and Tertiary Education, June, p.4

139 CORS infrastructure placed at 50–70 km inter-station distances enables three-dimensional positioning accuracy within 2 centimetres with 1-sigma uncertainty using the Network Real-Time Kinematic (NRTK)technique.

140 NCRIS 2 progress reports, CORS program, Q1 2015. In 2015, Analysis Centre Software (ACS) project was initiated under the CRC for Spatial Information. The ACS will exploit the AuScope GNSS array's unique position as being one of the few infrastructure in the world to see all the new and emerging navigation satellite systems including Galileo (Europe), GPS III (USA), GLONASS (Russia), Beidou (China), QZSS (Japan) and IRNSS (India). The ACS will implement new methods of processing of real-time data streams from existing GNSS stations in Australia to generate regionally enhanced products including highly precise orbit and clock corrections for GPS, GLONASS, QZSS and Beidou satellites.

141 Hausler, G. & Collier P. 2013, National Positioning Infrastructure: Where are we now?, International Global Navigation Satellite Systems Society Symposium, July

142 Tregoning, P / University Component of the AuScope Geospatial Team 2008, op cit

143 Personal communication with John Dawson, Geoscience Australia

Table 16 – Qualitative summary of key uses and impacts of Geospatial framework and Earth dynamics

Impact area	Contribution	Nature of impact and benefit
Fundamental Earth science	Major	Greater accuracy of geodetic analyses through better reference frame definition (e.g. accurate imaging of radio sources, more accurate modelling of reference frame deformation) Improved understanding of continental deformation patterns across certain GNSS transects
Resource exploration	Medium	Greater accuracy of gravity surveys in identifying mineral deposits
Natural and built environment	Major	Land use planning and coastal management informed by improved sea level estimates (e.g. coastal inundation studies, climate change adaptation studies, ocean circulation studies) Land use planning and risk management for built infrastructure resulting from understanding seismic risk (e.g. intra-plate Earthquakes) Better knowledge of hydrological cycle and land water storages (e.g. observation of changes in components of water storage) to reduce uncertainties for climate forecasting Better meteorological products and improved knowledge of weather/climate patterns through air moisture data More sustainable management of soil and groundwater through assisting research into landscape evolution and soil profiles
Spatially-sensitive industries	Major	More accurate spatial positioning for diverse social and industrial users (e.g. transport, agriculture, mining, defence), to improve productivity More accurate positions for real-time positioning arising from denser GNSS network, including across major transport routes, to improve productivity
Other	-	Contribution to international reference frame improvements

Using GNSS meteorology to better predict severe storms in Victoria

Severe storms and flooding can have a substantial economic impact through property damage and, in some cases, injury and loss of life. With sufficient warning, the public can take action to mitigate some of these impacts.

Lightning Storm Over Melbourne; Source Chris Phutully

Monitoring and predicting the intensity, time and extent of severe storms depends of the availability of precise water vapour information. Existing techniques of sensing water vapour in the atmosphere (e.g. instruments on weather balloons) are expensive and not always timely, resulting in sparse measurement.

The ability of space geodetic techniques to remotely sense the atmosphere has dramatically improved with advances in space-based technologies, large scale and dense CORS networks and the developments of new algorithms and methodologies.

RMIT University, the Bureau of Meteorology, the Victorian Government, the University of Melbourne and the CRC for Spatial Information are working on ways to reduce the risks and impact of natural weather disasters through the emerging area of GNSS technology with a high spatio-temporal resolution for near real-time monitoring and forecasting.

Case studies, using observations from the Victorian state-wide CORS network and underpinned by the broader AuScope-influenced geodetic framework, investigated:

- GNSS-derived precipitable water vapour (PWV) estimation; and
- four-dimensional (4-D) tomographic modelling for wet refractivity fields.

Results have been highly promising, for both monitoring and prediction.

Researchers found strong spatial and temporal correlations between variations in ground-based GPS-derived precipitable water vapour and the passage of the thunderstorm complexes (severe mesoscale convective systems). This indicates that the GPS method can complement conventional meteorological observations for the studying, monitoring, and potentially predicting of severe weather events.

Results also suggest that GPS-derived precipitable water vapour can resolve the synoptic signature of the dynamics and offer precursors to severe weather. The tomographic technique has the potential to depict the three-dimensional (3-D) signature of wet refractivity for the convective and stratiform processes evident in thunderstorm events.

Source: Wu, S., Manning, T, Yuan, Y, Wang, X, Kealy, A, le Marshall, J. 2014, "Strengthening Severe Weather Prediction Using the Advanced Victorian Regional GPS Network – a Recent NDRGS Project"; Zhang, K, Manning, T., Wu, S., Rohm, W., Silcock, D. and Choy, S. 2015, "Capturing the Signature of Severe Weather Events in Australia Using GPS Measurements", IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 8 no 4, April, pp.1839-1847

Key points

- Data exchange, delivery and visualisation in a data-rich Earth science context is a major task
- Data layers have progressively become available via the aggregating AuScope portal
  - from various parts of CSIRO, Geoscience Australia, state and territory geological surveys, universities including Curtin University, University of Queensland and University of Melbourne
  - but it is not yet comprehensive, particularly for geological survey data
- There is insufficient evidence on the extent to which end-users are using the AuScope Grid to access data for impact.
  - However, the planned integration of the AuScope Grid approach into an expanded National Geoscience Portal administered by Geoscience Australia suggests that government geoscience agencies (who interact with industry end-users) see merit in it.
- There appears to be effective use of the AuScope-supported Terrawulf computing facility, particularly since the Terrawulf-III upgrade in 2012, to support data-rich investigations.
- The approach to spatial data access through the AuScope portal is being applied to other sectors, notably the current National Environmental Information Infrastructure led by the Bureau of Meteorology

10.1 Scope and outputs

Scope

The scope of the AuScope Grid was to develop information infrastructure:

- make all new data and information collected through AuScope components to be accessible as online web services
- to, over time, also provide integration with other geoscience and geospatial data, nationally.

Data is held in existing databases distributed across the country (e.g. in universities or government agencies) and recorded in different ways. Computer resources are also distributed. Essentially it standardises formats, through dataholders mapping their data to a consistent set of standards (while not necessarily changing the underlying database structure). Data from various sources is brought together via information exchange through a single national portal. This allows queries to be made across the datasets, as well as through individual dataholders.

The broad vision was to allow researchers and other users with seamless access to facilities (computational and data storage) and services (simulation codes, data inference) and reduce barriers to information exchange.

Outputs

The main areas of outputs, largely delivered by CSIRO, were:

- a spatial information services stack – an architecture and suite of tools for spatial data interoperability, built on open source technologies
- an online 'discovery portal' interface – a web-based interface for searching and accessing data, information, imagery, services and applications connected to the grid.

The various outputs associated with the Grid included improving the technology involved (through various updated releases), and working with the various government agencies and universities involved in AuScope to implement the spatial information services stack as relevant to particular AuScope components and other data sources. These outputs were progressively achieved over the length of the AuScope initiative. Layer visualisation (e.g. 3-D visualisations) and analytical tools continue to be developed, to make the interface easier and more useful for users.

A further output of the Grid was acquisition of TerraWulf II computing cluster[144] at the ANU, able to manage large complex computational problems in the Earth sciences using parallel processing techniques. This was in production mode by 2008-09. There was an upgrade (Terrawulf-III) in 2012.

144 A 386 core computing cluster, consisting of 96 dual processor dual-core IBM x3655 boxes, connected through Gigabit and Inifiniband switches. It has a total of 24 Tb of disk storage and 1Tb of RAM. ially identified for TII include applications in seismic imaging of Earth Structure, Geospatial data analysis and mathematical geophysics. TII is open for access by the Australian Earth Science community for projects consistent with the AuScope vision to '... characterise the structure and evolution of the Australian continent from surface to core in space and time.'

10.2 Nature and scale of usage

Types of usage

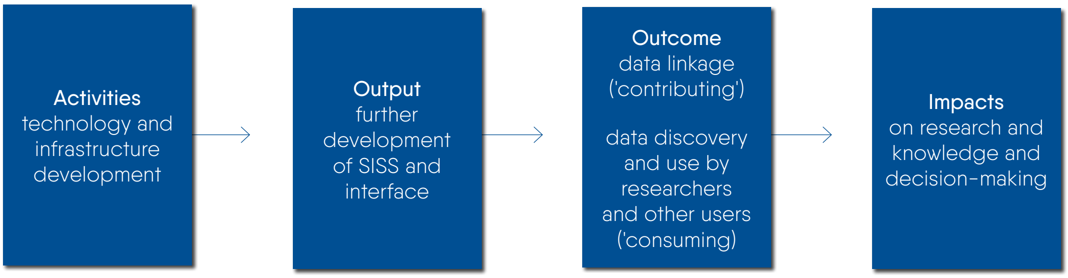
Usage can be considered in two ways:

- 'contributing' usage of the SISS as an underlying architecture or for integration, which is demonstrated through availability of data through the portal – by maintainers of geoscience and geospatial data
- 'consuming' usage of the discovery portal itself to discover and use data – by end users or their intermediaries.

Also, while it is relatively standalone, the Terrawulf facility can also be used by Australian researchers in Earth imaging, geospatial and inversion requiring the computational power.

In a broader sense, there is also indirect usage through others outside of geoscience utilising the interoperability approach developed and matured through the AuScope GRID, separate from the AuScope GRID itself.

Figure 25 – Pathways to impact for GRID and interoperability



Nature of usage

'Contributing' usage

There has been a mixed story on 'contributing' usage of Grid. Layers (i.e. data) have been progressively become accessible through the AuScope portal via SISS. There is now data available[145] through GRID from:

- CSIRO – various parts of the organisation including ASTER spectral data from the Centre of Excellence for 3D Mineral Mapping (C3DMM) and CSIRO Petroleum data
- the former CRC for Predictive Mineral Discovery (pmd*CRC) – geochemistry data
- Geoscience Australia – e.g. onshore seismic surveys, geodetic data observations
- universities and/or CSIRO research projects – e.g. Northern Yilgarn hydro-geochemistry
- some National Virtual Core Library (NVCL) borehole data from most of the states and territories (although varying in comprehensiveness)
- Earth resource/mineral occurrence and mining activity data from state and territory geological surveys
- the John De Laeter Centre (Curtin University) mineralogy library
- University of Queensland – Virtual Rock Laboratory running ESyS-Particle Discrete Element (DEM) simulations
- University of Melbourne's multi-sensor core logger (MSCL) observations on borehole cores from the NVCL

The ambitious vision of full integration of national geoscience data has not yet occurred, particularly for data from across the state and territory geological surveys (and it should be recognised that the scope of AuScope deliverables did not intend to achieve this).

'Consuming' usage

There is insufficient evidence on the extent to which end-users are using the AuScope Grid to access data.

There is no consolidated information on who is utilising information through the AuScope discovery portal, the extent of usage or the utility of that usage to users. Anecdotally, university or other researchers are more likely to utilise the data and analysis than industry given the likelihood of their greater awareness of the portal and greater interest in continent-wide phenomena. One geological survey informally suggested that the exploration industry prefers to use data from the state government data portal, which is their traditional practice.

145 As shown at: http://portal.auscope.org/portal/gmap.html

Recently, the federal and state governments decided, following a proposal by Geoscience Australia, to incorporate the AuScope portal and related services in an expanded National Geoscience Portal administrated by Geoscience Australia.[146] This suggests that the demonstration provided through AuScope GRID has merit from the perspective of government agencies that interact with industry end-users – effectively, mainstreaming it in the geological survey activities.

With respect to the Terrawulf facility, ANU reported in 2015 that since the Terrawulf-III upgrade in 2012, cluster throughput has increased by almost a factor of five over the previous Terrawulf-II era. Average cluster utilisations were around 54% with frequent peaks of over 90%, for instance:[147]

- in January to June 2014, the Terrawulf cluster run at an average 55% capacity, with 26 distinct active users
- in January to June 2015, the cluster ran at an average 43% capacity with peaks above 80% (albeit affected by the facility needing repairs in May and June), with 18 distinct active users.

Other (indirect) usage

Spatial data discovery and access underpins a research in a wide range of fields beyond geoscience, including environment, climate, social sciences, minerals, biology, urban environment and other fields. The 'learning by doing' through AuScope Grid – including the software and approaches developed and extended by CSIRO – is being applied to data discovery and access in other sectors.[148]

Notably, the current National Environmental Information Infrastructure (NEII)[149] initiative led by the Bureau of Meteorology has applied many of the themes and learnings from the AuScope Grid. The NEII Reference Architecture proposes (as with AuScope) harmonised online services and web portals and standards-based IT architecture, and specifically adopts the SISS open source software as a reference implementation software stack for implementing NEII components.[150]

10.3 Impacts and benefits – qualitative assessment

Counterfactual

Without AuScope, we can assume a counterfactual that some of the underlying standards and technology may be developed (albeit potentially at a slower pace), but there would have been less cross-institutional interaction and a demonstration portal may not have been implemented.

Actual

The main impact probably results from the new ability to draw together certain AuScope data sets and also non-AuScope data sets in a consistent manner, which may have utility to some users. To avoid 'double counting', for those aspects of AuScope that involved data development, the impact of the GRID component is the additional end-user usage of that data generated or made more efficient beyond traditional or usual data sources (e.g. geological survey publications and online databases, Geoscience Australia online databases).

Table 17 – Qualitative summary of key uses and impacts of GRID and interoperability

Impact area	Contribution	Nature of impact and benefit
Fundamental Earth science	Major	Greater access to and use of rich geoscience and geospatial data for various scientific research
Resource exploration	Medium	Reduced exploration costs Discovery brought forward through reduced uncertainty
Natural and built environment	Medium	More efficient development of online data discovery and access in environmental sector
Spatially-sensitive industries	-	-
Other	-	-

146 The current Geoscience Portal (http://www.geoscience.gov.au/index.html), an initiative of the Commonwealth and state governments through the Exploration Investment and Geoscience Working Group (EIGWG), provides basic links and other information regarding the federal and state geoscience data.

147 Quarterly reporting from ANU

148 https://www.seegrid.csiro.au/wiki/ASRDC/WebHome and https://projects.ands.org.au/id/EIF003

149 See http://www.neii.gov.au/

150 Bureau of Meteorology 2014, National Environmental Information Infrastructure: Reference Architecture, Environmental Information Programme Publication Series, document no. 4 (http://www.bom.gov.au/environment/doc/NEII_Reference_Architecture.pdf)

11.1 Overarching parameters

As key parameters across the economic analysis:

Standing

The benefits and costs in scope for the economic analysis are those that relate to Australians or those resident in Australia. That is, impacts on overseas production, consumers or researchers are not in scope. This focus on national costs and benefits is mainly because resources (i.e. funding, time) being utilised for AuScope are typically Australian, and the conclusions of this analysis are principally to help inform decisions of Australian research institutions or governments in Australia. (Note that discussion of each AuScope component does include qualitative discussion of international relationships.)

Time horizon

Earth science information has a long lifetime, given the potential for use and re-use over time (as described in the main report). This suggests a longer rather than shorter time horizon for the analysis, to ensure a proper depiction of impacts over time. We assume a 25-year timeframe to 2040-41 (roughly, 5 years of funded AuScope activity and 20-25 years of subsequent impacts).

Social discount rate and base year

The social discount rate assumed is an annual real discount rate of 7 per cent. This follows the guidelines of the Australian Government's Office of Best Practice Regulation (OBPR) regarding the standard discount rate for assessing regulatory interventions.[151] Sensitivity tests incorporate annual real discount rates of 3 per cent and 10 per cent respectively, also in line with OBPR guidance. The base year for present value is 2015-16, the year in which the assessment is being conducted.[152]

Annual real increase within projections

In parts of the economic assessment, we make projections to 2040-41 for various economic measures, before accounting for the impact of AuScope. We typically make these projections by extending an annual real growth rate from the last year of available historical data or the last year of available forecasts from credible sources. The annual real growth rate is intended to recognise a trend of general growth in the economy or sectors of it and associated expenditures over time. The detail of each projection is explained within the sections below.

11.2 Resource exploration – reduced exploration cost

We assess the benefit of AuScope for Australian resource exploration through two complementary but separate effects: (a) reduced exploration cost, and (b) discovery brought forward.

The benefit of reduced exploration cost relates to use of AuScope-related data to target exploration effect, for a given discovery. The following method is used for each of existing mineral deposits, new mineral deposits (greenfields) and onshore petroleum, which sum for an overall benefit.

Counterfactual scenario without AuScope

We firstly establish exploration costs in Australia 'without AuScope' as a counterfactual (see Figure 29), building from historical exploration expenditure data from the Australian Bureau of Statistics (ABS)[153], adjusted for inflation.[154] To do this, we:

- infer an actual exploration expenditure figure for 2015-16 based on reported ABS data for the first two quarters of 2015-16 (i.e. double the first two quarters as reported)
- adjust actual exploration expenditure between 2011-12 and 2015-16, to infer a counterfactual expenditure level during this period (i.e. increase actual historical expenditure by the expected 'cost saving' of AuScope) – the adjustment is only small as the AuScope impact in this time period is small (impact calculation described below)
- project forward expenditure to 2040-41 from the counterfactual 2015-16 figure, using a standard annual real increase (2.5%).

Although year-to-year exploration expenditure can be highly variable, the resultant forward projection (considerably lower than peak levels for exploration expenditure in 2011-12) appears consistent with longer-term historical trends.

151 Australian Government Department of the Prime Minister and Cabinet 2016, Guidance Note – Cost–benefit analysis, Office of Best Practice Regulation, February, pp. 7–8

152 See Australian Government Department of Finance and Administration 2006, Handbook of Cost-Benefit Analysis, January, p.52

153 ABS 8412.0, Mineral and Petroleum Exploration, Australia, December 2015, table 2

154 Utilising ABS 6401.0, Consumer Price Index, Australia, Dec 2015, Table 1,

Impact scenario with AuScope

The impact of AuScope is a function of two variables[155], for each of existing mineral deposits, new mineral deposits (greenfields) and onshore petroleum:

- the proportion of exploration activity in Australia influenced by AuScope-related data/research ('adoption')
- the (average) reduction in exploration expenditure when adopting AuScope-related data/research ('productivity')

Adoption

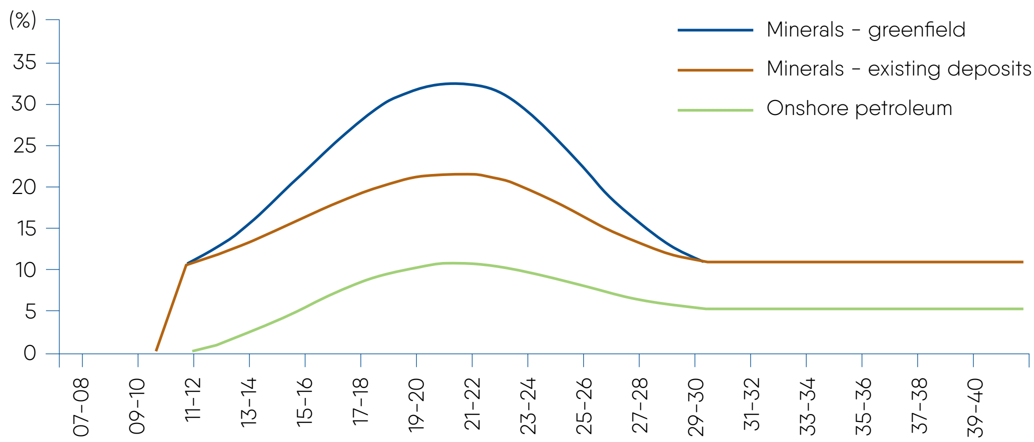
In terms of adoption, we note that in 2013, CSIRO[156] estimated that its Minerals Down Under Flagship – most of which is incorporated within or related to AuScope in some way – had 15% penetration in target market (e.g. explorers) at maturity. This is presumably inclusive of all types of mineral exploration (both new and existing deposits).

Drawing from qualitative input from key AuScope researchers about where AuScope outputs are relatively more useful, we assume a similar level adjusted for:

- adoption patterns over time, which we assume starts in 2011-12 when initial AuScope outputs start to become available, rising to peak levels in 2020-21 as outputs are fully available and as awareness grows, and receding as other geoscience products and new data start to substitute at least some of what AuScope provides;
- a generally higher rate of adoption given AuScope contains further elements beyond only those of CSIRO;
- a higher rate of adoption for greenfield exploration (peak 30%) than exploration of existing deposits (peak 20%) or onshore petroleum (peak 10%).

Figure 26 shows the assumed adoption trends.

Figure 26 – Assumed adoption trends for resource exploration



Productivity

In terms of productivity, we also draw on literature on the exploration productivity impacts of similar activities, which roughly suggest impacts in the range of 5% to 20%:

- in 2013, CSIRO[157] estimated that data from its Minerals Down Under Flagship led to a 17.5% reduction in exploration costs at maturity, if used;
- a 2011 study, based on a user survey and expert interviews, concluded that 17% of project costs would have to be spent on information gathering and research to gain the corresponding insight from geological maps provided by the Ohio Geological Survey, on average;[158]
- a 2002 Queensland study[159] of the effect of geological survey information on exploration companies' expenditure indicated that upgraded government data sets, including geophysical data, accounted for about 7-10% of variance in proposed exploration expenditure, and existing (old) data sets contributed approximately 4-5%.[160]

*155 Annual exploration expenditure with AuScope = counterfactual exploration expenditure'/ (1*adoption rate*productivity rate)*

156 Deloitte Access Economics 2013, Evaluation of CSIRO's research impacts – Impact Case Studies, p.60

157 Deloitte Access Economics 2013, Evaluation of CSIRO's research impacts – Impact Case Studies, p.60

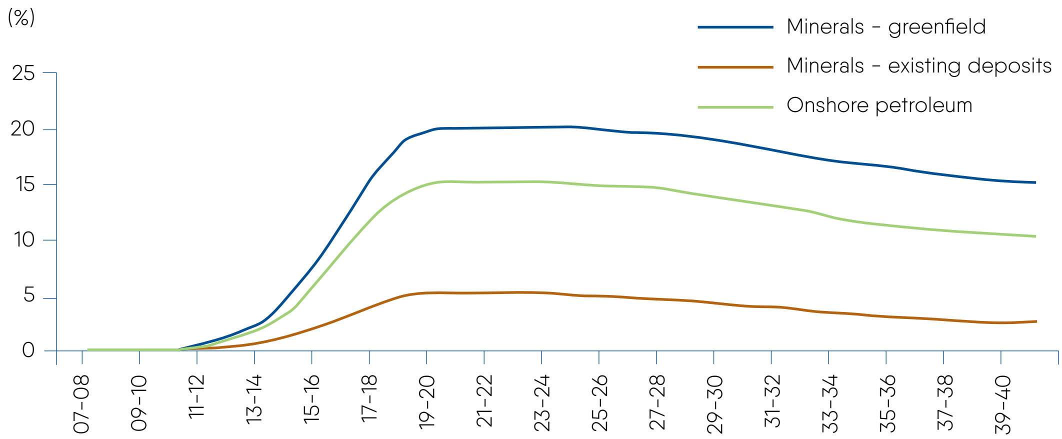
158 Kleinhenz and Associates 2011, An Economic Impact Analysis of the Ohio Geological Survey's Products and Services, Ohio Geological Survey

159 Scott M, Dimitrakopoulos R and Brown RPC 2002, "Valuing regional geoscientific data acquisition programmes: addressing issues of quantification, uncertainty and risk", Natural Resources Forum, vol.26

160 Noting this figure for existing data sets was prior to today's online processes to more easily access many existing data sets, which could potentially close the difference between new and existing data sets.

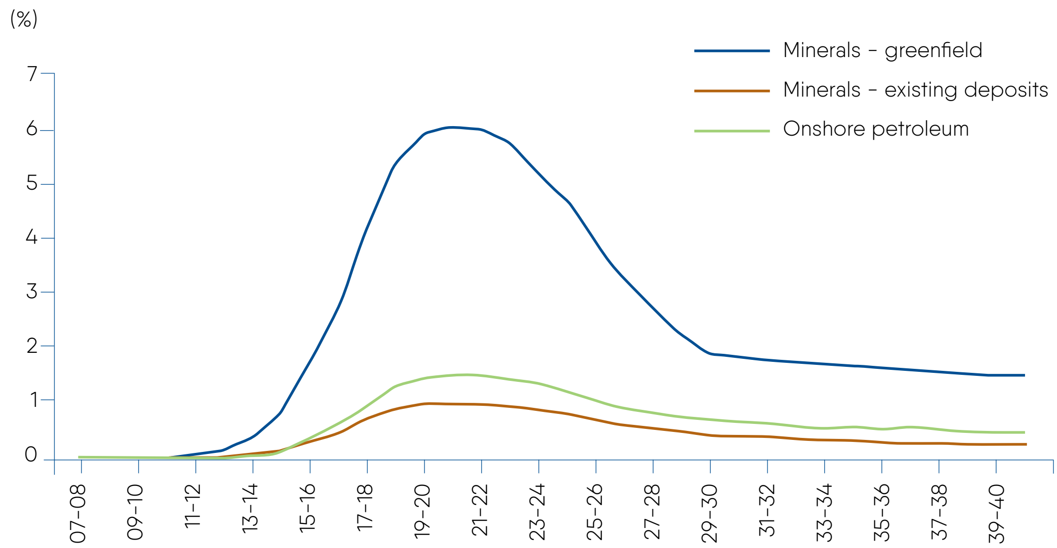
Following similar adjustments as in adoption assumptions (e.g. higher productivity benefit for greenfields, a ramp-up as all AuScope data becomes available, albeit with a slower ramp-down given the potential for data re-use over time), we assume trends as per Figure 27.

Figure 27 – Assumed productivity trends for resource exploration



The combined effect of adoption and productivity is shown in Figure 28.

Figure 28 - Combined impact of AuScope adoption and productivity on exploration cost



Impact results

In each year, the (cost saving) benefit of AuScope is the difference between counterfactual (without-AuScope) exploration expenditure and with-AuScope exploration expenditure, as shown in Figure 28. This difference is shown in Figure 29.

Figure 29- Actual and projected real annual exploration expenditure with and without AuScope ($m, 2015-16)

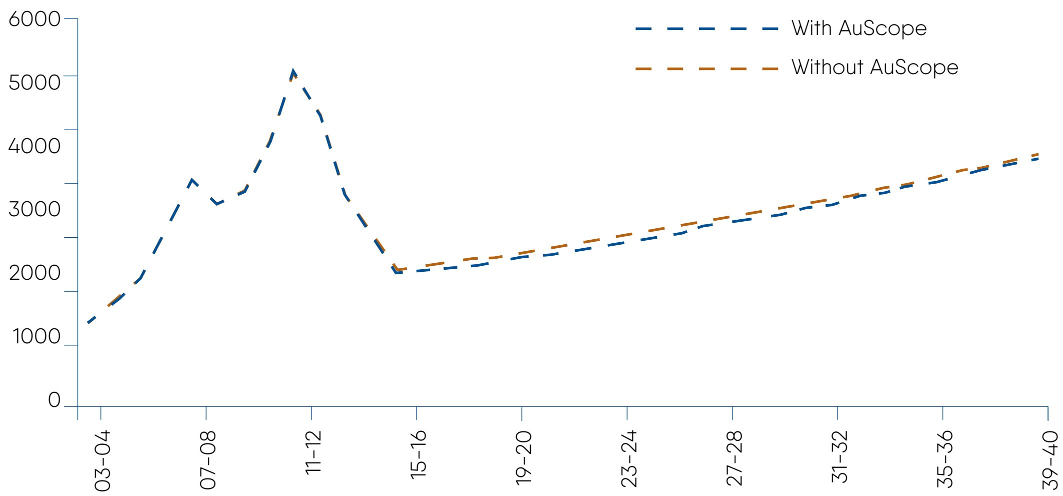
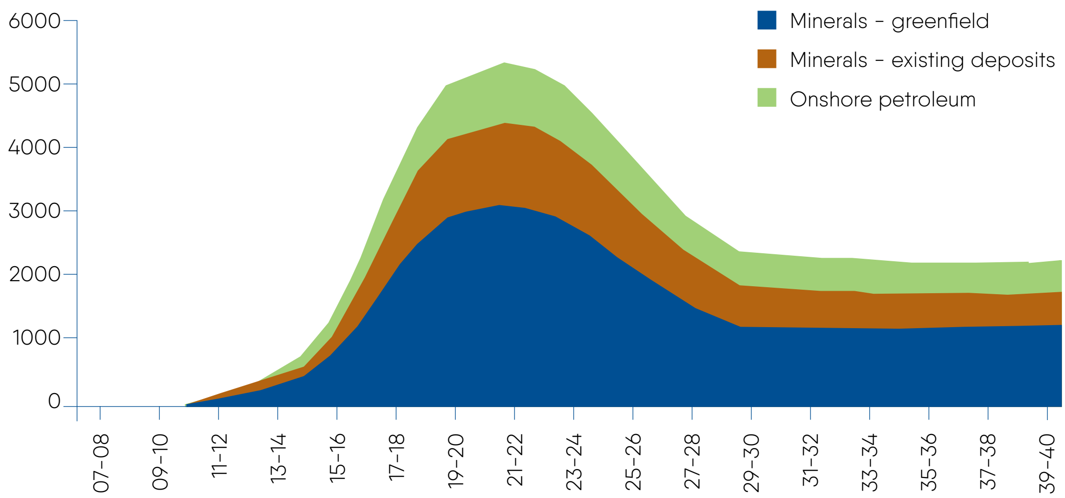


Figure 30 – Projected real annual exploration cost savings from AuScope ($m, 2015-16)



Combined over the period of analysis, the total impacts sum to $836 million (2015-16 terms). As a present value (i.e. adjusted by the social discount rate), this is $450 million.

Table 18 – Summary of reduced exploration costs gross benefits ($m, 2015-16)

Exploration type	Sum	Present value
Minerals - greenfield	469.0	256.7
Minerals - existing deposits	210.3	113.5
Onshore petroleum	157.0	79.7
Total	**836.2**	**450.0**

11.3 Resource exploration – discovery brought forward

The second benefit is the value of discovery brought forward. This assumes that AuScope data/research contributes to reduced uncertainty about Earth composition and structure which leads to a higher chance of high grade/quality economic discoveries which can be extracted at a lower unit cost than existing mines. In short, if more is discovered, if gives miners more options about where to mine – and some of those options will be more commercial in the production phase than existing locations.

The relevant impact is calculated as the difference between the value-added to the Australian economy from the minerals sector under:

- a scenario where AuScope has contributed to economic discoveries (assumed to match medium term official forecasts); and
- an alternative scenario without AuScope (counterfactual).

Impact scenario with AuScope

There are separate estimates for each of gold, iron ore and copper, which constitute the bulk of the Australian minerals market by income (a combined 84% in 2013-14, see Table 18). We assume the effect for the remainder of the market (16%) is proportionate to the effect for the three main commodities in total.[161]

Table 19 – Sales and service income for minerals mining

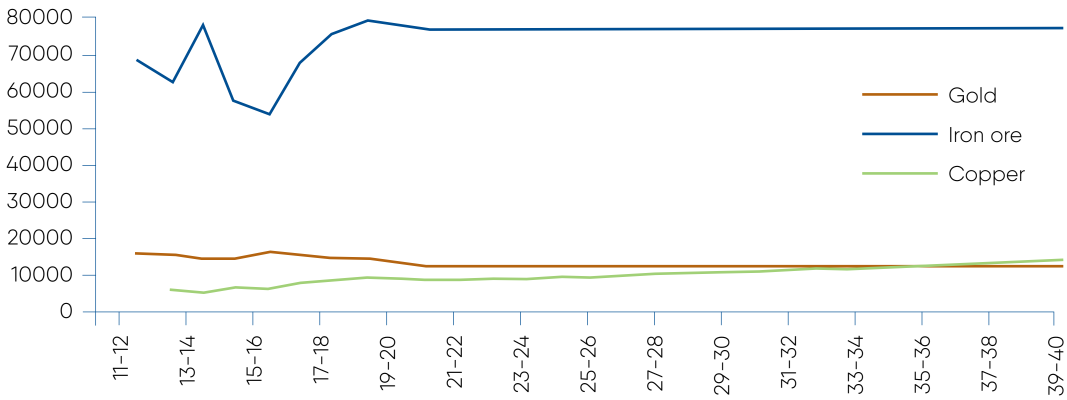
Mining type	Sales and service income ($m, 2013-14)	% of total
Gold ore mining	13,069	11%
Iron ore mining	78,289	68%
Copper ore mining	5,433	5%
Other metal ore mining and Non-metallic mineral mining and quarrying[162]	17,807	16%

For the scenario with AuScope, for each of gold, iron ore and copper, we derive total value of production:

- using historical data to from 2011-12 to 2013-14 on production volume and unit prices;[163]
- Australian Government forecasts to 2020-21 on production volume and unit prices;[164] and
- projecting forward to 2040-41 from the forecast 2020-21 value, assumed to be:
  - for gold and iron ore, a stable real value given either a highly variable or slightly declining historical and forecast trend
  - for copper, a gently rising value using a standard annual real increase (2.5%) consistent with the historical and forecast trend.

This is shown in Figure 31.

Figure 31 – Value of Australian production of gold, iron ore and copper ($m, 2015-16)



161 As per ABS 8415.0, Mining Operations, Australia, 2013-14, released 29 June 2015. Gold ore mining, copper ore mining and iron ore mining. Other resources included in 'the remainder of the market' are mineral sand mining; silver-lead-zinc ore mining; bauxite, nickel ore and other metal ore mining, and non-metallic mineral mining and quarrying.

162 This incorporates mineral sand mining; silver-lead-zinc ore mining; bauxite, nickel ore and other metal ore mining, and non-metallic mineral mining and quarrying.

163 ABS 8415.0, Mining Operations, Australia, 2013-14, released 29 June 2015

164 Department of Industry, Innovation and Science, Office of the Chief Economist, Dec 2014, Dec 2015 and March 2016 Commodity data, http://www.industry.gov.au/Office-of-the-Chief-Economist/Publications/Pages/Resources-and-energy-quarterly.aspx

We also derive a gross value added share of output for each commodity from ABS data about mining operations.[165] We then apply the value share to the value of production in each year to derive the value added to the Australian economy from the relevant type of mining to 2041-42.

Table 20 – Selected metrics for minerals mining

Mining type	Sales and service income ($m, 2013-14)	Industry value-added ($m, 2013-14)	Gross value added share of output
Gold ore mining	13,069	5,911	42.5%
Iron ore mining	78,289	57,247	73.1%
Copper ore mining	5,433	2,043	37.6%

Counterfactual scenario without AuScope

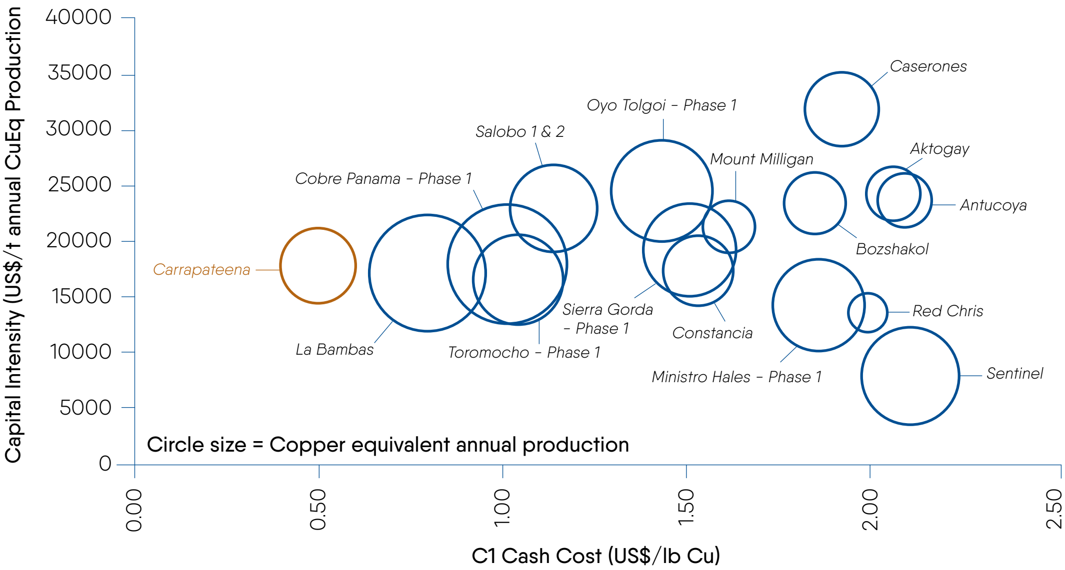
For the counterfactual scenario without AuScope, we assume what would be different to the above scenario. Similar to the 'reduced exploration cost' impact, we assume long-term trends on two variables relating to AuScope impact:

- the average difference in production cost from less costly per-unit mineral extraction where AuScope data/research is utilised to find more economic discoveries, that is attributable to AuScope ('productivity');
- the proportion of exploration utilising AuScope ('adoption').

Productivity

Discoveries – particularly greenfield discoveries – can have a major effect on unit costs. For example, the x-axis in Figure 32 shows the expected C1 cash costs[166] of various worldwide copper projects, including the Carrapateena iron-oxide copper-gold deposit on the eastern margin of the Gawler Craton in South Australia. Carrapateena is in some cases a quarter of the unit cost of other sites, although there is substantial variation.

Figure 32 – Differences in C1 cash cost of major greenfield copper projects



*Major recently developed or in-construction greenfield projects. Capital intensity is total spend to reach first production. Carrapateena capital intensity includes Feasability Study costs, other projects do not.

Source: OzMinerals 2014, Carrapateena Pre-Feasibility Study, 18 August 2014, http://www.ozminerals.com/uploads/media/ASX-20140818-Carrapateena-Pre-Feasibility-Study-Presentation-c977865c-a2c8-491f-a050-4a7e9cf6086c-0.pdf

165 ABS 8415.0, Mining Operations, Australia, 2013-14, released 29 June 2015. Calculated by industry value-added as a proportion of sales and service income. This could be a conservative estimate, as the ideal denominator is production income. Sales and service income could be bigger than production income, so the estimated value could be smaller than the actual value.

166 C1 cash costs are the costs of mining, milling and concentrating, onsite administration and general expenses, property and production royalties not related to revenues or profits, metal concentrate treatment charges, and freight and marketing costs less the net value of the by-product credits (see http://www.nyrstar.com/SiteCollectionDocuments/Nyrstar%20AR11%20Part%202%20EN%20Glossary%20280312.pdf)

For productivity, given different mining methods, we assume the average impact would be 0.5% of total supply costs for gold, 0.2% for iron ore and 0.7% for copper, annually. The main difference between commodities would be the level of unit cost reduction, which is related to mining system – for example, most iron ore is accessed through open cut mines whereas most copper comes from underground mines, suggesting different cost profiles.

This average impact is a summary measure of a number of different effects working in combination. For example, a 0.5% impact would be equivalent to a particular mine achieving a 25% cost reduction per unit of gold, for a company where 20% of their mining comes from a significant new discovery, and we roughly attribute 10% of the discovery to the knowledge achieved through AuScope (i.e. 0.5% = 25%*20%*10%).

There is substantial uncertainty in this assumption, because if we do not know what is going to be discovered, it is difficult to estimate the 'productivity' effect (i.e. extraction cost reduction). Our estimates are conservative – a major discovery with cost-effective extraction could substantially increase the overall impact.

Adoption

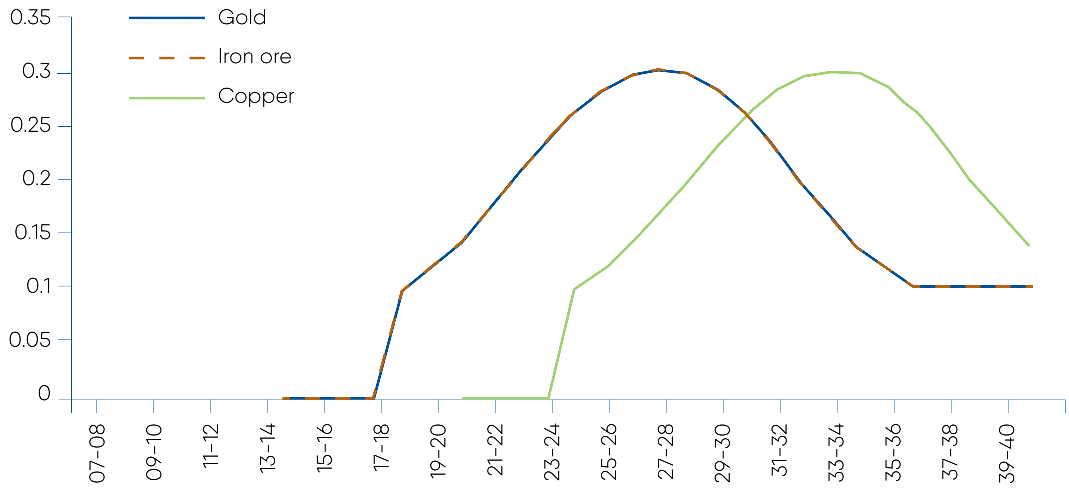
We utilise the same adoption assumption as for the proportion of exploration activity influenced by AuScope in the 'reduced exploration cost' component.

However, we apply this to the productivity variable with a time delay to account for the lag between discovery and extraction. This is assumed to be 7 years for gold and iron ore and 13 years for copper.[167]

In effect, we assume the rates of adoption (illustrated in Figure 33):

- for gold and iron ore (with a 7-year delay) commencing at 10% in 2018-19, rising to 30% by 2027-28 and falling to 10% by 2036-37
- for copper (with a 13-year delay), the same trend but commencing six years later than gold or iron ore.

Figure 33 – Assumed rate of exploration adoption involving AuScope with extraction delay



Impact calculation

To establish a quantity effects resulting from AuScope, these two variables are multiplied with the:

- supply cost share of output (76% for gold and copper, 47% for iron ore[168]), and
- an assumed medium-run elasticity of supply (0.6 for gold, 0.8 for iron ore, 0.5 for copper[169]).

The resultant quantity effect is applied to adjust annual market value for each commodity, given the change in quantity. The value-added produced under this scenario is then established by applying the same gross value added share of output as in the original scenario to the new market value. There is also a further adjustment for the cost effect of the change in quantity in each year, which slightly reduces the value added.

The (discovery brought forward) benefit of AuScope is, in each year, the difference between the original (with AuScope) value added and the counterfactual (without-AuScope) value added.

Impact results

The difference between these two scenarios is relatively small (peaking at 0.12% of value added expenditure), as shown by almost-the-same trends in Figure 34. The difference is shown by commodity and as a total in Figure 35 and Table 21.

167 MinEx Consulting (Richard Schodde) 2014, "Key issues affecting the time delay between discovery and development - is it getting harder and longer?", presentation to PDAC 2014, March, http://www.minexconsulting.com/publications/Schodde%20presentation%20to%20PDAC%20March%202014.pdf

168 Derived from ABS 5209.0.55.001, Australian National Accounts: Input-Output Tables, 2012-13, released 25 Jun 2015, http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5209.0.55.0012012-13?OpenDocument (Table 5, Non Ferrous Metal Ore Mining for gold and copper; Iron ore mining). ABS historical data adjusted to acknowledge likely differences between historical production and future production resulting from the slowdown of the mining boom.

169 Estimate based on observation of historical data on community supply and prices

Figure 34 – Value added to Australian economy from minerals mining ($m, 2015-16)

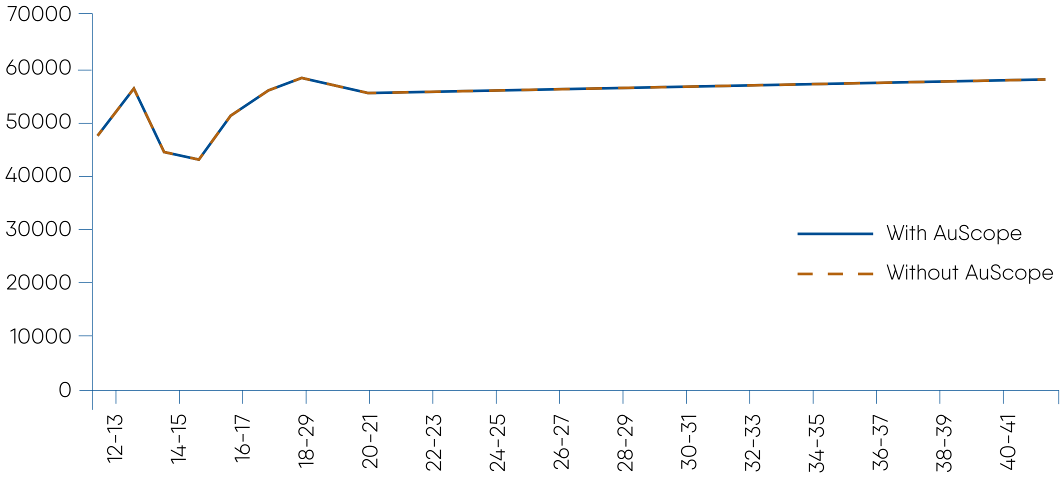
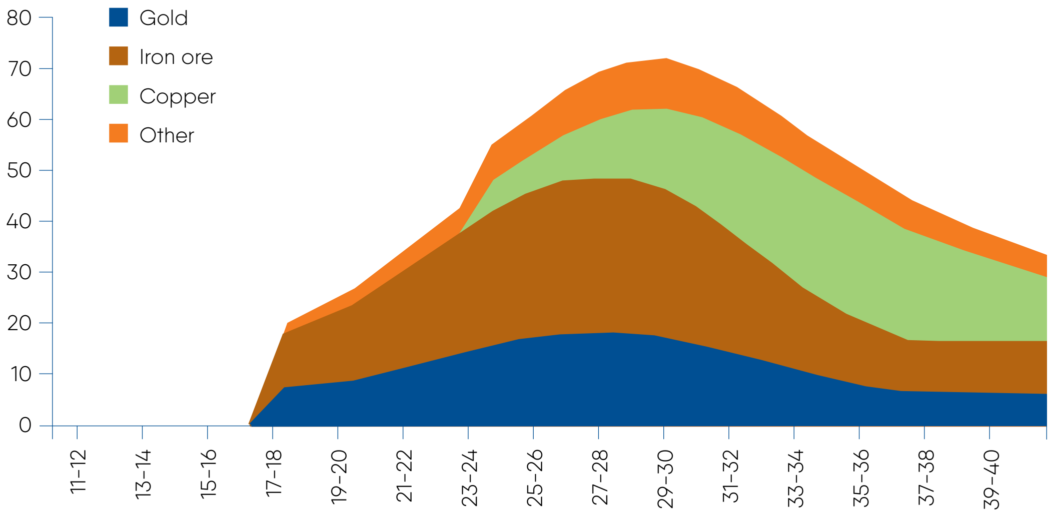


Table 21 – Summary of discovery brought forward gross benefits ($m)

Mining type	Sum	Present value
Gold ore	256.7	114.1
Iron ore	434.6	192.2
Copper	270.2	83.7
Other	149.4	71.7
Total	**1110.8**	**461.6**

Figure 35 – Impact of discovery brought forward ($m, 2015-16), by commodity



11.4 Spatially sensitive industries

AuScope's geospatial infrastructure and data can contribute to operational efficiencies (productivity) in various industries and parts of the public sector that utilise, or have the potential to utilise, spatial information.

In order to assess AuScope's contribution, we firstly estimate the current and future economic benefit of geospatial technology in general (i.e. not just AuScope-related) across various sectors of the Australian economy, expressed as the sum of:

- the productivity-based efficiency in supply costs; and
- the change in value-added due to the increase in output.

We then use this as a foundation to judge AuScope's relative contribution to this situation over time i.e. the incremental benefit of AuScope.

Impact scenario with AuScope

To estimate the current and future benefit of geospatial technology in general (including AuScope), we draw on 2013 research by ACIL Allen with Sinclair Knight Merz (SKM) and Lester Franks Surveyors and Planners for the then Australian Government Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (Space Coordination Office). This research across sectors[170] such as grains, mining, construction, road transport, and transport storage and handling is the most contemporary and comprehensive available studies of cost savings and industry adoption in the Australian context. ACIL Allen models increases in output associated with augmented GNSS services in 2012 and 2020 across various sectors (relative to what would have otherwise been), based on assumed levels of adoption and unit cost savings within a model of the Australian economy. ACIL Allen's low estimate is shown in Table 22, as adjusted by Lateral to be 2015-16 real terms.

Table 22 – Increases in sector outputs associated with augmented GNSS services ($m, 2015-16)

Sector	Sum		Present value	
	$m	% increase	$m	% increase
Grains	303	1.9%	840	7.6%
Dairy, beef	20	0.1%	114	0.4%
Other crops including sugar cane	1	0.1%	7	0.4%
Mining	741	0.4%	2,647	1.1%
Construction	478	0.1%	1,522	0.3%
Utilities	54	0.1%	188	0.3%
Road transport	104	0.2%	480	0.6%
Transport storage and handling	63	0.1%	101	0.1%
Rail transport	1	0.025%	11	0.1%
Aviation	11	0.035%	52	0.16%
Maritime	10	0.1%	45	0.4%

Note: Surveying is included in the construction and mining sectors. Data source: ACIL Allan 2013, pp.33

We use this to derive total output, and also project sectoral output to 2040-41 based on continued output growth at the same rate as between 2011-12 and 2019-20 (see Table 22). The one exception to this is the grains sector which had a -4% annual growth rate and which we have assumed stays stable in real terms (i.e. 0% growth rate from 2020-21) given uncertainty over whether this will contraction will continue into the longer-term.

170 Summarised in ACIL Allen Consulting 2013, The value of augmented GNSS in Australia: an overview of the economic and social benefits of the use of augmented GNSS services in Australia, report for the then Australian Government Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education. Further detail is available in individual sector reports (for example, ACIL Allen Consulting and SKM 2013, Precise positioning in the mining sector: an estimate of the economic and social benefits of the use of augmented GNSS in the mining sector).

Table 23 – Assumed sectoral output growth rate with augmented GNSS

Annual real growth rate in output	2019-20 and prior	2020-21 and after
Grains	-4%	0%
Dairy, beef	5%	5%
Other crops including sugar cane	5%	5%
Mining	3%	3%
Construction	1%	1%
Utilities	2%	2%
Road transport	6%	6%
Transport storage and handling	6%	6%
Rail transport	12%	12%
Aviation	1%	1%
Maritime	2%	2%

To assess the change in value-added due to the increase in output above, we:

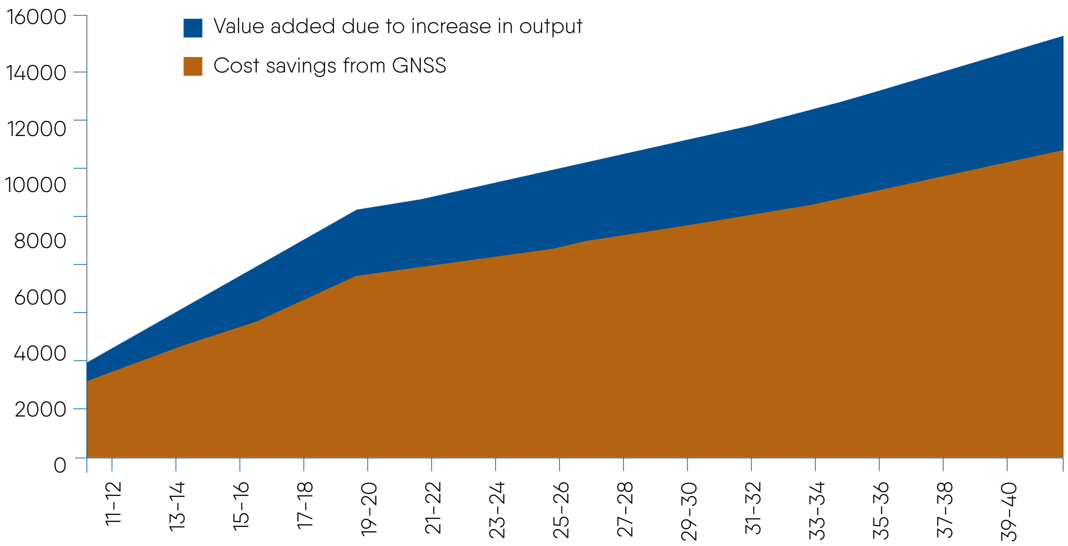
- calculate a value-added share of output for each sector using ABS input-output tables – which range from around 29% to 58% depending on the sector[171]
- apply the value-added share of output by sector to the increase in output by sector in each year.

Then, to assess the productivity-based efficiency in supply costs (cost saving), we firstly establish a trend for supply costs to 2039-40. We:

- calculate a supply-cost share of domestic output for each sector using ABS input-output tables[172]
- establish supply costs by year by applying the supply-cost share of domestic output by sector to the output by sector in each year
- apply productivity gain ratios derived from ACIL Allen (based on research and case studies) for each sector in 2011-12 and 2019-20 – assuming a linear increase between these years and a stable ratio for each subsequent year between 2020-21 and 2040-41 at the 2019-20 level.

These two effects combine as the current and future economic benefit of geospatial technology in general (inclusive of but not limited to AuScope), as shown in Figure 36.

Figure 36 – Economic effect of geospatial technology in general (inclusive but not limited to AuScope) ($m, 2015-16)



171 ABS 5209.0.55.001, Australian National Accounts: Input-Output Tables, 2012-13, released 25 June 2015. Calculated for each sector as the sum of Compensation of employees, Gross operating surplus & mixed income, and Other taxes less subsidies in employees, divided by output. For each sector: Grains – using Sheep, grains, beef and dairy cattle category in ABS data; Dairy, beef – using the same; Other crops including sugar care – using Other agriculture; Mining – using a weighted average of Iron ore mining and Non-ferrous metal ore mining; Construction – using a weighted average of Residential building construction, Non-residential building construction and Heavy and civil engineering construction; Utilities – using a weighted average of Electricity transmission, distribution, on-selling and electricity market operation, Gas supply, and Water supply, sewerage and drainage services; Road Transport – using road transport; Transport storage and handling – using Transport storage and handling; Rail transport – using Rail transport; Aviation – using Air and space transport; Maritime – using Water, pipeline and other transport.

172 Calculated for each sector as (Output minus Gross operating surplus minus Taxes less subsidies minus Other taxes less subsidies) divided by (Output)

Counterfactual scenario without AuScope

The counterfactual scenario without AuScope is the above scenario minus the incremental contribution of AuScope to that scenario. Without AuScope, precision or automation would be less precise and/or available in fewer parts of Australia than the above scenario. That is, unit cost savings and adoption levels could each be smaller. As such, to estimate AuScope's relative contribution, we assume AuScope can have two effects (which can be multiplied for an overall effect):

- positive change in the unit cost reduction rate (e.g. resulting from greater accuracy, or maintaining such accuracy over time) ('productivity')
- positive change in 'adoption' rate (e.g. from greater availability of precise applications, or maintaining availability, in particular locations)

Impact assumptions

The assumed pattern and scale of AuScope's incremental effect is based on input from geospatial stakeholders. It is highly indicative, as it is not common practice within geospatial fields to isolate the impact of one part of the geospatial system on geospatial applications, let alone assess that impact in quantitative terms. No literature was identified that could further validate the assumptions made.

In general, we assume that AuScope's impact is negligible in 2012, and increases over time as legacy infrastructure (i.e. what would have existed have AuScope not existed) becomes less fit-for-purpose in meeting community need for geospatial applications. However, we also assume that infrastructure equivalent to (or better than) that under AuScope would eventually be resourced, and from this point AuScope has effectively no impact (even if in reality the actual physical infrastructure built under AuScope would still be in use).

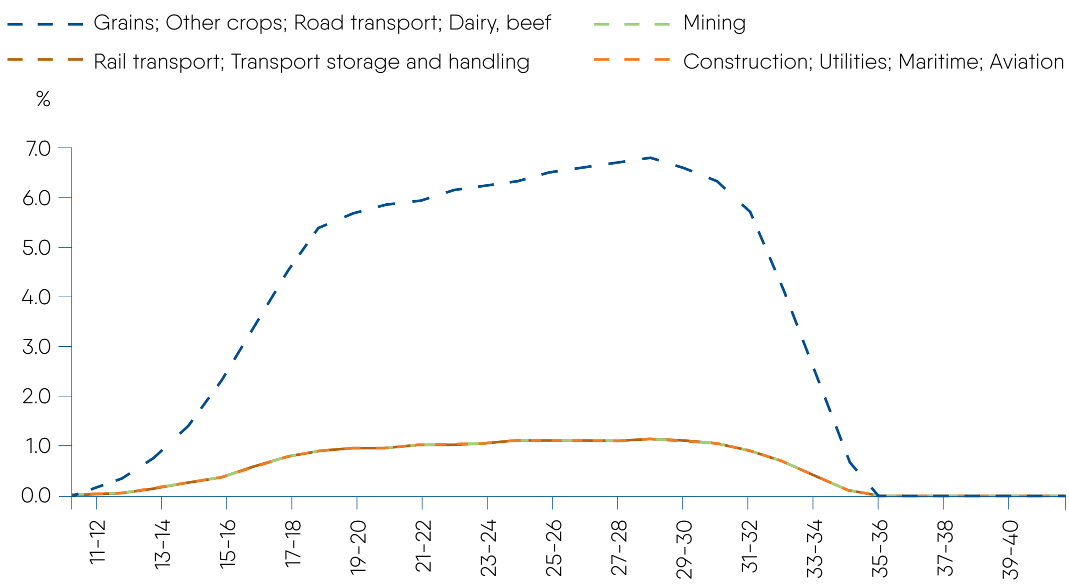
We also assume varying effects by sector, based on their location, precision applications, and use of substitutes for augmentation. We group similar sectors as:

- Grains; Other crops; Road transport; Dairy, beef
- Rail transport; Transport storage and handling
- Mining
- Construction; Utilities; Maritime; Aviation

Productivity in all sectors benefit to some extent from AuScope's contribution to maintaining reference system accuracy over time. As a general assumption we assume this peaks at 1% of productivity benefits of geospatial technology for most sectors.

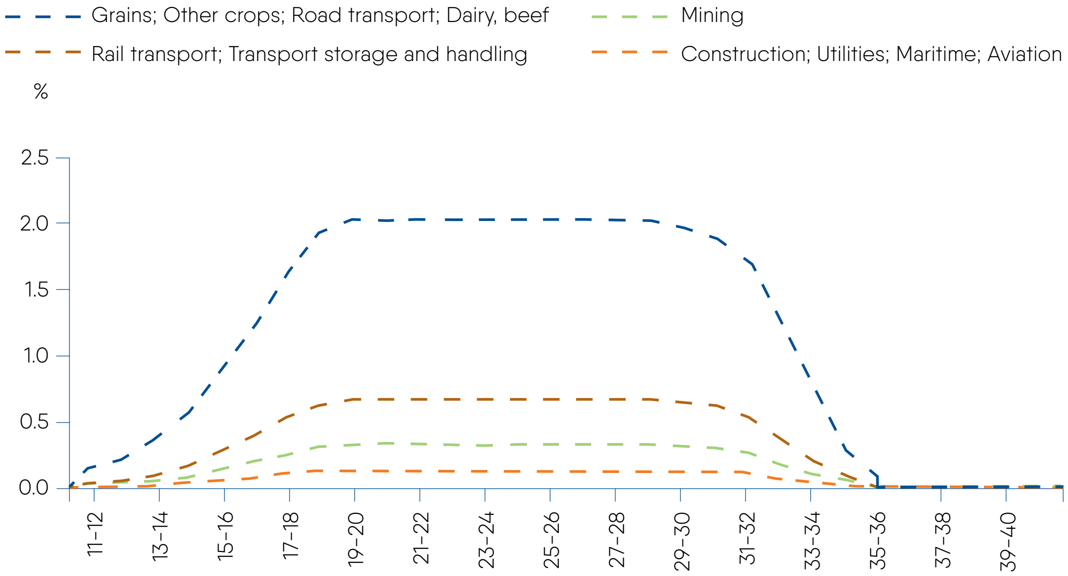
Significant larger productivity effects of AuScope (Figure 37) are assumed to be for cropping, livestock and road transport that without positioning accuracy cannot fully realise the potential of major geospatial applications (e.g. facilitation of automated machinery, or remote observation of pasture and breeding patterns). These are also in rural areas that may not have otherwise achieved augmentation technology without AuScope (although only in part for road transport).

Figure 37 - % change in unit cost reduction resulting from AuScope



There is also some assumed different in adoption rates by sector (Figure 38). This impact has more variation by sector. For example, construction is predominantly located in major urban centres that do not particularly benefit from CORS augmentation which occurred mainly in rural and regional areas, so we assume only low incremental adoption of geospatial resulting from AuScope. In general the effects for adoption are less than for productivity given the key effect of AuScope relates to helping technologies that industry use to work better, rather than making any geospatial application viable.

Figure 38 – % change in adoption rate resulting from AuScope



Impact results

The overall impact by group is shown in Figure 39. This is also shown as the overall difference between the two scenarios in Figure 40.

Figure 39 – Incremental value of AuScope by sector groups ($m, 2015-16)

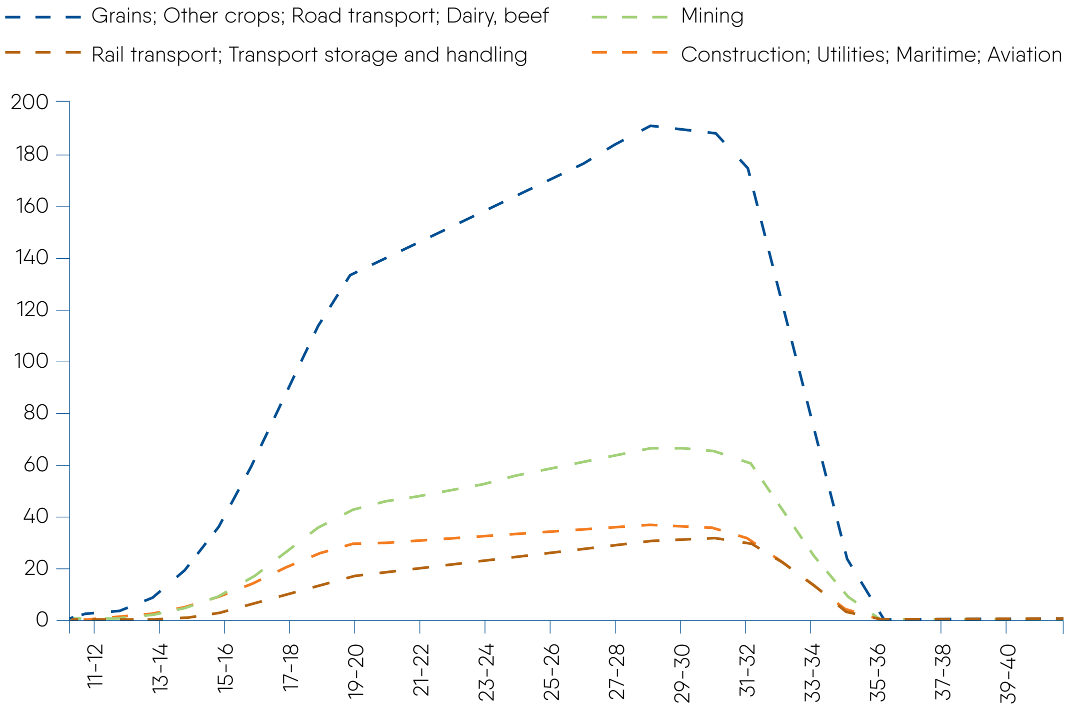
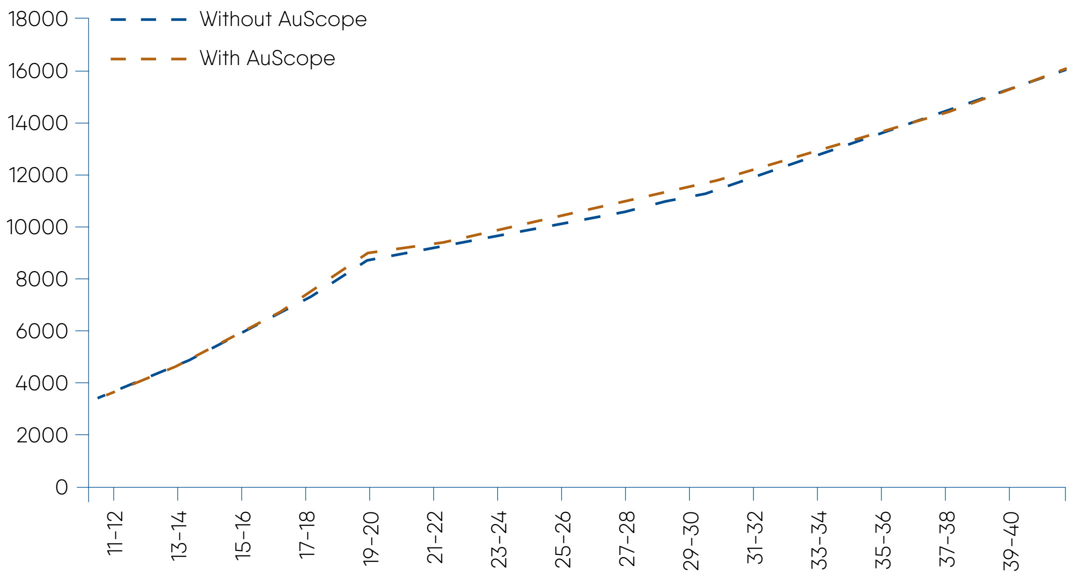


Figure 40 – Incremental value of AuScope geospatial ($m, 2015-16)



Expressed in present values, the effect is as Table 24. Major impacts are from grains ($787 million), road transport ($669 million), mining ($483 million), construction including land management and surveying ($272 million), and dairy and beef ($167 million).

Table 24 – Summary of AuScope geospatial gross benefits ($m)

Sector	Sum	Present value
Grains	1,387.8	786.9
Dairy, beef	325.2	167.2
Other crops including sugar cane	20.8	10.9
Mining	908.2	483.3
Construction	485.0	272.2
Utilities	33.9	18.3
Road transport	1303.6	669.0
Transport storage and handling	67.2	35.0
Rail transport	6.5	3.0
Aviation	28.6	15.6
Maritime	5.1	2.8
Total	**4,571.8**	**2,464.3**

11.5 Natural and built environment

There is reasonable evidence that disaster risk reduction activities in general are cost-beneficial. For example, a recent meta-analysis of cost-benefit analyses of various different disaster risk reduction activities (across various hazards and locations) indicated maximum BCRs from 3 to 15.[173] A major analysis in the US (probably most applicable to Australia) reporting an overall average BCR of 4.[174]

The benefit of AuScope is through informing better hazard prediction, land use planning and other mitigation activities or management decisions, which can reduce the economic costs of natural hazards. The benefit of geoinformatics is indirect but logical: "technologies themselves do not result in a reduction in damages and losses; it is the better decisions, facilitated by their use, which can bring this about". Experts consider that

173 Shrevea, C.M. Kelmanb, I. 2014, "Does mitigation save? Reviewing cost-benefit analyses of disaster risk reduction", International Journal of Disaster Risk Reduction, vol. 10, Part A, December, pp.213-235

174 Multihazard Mitigation Council 2005, Natural hazard mitigation saves: an independent study to assess the future savings from mitigation activities. Vol. 1 – Findings, Conclusions, and Recommendations. Vol. 2 – Study Documentation. Appendices. National Institute of Building Sciences, Washington, D.C.

some of the most important geoformation items for disaster mitigation are flood risk monitoring systems, flood risk maps, damage assessment maps and inundation maps (for flood), and Earthquake urban classification for risk analysis and damage assessment maps (for Earthquake).[175]

Counterfactual scenario without AuScope

We firstly estimate economic costs of natural hazards 'without AuScope' as a counterfactual, then use this to estimate the avoided costs attributable to AuScope's contribution to better planning for and management of natural hazards.

Total economic costs of natural hazards include not only tangible damage costs but also indirect tangible costs such as business interruption and emergency relief and recovery and intangible 'social costs' such as human injury and death and impacts of wellbeing. As an estimate of tangible damage costs under the counterfactual, we derived the expected insured loss per year based on historical data on natural disasters of different kinds (flood, storm, Earthquake) in Australia[176] to construct a value for a typical year. These figures were adjusted for inflation to 2015-16 terms.

We then adjusted the damage cost figure to account for 'total economic losses', based on ratios (5 for storm, 18 for flood, and 7 for Earthquake) developed in a 2016 report by Deloitte Access Economics which built on earlier work by the Australian Government Bureau of Infrastructure, Transport and Regional Economics.[177] These ratios were based on case studies and other detailed empirical evidence on the scale of indirect tangible costs and intangible social costs.

The counterfactual annualised total economic losses from relevant natural hazards, for the year 2015-16, is approximately $17,174 million:

- $8,831 million for storm (inclusive of hailstorm and cyclone)
- $7,231 million for flood
- $1,114 million for Earthquake.

A projection of total economic losses from relevant natural hazards under the counterfactual was then made to 2040-41, using a standard real annual increase (2.5%) to broadly reflect economic growth.

Impact scenario with AuScope

The assumed pattern and scale of AuScope's incremental effect is based on qualitative input from stakeholders. It is also highly indicative, given the range of factors affecting risk reduction activities and the lack of economic literature that can further validate the assumptions made.

AuScope's impact on this counterfactual is reasonably modest, with AuScope being only one contributor to hazard management. We assume (summarised in Figure 41):

- AuScope's impact grows over time as data from AuScope and resultant research becomes known and used, then AuScope becomes relatively less influential over time as other knowledge sources take over.
  - For flood and storm, this is reflected in a roll-out rate that starts at 0% of peak cost reduction (see below) in 2010-11, grows to 100% of peak from 2020-21 to 2022-23 then reduces to 30% by 2040-41. For example, even though LIDAR data for flood modelling has been referenced against the AuScope ground network for position and height control, it will take time to flow through to practical flood management initiatives.
  - For Earthquake, there is a further lag of four years, as Geoscience Australia is only now starting to generate detailed analysis resulting from AuScope-derived data.
- Peak cost reduction is 0.3% of the counterfactual level of annualised economic costs for storm, 0.2% flood and 0.1% Earthquake.
  - Different levels of cost reduction for different hazards acknowledges the different contexts, for example, the multiple uses of spatial information in flood planning and real-time operations[178], and the challenges in Earthquake prediction in regions like Australia that are not at plate boundaries. As acknowledged earlier, assumptions around the level of cost reduction are highly indicative given the absence of established evidence.

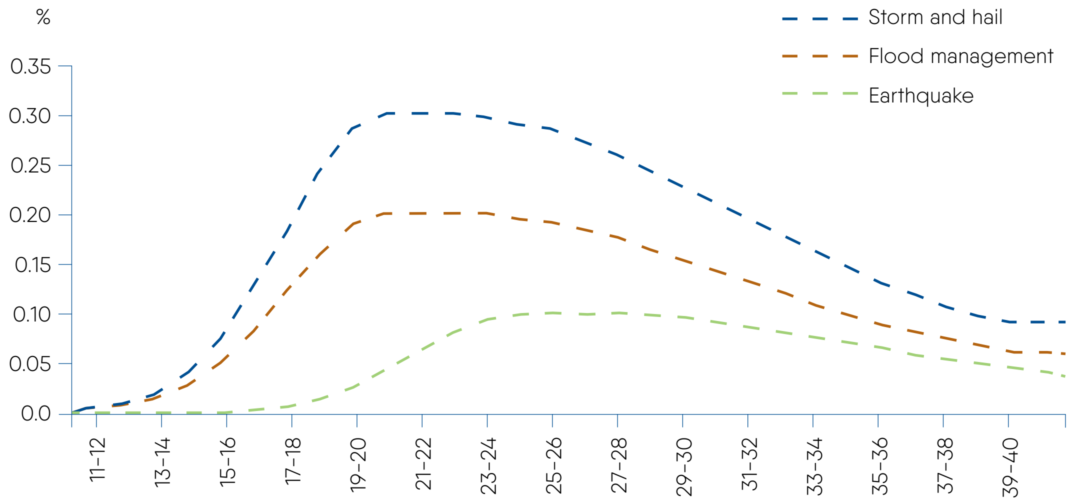
175 Altan, O., Backhaus, R., Boccardo, P., Tonolo, F.G., Trinder, J. van Manen, N., Zlatanova, S. (eds) 2013, The Value of Geoinformation for Disaster and Risk Management (VALID) – Benefit Analysis and Stakeholder Assessment, International Council for Science (ICSU) - Geo-Unions, Joint Board of Geospatial Information Societies (JB GIS) 2013, United Nations Office for Outer Space Affairs (OOSA), p.12, http://www.unspider. org/sites/default/files/VALIDPublication.pdf

176 Derived from ICA (Insurance Council of Australia) Catastrophe Dataset, https://docs.google.com/spreadsheets/d/1vOVUkIm2RR_XU1hR6dbGMT7QFj4I0BGI_JAq4-c9mcs/edit#gid=2147027033. We utilised 6 floods recorded in the most recent 6 years; 42 cases of storm, hailstorm, cyclone and tornado in the more recent 3 years; and 5 cases of Earthquake in the last 30 years.

177 Deloitte Access Economics 2016, The economic cost of the social impact of natural disasters, report for the Australian Business Roundtable for Disaster Resilience & Safer Communities, p. 95

178 See, for example, http://www.ses.nsw.gov.au/resources/research/gis-and-spatial-data/gis-and-spatial-data-in-the-service-of-flood-management

Figure 41 – Assumed natural hazard economic cost reduction impact of AuScope (% of economic costs)



Impact results

Combined, the cost reduction effect over time is shown in Figure 42. This (small) difference between the two scenarios is also shown in Figure 43, which illustrates the small proportional change of overall economic costs.

The total present value of AuScope's impact on storm, flood and Earthquake are estimated to be $305 million, $166 million and $10 million respectively – or $481 million combined.

Table 25 – Summary of natural hazard reduction gross benefits ($m)

Natural hazard	Sum	Present value
Storm/cyclone and hail	617.9	304.6
Flood	337.3	166.3
Earthquake	25.8	10.3
Total	1,149.8	481.2

Figure 42 – Projected avoided costs of natural hazards due to AuScope ($m, 2015-16)

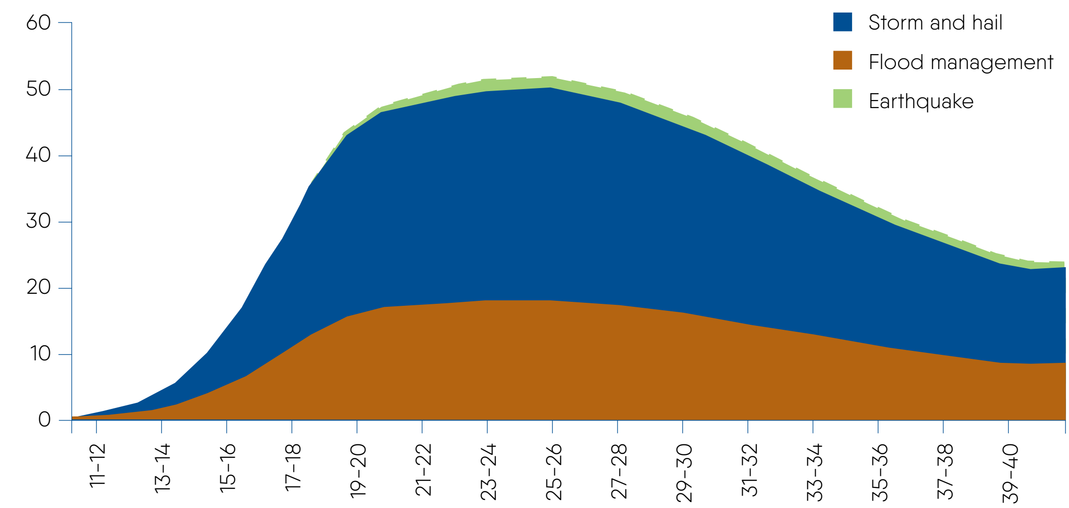
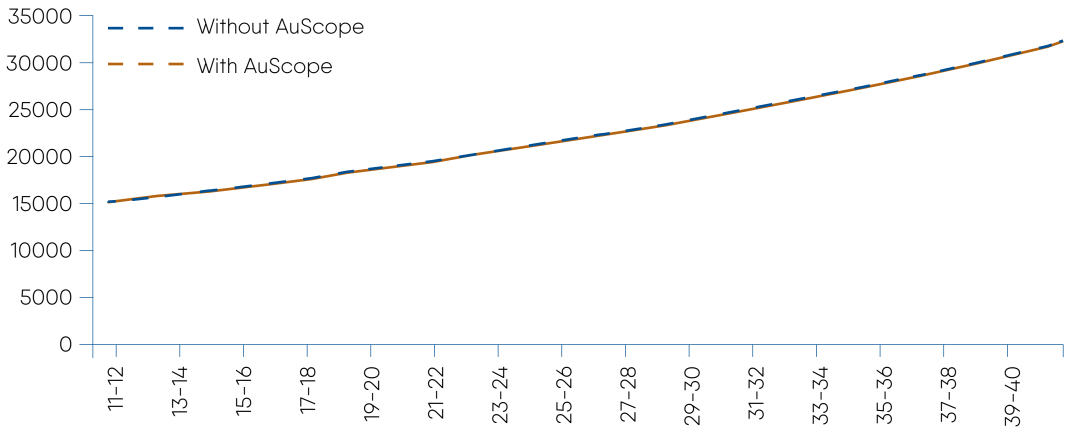


Figure 43 – Projected real annual natural hazard costs with and without AuScope ($m, 2015-16)



11.6 Existence value

Existence value (i.e. the value the community places on basic scientific knowledge that does not necessarily result in downstream usage) is challenging to quantify. The standard approach to quantifying such intangible values in fields such as environmental economics is through generating empirical estimates of society-wide willingness-to-pay (WTP) through various techniques of stated or revealed preference (e.g. contingent valuation surveying).

Estimation of WTP for scientific research is an under-developed area of economic literature. Our literature review indicated only one major study – a very recent project supported by the European Investment Bank Institute exploring what it calls "for the first time, an empirical estimation of the willingness to pay for discoveries in basic research by the general public". The study focusses on the existence value (for Europe) of Large Hadron Collider participle accelerate at CERN in Switzerland, based on a contingent valuation survey designed for this specific purpose. The existence value was assessed as €3.2 billion, equivalent to 24% of the Large Hadron Collider's substantial economic costs.[179]

We are not aware of any relevant data regarding social preferences of the Australian public that can be used to infer a value to the knowledge and scientific discovery generated from basic research associated with AuScope. AuScope is of a much smaller scale to the Large Hadron Collider and not directly analogous. However, in order to recognise the likely presence of existence value, we adopt a conservative assumption that AuScope existence value is equivalent to 10% of AuScope's economic costs. This is likely to be a considerable under-estimate, given long-standing public investment in fundamental Earth sciences (including but not limited to through universities) indicates that the Australian community values fundamental Earth science at a level at least equivalent to public expenditures for this purpose.

11.7 International contribution

In this analysis, the economic benefit of international users utilising AuScope outputs/knowledge is targeted to how Australians benefit from such usage, given the standing is limited to Australia. The method used for assessing this is relatively rudimentary given substantial uncertainty, and provides a modest value relative to other impacts.

Firstly, we assume that only a proportion of AuScope is utilised internationally. As with adoption trends on other impact areas, we assume a ramp-up of adoption:

- starting at 0% in 2011-12, rising to 10% in 2020-21 and thereafter staying stable

We then assume, some proportion of that overseas work returns to Australia in a manner that adds value to Australia:

- the same trend, but with a lag of three years (for the first international work to be conducted) – i.e. starting at 0% in 2014-15, rising to 10% in 2023-24 and thereafter staying stable

179 For more detail on the method used in the Large Hadron Collider assessment, see Florio M, Forte S, Sirtoro E 2016, "Forecasting the socio-economic impact of the Large Hadron Collider: A cost-benefit analysis to 2025 and beyond", Technological Forecasting & Social Change, in press and Catalnao G, Florio M, Giffoni 2016, "Contingent valuation of social preference for science as a pure public good: the LHR case", DEMM working paper, University of Milan

This creates an impact that rises from 0% in 2011-12 to 1.0% by 2023-24. We then assume the additional value created is proportionate to the value for the other four areas combined (i.e. resource exploration, spatially-sensitive industries, natural and built environment, fundamental science). For example, the benefit from international contribution in the year 2023-24 equals 1.0% multiplied by the gross benefit of the other four areas of impact in 2023-24.

11.8 Costs

We assume that financial costs of AuScope from 2007-08 to 2014-15 are a reasonable proxy for the economic costs incurred by society (i.e. the opportunity cost of resources utilised for AuScope), given competitively determined market prices for labour and capital equipment. This includes costs financed by NCRIS funding as well as cash and in-kind contributions by AuScope partners (universities, government agencies).

In-kind contributions are mostly personnel. It could be argued that personnel contributions should not be included if NCRIS partners would still incur these costs (i.e. employ the personnel) in the absence of AuScope, particularly if the AuScope activity is only a minor part of relevant personnel's work. The opposite could also be argued – that NCRIS partners would not employ (or continue to employ) the labour time of such personnel in aggregate if it were not for AuScope, and so the opportunity cost of their wages and on-costs should be included. Taking a conservative approach, we include non-cash in-kind contributions as a cost of AuScope (even if this may not strictly be the case in some situations).

We assume that reported cash and in-kind contributions by AuScope partners to AuScope (which were only available as totals) are phased across years as per NCRIS cash expenditure. We also assume a small annual cost of $0.25 million (nominal) continues through to 2023-24, intended to recognise the in-kind operational resources AuScope partners continue to apply for AuScope-related data and infrastructure to be accessible for use.

A further economic cost included is the marginal excess burden of taxation. Sources of funding for AuScope are almost entirely government (whether directly through NCRIS or through budgets of public universities or government department budgets). Raising government revenue to invest in science is not costless to society. There is a cost to society from raising revenue through taxation. Consistent with recent Productivity Commission analysis derived from Treasury analysis, we apply a rate of 24% on the economic costs to account for such 'deadweight loss'.[180]

Table 26 provides a summary of economic costs in nominal terms.

180 Productivity Commission 2011, Disability Care and Support, inquiry report no.54, volume 2, 31 July, pp.955. This discusses studies undertaken for the Henry Tax review suggesting that the MEB of income tax is around 24 per cent. Using a MEB for income tax is reasonable given AuScope is principally funded from federal tax revenues.

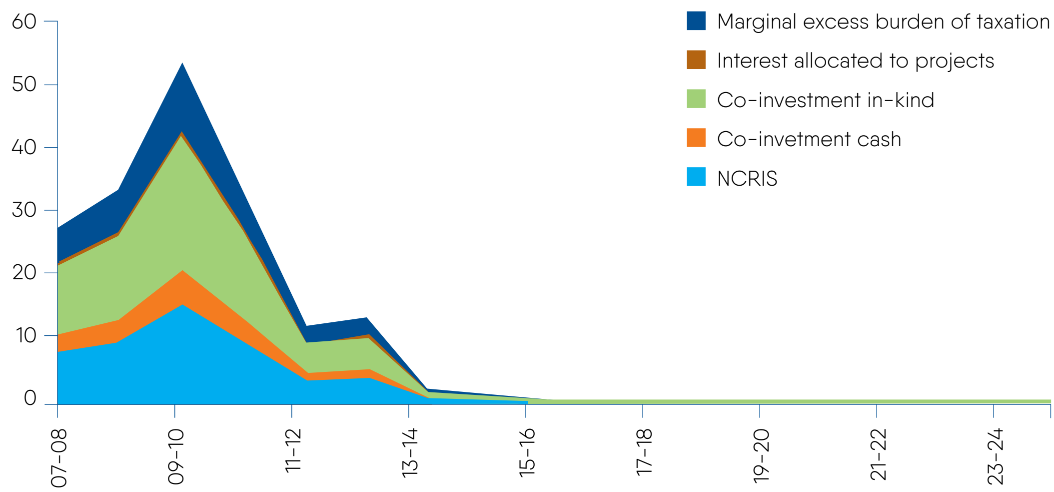
Table 26 – Summary of AuScope economic costs in nominal annual values ($m, nominal)

Cost type / Year	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16 to 23-24	Total
NCRIS cash										
Geospatial	1.30	2.83	3.72	3.62	0.66	2.92	0.36	0.08	-	15.47
Earth imaging	1.45	1.23	3.85	1.08	0.07	0.00	0.00	0.00	-	7.68
NVCL	0.00	0.82	1.20	0.20	0.43	0.00	0.00	0.00	-	2.65
ECE (geochem)	1.62	0.20	0.32	0.50	0.13	0.00	0.00	0.00	-	2.77
SAM	1.41	1.11	2.19	1.44	1.25	0.00	0.00	0.00	-	7.41
GRID	0.33	1.68	1.66	1.49	0.43	0.31	0.00	0.00	-	5.90
NCRIS sub-total	6.10	7.87	12.94	8.33	2.97	3.23	0.36	0.08	-	41.88
HQ	0.29	0.17	0.20	0.24	0.08	0.23	0.15	0.15	-	1.51
NCRIS Total	6.39	8.04	13.14	8.57	3.05	3.46	0.51	0.23	-	43.39
Phasing over time	14.7%	18.5%	30.3%	19.8%	7.0%	8.0%	1.2%	0.5%	-	
Cash co-investment	2.25	2.83	4.63	3.02	1.08	1.22	0.18	0.08	-	15.28
In-kind co-investment	8.86	11.16	18.24	11.90	4.24	4.80	0.70	0.32	0.25 annually	62.47
Interest allocated to projects	0.43	0.54	0.88	0.57	0.20	0.23	0.03	0.02	-	2.89
Total resources used	**17.92**	**22.57**	**36.87**	**24.06**	**8.57**	**9.71**	**1.42**	**0.65**	**0.25 annually**	**124.03**
Marginal excess burden of taxation	4.30	5.42	8.85	5.77	2.06	2.33	0.34	0.15	0.06 annually	29.77
Economic cost	**22.22**	**27.98**	**45.72**	**29.83**	**10.63**	**12.05**	**1.76**	**0.80**	**0.31 annually**	**153.79**

Source: AuScope reporting (nominal value by year).

Adjusting these nominal values to 2015-16 dollars, the total cost is $175.3 million, phased as shown in Figure 44. In present value terms, the economic cost is $260.6 million.

Figure 44 – Economic cost profile of AuScope ($m, 2015-16)



11.9 Sensitivity tests

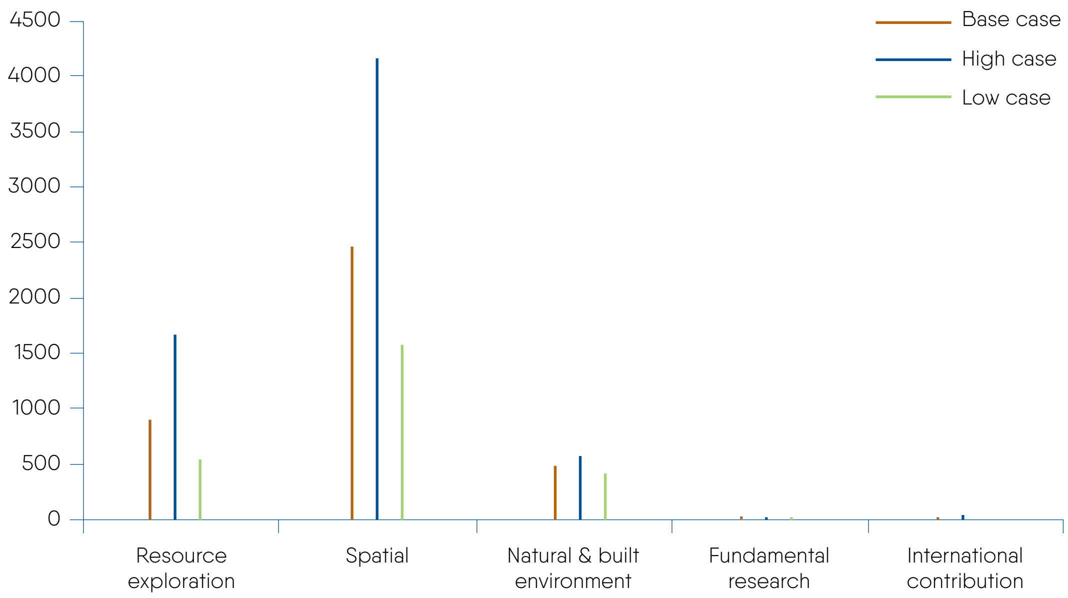
Overview

We incorporate two sensitivities in addition to the base case: a 'high case' and a 'low case'. These are generated through applying a package of changes to the base case, adjusting:

- the real social discount rate (using sensitivities of 3% and 10%, as per OBPR requirements)
- annual growth rates in various general industry or market matters
- various assumptions regarding the main impact areas of resource exploration and spatially sensitive industries

Figure 45 highlights the effects of the sensitivity tests on the various impact areas (gross benefit).

Figure 45 – Effect of sensitivity tests on impact areas gross benefit ($m, present value)



High case

Table 27 details the package of assumptions for the 'high' case sensitivity test.

Table 27 – Assumptions for the 'high' sensitivity test

Category	Base Case	'High' sensitivity test
Real social discount rate	**7.0%**	**3.0%**
General industry or market growth rates		
Exploration cost savings		
Exploration expenditure from 2016-17	2.5%	+0.2% (2.7%)
Discovery brought forward		
Market value of gold and iron ore from 2021-22	0%	+0.2% (0.2%)
Market value of copper from 2021-22	2.5%	+0.2% (2.7%)
Spatially sensitive industries		
Output of each sector from 2020-21	Varies between 0% and 12.1%, by sector	+0.2% (varies between 0.2% and 12.3%)
Impact assumptions		
Exploration cost savings		
% reduction in exploration cost	Varies over time (see Figure 27)	1.2 x base case
Discovery brought forward		
Average difference in cost saving (gold)	0.5%	1.2x base case (0.6%)
Average difference in cost saving (iron ore)	0.2%	1.2x base case (0.24%)
Average difference in cost saving (copper)	0.7%	1.2x base case (0.84%)
Spatially-sensitive industries		
% change in unit cost reduction rate	Varies over time (see Figure 37)	1.2x base case
% change in adoption rate	Varies over time (see Figure 38)	1.2x base case

Low case

Table 28 details the package of assumptions for the 'high' case sensitivity test.

Table 28 – Assumptions for the 'low' sensitivity test

Category	Base Case	'Low' sensitivity test
Real social discount rate	**7.0%**	**10.0%**
General industry or market growth rates		
Exploration cost savings		
Exploration expenditure from 2016-17	2.5%	-0.2% (2.3%)
Discovery brought forward		
Market value of gold and iron ore from 2021-22	0%	-0.2% (-0.2%)
Market value of copper from 2021-22	2.5%	-0.2% (2.3%)
Spatially sensitive industries		
Output of each sector from 2020-21	Varies between 0% and 12.1%, by sector	-0.2% (varies between -0.2% and 11.9%)
Impact assumptions		
Exploration cost savings		
% reduction in exploration cost	Varies over time	1.2 x base case
Discovery brought forward	(see Figure 27)	
Average difference in cost saving (gold)	0.5%	0.8x base case (0.4%)
Average difference in cost saving (iron ore)	0.2%	0.8x base case (0.16%)
Average difference in cost saving (copper)	0.7%	0.8x base case (0.56%)
Spatially-sensitive industries		
% change in unit cost reduction rate	Varies over time (see Figure 37)	0.8x base case
% change in adoption rate	Varies over time (see Figure 38)	0.8x base case

AuScope