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Precision to Decision – Current and Future State of Agricultural Data in Australia

3 August 2017

1 Executive summary (one-page summary)

- Include key recommendations

2 Scope

Digital agriculture is a diverse field across both multiple agricultural industry sectors and associated product and services supply chains. In addition, the systems and business models used will potentially vary across the industries. Thus while there are multiple potential opportunities across this business landscape, reviewing them all is a significant undertaking and is much better suited to industry-specific analysis. The report focuses on cross-sectorial, publicly available data and decision tools relevant to Australian producers. The term ‘sector’ here means the primary natural resource sectors, agriculture, fisheries and forestry and the industries within these. We have further grouped agricultural industries into cropping and livestock. This grouping focuses attention on the datasets common to the industries and acts as a guide for prioritising recommendations.

We consider datasets available and accessible for and relevant to producers and service providers. This includes data and tools provided by government or statutory authorities within Australia as well as datasets and tools provided by commercial service providers. The limitations of access to commercial products has limited the information on some of these products. The information from these sites has been presented as reported by the company.

The scope is also limited to considering data and decision tools that impact on activities directly related to production. We note that there is some ambiguity in this as a key opportunity of digital agriculture is to increase information flow though the value chain. This information can then drive on-farm decisions. Given this, we believe that the primary cross-sectorial opportunities will be in common information architectures rather than in shared decision tools and data.

Many websites, such as the Biosecurity Portal, provide a lot of information as fact sheets and pdf files. We have not included these except where specific data and tools are provided.

The findings and recommendations in this report are based on discussions with industry experts, service providers and producers during interviews and producer workshops. Ethics approval was obtained on the basis that the information was anonymised.

3 Recommendations

Recommendation

> Establishment and ongoing funding be provided to establish and support a national Facility to fill a critical gap in Australia’s overall system for monitoring and managing its natural resources, and in particular, its agricultural landscapes.

Recommendation

It is recommended that this new Facility be closely integrated with existing national facilities and other national agencies in related fields to generate economies of scale and accelerate the rate of discovery and innovation.

Recommendation

Mapping and monitoring of soil change by this Facility needs to be based on agreed specifications that address the required accuracy and precision for different systems of land use and locations. A recommended initial focus is on soil nutrients, acidification, carbon, soil-water balance and soil microbial populations noting that the Facility is intended to serve both public and private sector interests.

Recommendations

Australian governments should increase available funding for the development of statistically well calibrated seasonal forecasts at fine scale specific to Australian landscapes and industry requirements including the development of industry specific weather metrics.

Recommendation

Australian governments should increase funding to assimilate global climate forecasting tools into decision support tools for Australian producers. Access to an increasing number of forecasting products and data is increasing. Analytics needed to merge these outputs can improve predictions over any individual product thereby benefitting the end user.

Recommendation

Existing decision support tools should allow for producer needs outside of production focussed outcomes and objectives. Funding is recommended for research aimed at defining a broader view of desirable outcomes for producers such as achieving better physical and mental health for producers and their families while achieving traditional production goals.

Recommendation

Further development of analytic tools is recommended to facilitate on-farm experimentation. Over time, these tools would producers to make robust decisions that they feel are more relevant to their unique environment.

Recommendation

Funding support is recommended for research into new technologies like homomorphic encryption applied to data sharing platforms to benefit producer and agricultural industries while ensuring confidentiality. Table of Contents

4 Introduction

Digital technologies are currently underpinning revolutions in business and society. This is occurring on two levels: (i) improvements to the efficiency of traditional/conventional business models, and (ii) the creation/development of completely novel and innovative new business models. New technologies have always driven improvements to business efficiency. In particular, digital technologies have driven major efficiency gains since the late 1970s. But more radical changes have occurred as well. Digital technologies, and the complex infrastructures such as the internet created by them has opened up entirely new business models and opportunities. Whole industries can be disrupted. New industries can arise where none existed before.

The power and reach of digital corporations is clear. The top five US companies based on market capitalisation are technology companies – Apple, Alphabet, Microsoft, Amazon and Facebook. Companies such as Uber who enable a ride-sharing service can enter local markets in contravention of existing regulation and effectively force change that is advantageous to them. A company such as Alphabet (i.e. Google) has access to staggering amounts of information both in terms of total documents and the underlying knowledge of people's behaviours and browsing activities.

Agricultural industries have long been innovators in the use of technology. Mechanisation, industrial production of fertilisers and pesticides and the dramatic improvement in the varieties and breeds have led to substantial productivity improvements over the previous century. Digital technologies have been part of this increase in efficiency. For example, computers have been used to develop models to predict yield based on management choices which can be used to aid decision making. Global positioning technology has been used in broad acre cropping since the 1990s to implement auto-steer systems in machinery. Farm management is routinely performed via spreadsheets and databases.

The advent of GPS and yield monitors heralded the beginnings of precision agriculture. The core idea of precision agriculture was that collection and analysis of spatial information would allow more efficient production. More recently there has been heightened interest and associated hype around digital agriculture. This is being driven by a range of forces and was initially centred in the US. The primary opportunities have arisen by the confluence of a number of factors. First, the cost of collecting data is falling as new technology comes online. Machinery is increasingly 'smart' and is sensorised and able to communicate digitally. Second, the computing platforms and services such as the cloud are becoming ubiquitous, providing natural platforms to deliver digital agriculture services. Third, existing agricultural companies are going digital to ensure their future relevance and to open new data streams to exploit to develop new products and services. Fourth, there are a range of successful digital business models that are being imported into the agriculture space. For example, Google has shown that having access to data about users can provide information to sell to advertisers, as well as information to tailor the experience to individual users. Some digital agriculture companies are trying to replicate this model. Other companies are trying to implement decision-support techniques in agriculture which are well developed in business analytics (for example dashboards) to provide situational awareness to managers.

These factors combine with the relative lack of maturity of the industry to produce a complex range of products in the market. Some products are centred on a new sensor technology such as drones. Some are centred on providing services to support information platforms using cloud services. Some are trying to integrate information to support more integrated information. Some are trying to setup more complex business models around producers and suppliers. And some are doing a mixture of all of these. There is also a variety of start-ups in this space that will pivot their business models to find a profitable configuration. So, the diversity can be quite bewildering. A key event in the development of digital agriculture was Monsanto's buyout of The Climate Corporation for USD$930 million. The Climate Corporation, a data-mining company, underwrites weather insurance for farmers thereby protecting the USD$3 trillion global agriculture industry from extreme weather events[1], it does this by ingesting extensive freely available public weather and geological open data gathered by the US Landsat satellite. It takes the eight years' worth of soil, moisture, and precipitation records for each of the 29 million farm fields in the USA to generate 10 trillion simulation data points. This amounts to processing 50 terabytes of weather information every day.

There are numerous other examples. John Deere has said precision services and its 'intelligent solutions group' would be a major piece of doubling its size from a USD$25 billion company in 2010 to a USD$50 billion company by 2018. Recently Amazon paid USD$13.7 billion to buy Whole Foods Market in the US. Whole Foods Market aspire to several standards for many of their products; sustainability in seafood, antibiotics in meat and pesticides in vegetables among others. To validate these claims, data on specific items need to be kept right through the production chain.

There is still considerable debate about the real potential business value of digital products and services in agriculture. It could be argued that many offerings are speculative. In addition, the platforms and technology are only now maturing so the industry has not consolidated. As companies seek market share they may trade current profitability for future earnings. For example, the ride-sharing service Uber is still valued at around USD$70billion while in the last three months of 2016 alone, the company lost USD$991 million.[2]

Many of the systems and platforms in digital agriculture have been developed in the US. This reflects the larger US market, the location of the major agribusinesses in that market and the bigger pool of venture capital. Many of the major platforms are in the process of establishing Australian operations and/or franchises. In a comprehensive report, the Australian Farm Institute (AFI) identified a number of potential challenges to the existing US technologies being applied in Australia. In particular they noted that the lack of publicly available soil and weather data meant that established approaches in the US corn and soybean industries would not directly transfer to the Australian market. The USA has detailed soil and weather information that Australia lacks.

This report explores these issues. In particular it considers whether the lack of available data in Australia will limit the benefit that can be derived from the adoption of digital technologies. It surveys currently available data sources and decision-support tools. Based on interviews with producers and industry representatives as well as independent research, it considers where future

[1] Jeni Tennison Director of Open Addresses UK and Technical Director of the Open Data Institute, 'The Economic Impact of Open Data: What Do We Already Know?', *HuffPost UK*, http://www.huffingtonpost.co.uk/jeni-tennison/economic-impact-of-open-data_b_8434234.html.

[2] Chris Mills, 'Uber Can't Stop Losing Money', *BGR*, April 14, 2017, http://bgr.com/2017/04/14/uber-2016-profit-loss-financials/.

investment may give economic returns. The review will serve as a resource for producers, policy makers and commercial technology suppliers to guide their decisions for future investment and planning.

The report is organised as follows. The following section defines digital agriculture and discusses how it is more than just collecting data. In Section 6, agricultural data is looked at from a workshop perspective. We describe the current and future state of data with respect to remote sensing/imagery, soils, weather, climate, and land boundaries in Section 7. The role of decision-support tools in the agricultural sector is presented in Section 8. In Section 9, we present our recommendations followed by a discussion. A summary of our workshop findings, a table of currently available cross-sectoral data sources, and a table of available agriculture-based decision-support tools can be found in the appendices in Section 10.

5 Digital agriculture: more than data collection

Digital agriculture is a generic term that is associated with the application of digital technologies to the farming sector. Digital agriculture typically involves both the collection and analysis of data to improve both on- and off-farm decision making leading to better business outcomes. While this has always occurred in agriculture to some extent, recent developments in sensor technology, data storage, analytics and robotics have opened up a large range of new opportunities to exploit the learning paradigm enabled by digital technology. At its heart, digital agriculture is about having sufficient data and associated analytics to explain observed variation and to act upon this information.

The term digital agriculture is applied to a very broad range of activities. This is due to a number of factors. Firstly, there are a diverse set of industries in the agricultural sector, ranging from broad acre cropping and livestock enterprises to intensive horticulture and livestock industries. Second, the value of data occurs across the value chain. Data is important for primary production but it is also important for processers, distributors and consumers. Third, data can provide value in multiple ways. Value can be created by isolated data collection targeted at particular management questions. As an example, a producer may monitor their soil moisture to be more efficient in their water use. But significant value is also potentially available by sharing this data between producers in a region. Fourth, the flow of data across the value chain can create value. Consumer preferences can inform livestock breeding. Quality data revealed during processing can be fed back to the producer to inform their management. Provenance data from a producer can be communicated to a consumer.

Given the broad definition of digital agriculture it is not surprising that the data used in agricultural industries is diverse. Some data is generally useful across sectors. Some is specific to an industry domain. Data can be spatial such as weather observations and yield data. It can be genetic information related to the farmed organism. It can be text-based information from consumer feedback. Technologies are needed to create, manage and analyse this data. In particular, platforms are becoming available to assist in these tasks.

In summary, the agriculture of the future will potentially be digitally enhanced at all stages of production, from the primary breeding and production, to processing and logistics and finally to the consumer. Agricultural industries can become more productive and sustainable with a greater capacity to innovate and risk manage their operations.

6 Cross sectoral data and decision tools in Australian agriculture

Australian agriculture is at an important juncture. Digital technologies are disrupting existing business models and transforming all aspects of the Australian and world economy. There is an existing and successful agricultural technology and advisory sector in Australia but the pool of resources to develop new technology is limited. There are major investments in new digital agriculture platforms occurring internationally. The challenge is to ensure that the potential efficiency gains from digital agriculture are achieved. Failing to do so is a risk to Australia's competitiveness.

Whether Australia can mitigate the risks and grasp the opportunities depends on a number of issues. First, it needs to provide opportunities for Australian companies to develop appropriate technologies. Second, there is opportunity to leverage off the international investments in platforms to access cutting edge technology developed in other markets. To allow this to happen requires understanding what potential barriers to this occurring exist. In particular, are there gaps in our data holdings and infrastructure that will make the Australian market less attractive for investment and development? The third issue is whether tools and platforms developed for other markets will be fit for purpose for Australian enterprises. Australian farming systems have similarities and differences to those overseas. A key policy question is whether these differences will lead to significant barriers or delays to entry and whether this risk can be mitigated in some way.

The primary data collection process of this project was based on interviews with people involved in Australian agriculture. This was done based on a number of different avenues. First, we attended eight regional workshops across multiple agricultural sectors and locations in Australia (details in the appendices). These workshops varied in their composition depending on the industry but typically involved primary producers and agronomists and advisors. In some cases, government scientists, academics, and digital platform consultants and banking officials attended. A second strand of activity was targeted at the fifteen research and development corporations. We conducted interviews with several of these. The third avenue was a workshop with technology companies that are active in Australian agriculture. This was supplemented by interviewing additional product representatives. The fourth avenue was through the engagement of agricultural and data experts to explore existing data holdings and to discuss high value opportunities to pursue.

While these interviews were targeted at exploring the use of data and decision tools with the aim of identifying cross-sectoral opportunities, a number of broader observations can be made. The first point to note is that while there is great awareness of the potential of digital agriculture, the development of the skills and products to exploit it is only beginning. There are fundamental issues with data processing and interoperability between systems. While individual sensor systems such as soil moisture or yield and the associated analytics to process them are becoming more commonplace there is still significant work needed to develop integrated solutions. There is a near-universal understanding that more and more data is become available to make decisions; the problem is framed in terms of how to analyse these streams to take value from this data.

The second point to note is that there is currently a range of successful technology and advisory companies servicing Australian agriculture. International companies are developing presences in Australia, either independently or in partnership with Australian companies. While it is early days in the development of these industries there is significant activity.

The third point is the sheer diversity of potential opportunities for the use of data. The opportunity to 'learn the farm', to benchmark production, to provide …

The fourth point is the lack of coherent views.

Overall the interview process identified five key areas of cross-sectoral data. These were soils, remote sensing/imagery, weather, climate and land use/land boundaries. We consider these in the next section.

7 Cross-sectoral data: current, future, and recommendations

Governor Phillip had been instructed to begin cultivation immediately on landing the First Fleet in Sydney Cove in 1788. The first wheat crop was grown nearby at the site of the existing Botanical Gardens. European farming practices applied to a comparatively barren landscape with different climate brought the new colony close to starvation. One of the more successful of the early European farmers in Australia, James Ruse, was recorded to have grown corn in the Parramatta area with a yield of 8 bushels/acre (approximately 540 kg/ha).

Originally trained as a mathematician, William Farrer began selectively breeding wheat varieties for drought and rust resistance in the late 19th century near Tharwa, ACT, originally as a privateer before joining the NSW Department of Agriculture. His greatest variety was 'Federation'; released in 1901 it quickly became the most widely grown variety in Australia. The four to five-fold increase in Australian wheat production between 1890 and 1920, was attributed to this and other varieties grown by Farrer. Farrer based his methods on Mendelian laws and kept good records to produce a variety resistant to rust and with short straw, suitable for the stripper harvester. 'Federation' was grown up until the late 1930s.

According to Australian Bureau of Statistics (ABS) records, the average yield broke through the 1 tonne per hectare (tonne/ha) barrier in the early 1940s and 1.5 tonnes/ha was achieved for the first time in 1979. Since 1989, yield has remained consistently above 1.5 tonnes/ha except in a few years of adverse weather conditions. The record national average yield of 2.11 tonnes/ha was set in 2002. It is of interest to note that according to Overton (XXXX), around the time of the first fleet the national estimate of wheat yields in the latter half of the 18th century in England and Wales was 900 to 1600 kg/ha.

Within months of the arrival of the First Fleet, Australia's first 'meteorologist', Lieutenant William Dawes, set up an astronomical observatory and commenced recording weather observations. Weather data was collected during the 1980s by state authorities until the Meteorological Act of 1908 empowered the Commonwealth meteorologists to take and record weather observations, forecast the weather, issue storm warnings, display weather, flood, frost, and cold wave signals and distribute weather information. The BOM moved from manual data entry from paper-based records to electronic databases, standardisation and calibration of equipment and the use of automatic weather stations replacing manual observers. Although BOM is the major source for observational weather data, private weather stations are being located on farms across Australia. For example, the Birchip Cropping Group is involved in a project to install around 50 weather stations and soil moisture probes on farms in the Wimmera Mallee region. The weather stations provide farmers with wind speed, wind direction, rainfall, temperature and humidity data every 15 minutes, through a mobile phone app. The data collected from these are helping farmers make decisions such as when to bale hay based on humidity records, when to spray based on wind direction and speed or when to irrigate based on soil moisture probe readings.

Data with direct benefit to agriculture is being collected from many sources at an ever-increasing rate. It is claimed that the use of big data in agriculture is in its infancy and with it comes the concern that many of the data services are built on proprietary technology which may hinder the aggregation and analysis of data from the disparate systems. The collection of data throughout the agricultural value chain requires well-calibrated measurement systems. The need for standardisation and quality assurance are often given as the reason for the tight control of the data and reluctance to accept data from other sources. Where standardisation is not possible, interoperability is an important requirement to allow these disparate data systems to be assimilated. Many of the major software service providers are including data translation tools as part of their platforms. Quality issues still need to be addressed which means data assimilation requires quality checking.

Data sharing will only be possible if secure systems are in place and producers see a tangible benefit. Natural variability and uncertainty in key drivers of agricultural production systems decreases the confidence of forecasting tools. The data collected by producers is important in the validation of these predictive systems, particularly at the scale required by the producers.

Another barrier to the advance of digital agriculture in Australia is the lack of communication infrastructure with the capacity required to transfer data from and to rural locations.

In the rush to deliver tools based on this flood of data collected, there is a real risk of analytical tools being released without proper processing and validation. There needs to be a deliberate, balanced and reasoned approach to develop a national strategy to guide policy in steering the advancements across all aspects of digital agriculture.

The following sections presents some of the challenges in five important types of data relevant to a wide range of agricultural production systems and provides recommendations to direct investment in digital agriculture.

7.1 Remote sensing/imagery

7.1.1 **Some brief technical aspects**

Remote sensing (RS) is the process of acquiring information about Earth by scanning it using ground, aerial or satellite-mounted sensors. Ground, aerial and satellite systems provide information over increasingly large areas, and different technologies of sensors are used to measure different properties. The device the sensor is mounted on is typically called the platform. Examples of ground-based platforms could be a tripod, a quad bike or a tractor. Aerial platform examples include aeroplanes, drones and blimps.

When collecting data, the practical aspects may be summarised as 'when, what, how much, and how often?'. 'When' may be the time of day or season, 'what' may be soil moisture or physical plant properties, 'how much' may refer to the geographic extent, and 'how often' could be hourly/daily or monthly measurement.

The characteristics of the platform and sensor influence what is possible. For instance, the orbital characteristics of a satellite determine overpass frequency (how often) and spatial coverage extent (how much), and the sensor what property is being sensed. There is typically a trade-off between temporal (how often), spectral (how many 'colours' or wavelengths are observed), and spatial resolution – the higher one is then the lower the others. The trend over the last few decades is to improve on all of these dimensions. This trend is matched by our increasing ability in sensing, computing, transmitting, storing and analysing. This results in a lot of data and the interest in methods for solving 'big data' challenges. There are sensing technologies (for example Synthetic Aperture Radar – SAR) that can see through clouds and those that cannot (for example 'optical' sensors). Historically, the latter has dominated.

For satellite-based optical sensors, the overpass frequency is an important characteristic of RS imagery as it determines how frequently a location can be measured, and this has shaped the use of RS over the past four decades. The more frequently a satellite acquires imagery over a location, the higher the chance of obtaining a cloud-free image and hence an observation of what's on the ground. If a geographic region or season is very cloudy, then cloud-free images of the ground may be few or not possible, or the timing not guaranteed, using optical sensors. To improve the chances of seeing the ground, satellites with a higher frequency of overpass are used with the trade-off that the spatial resolution is reduced. This high frequency imagery has a better chance of seeing the ground but generally can't detect small spatial features. Historically there has always existed a trade-off between spatial resolution and image frequency, between temporal and spatial precision. Historical archives of Earth observations of agricultural fields are predominantly observations from optical instruments. Current observations are compared with historical information when information on change is required.

More recently, SAR-based observations are also available for agricultural areas, and have the ability to see through clouds. These sensors provide guaranteed ground cover information and complement the current suite of optical sensors.

7.1.2 **History**

The most successful and widespread use of RS in agriculture has utilised optical imagery from several satellite platforms that provide complete spatial coverage (sometimes referred to as being wall-to-wall coverage). The sensors on these platforms are predominantly what are called broadband instruments, and they record reflected light aggregated into several spectral regions; roughly corresponding to what we observe as red, green and blue. They also record information in the infrared region of the spectrum which is not visible by the human eye. Such imagery is often free of charge. Instruments that record reflected radiation at hundreds of parts of the electromagnetic spectrum also exist, but these typically image over smaller areas due to data volume and other technical factors.

Many useful applications in agriculture of hyperspectral or radar imagery have been demonstrated, but low repeat frequencies, coarse spatial resolutions, and/or limited geographic coverage that are typical of these sensors have, historically, limited their use in agricultural applications.

The primary uses of broadband RS imagery in agriculture have been in the detection and mapping of classes of land cover of interest, or the change in land cover responses over time, or a combination of the two. For example, the detection of 'greenness' – the amount of ground covered by green foliage and its change over time – is a staple use of RS imagery. This is strongly correlated to foliage cover, fPAR (the proportion of incoming solar radiation absorbed by foliage), photosynthesis rates, and leaf area index (LAI, but only when LAI is <3). In addition to these quantitative biophysical variables, RS has also been used extensively to estimate qualitative variables (such as vegetation or crop-type mapping, tree clearing and soil colour) as well as for providing relative measures (such as greenness anomalies used in drought monitoring). Measures of land surface temperature have also been used, which are related to transpiration and evaporation, and so have been used to study water use and irrigation.

There have been three dominant workhorses in the RS-agriculture space over the past three to four decades: Landsat, AVHRR and MODIS.

Landsat is the oldest Earth observing mission and has an extensive history of use in agriculture. It started in the 1970s, but really came into widespread use around 1982, and is still going. The US Government maintain a Landsat Data Continuity Mission, ensuring observations into the future. There has been a succession of Landsat platforms which have all carried essentially equivalent sensors, with the latest being Landsat 8 carrying the 'OLI' sensor. Landsat imagery provides wall-to-wall coverage once every 16 days and at ~30 m resolution. This imagery is excellent for observing paddock and sub-paddock-scale features possibly every 16 days bar cloud cover. The 16-day repeat frequency can be problematic in obtaining multiple ground cover observations in regions or seasons prone to cloud, for example in rainfed agricultural regions. Assessment of trends and dynamics of cover in these regions cannot be guaranteed.

The next workhorse is commonly referred to as AVHRR (advanced very high resolution radiometer) imagery, which is hosted on the US National Oceanic and Atmospheric Administration (NOAA) series of satellites. AVHRR imagery has been continuously acquired since 1982. It has a daily overpass providing a high probability of observing the ground within a given time period. It has consequently been the preferred imagery for analysing vegetation dynamics and trends across large areas such as regional, continental, or planetary studies. AVHRR imagery has a resolution of around 1100 m, although a subsampling routine was applied earlier in its lifetime to reduce the data volumes.

Early in the new millennium, the MODIS mission started providing new-generation land-surface imagery of reasonably fine resolution (250 m), high overpass frequency (two per day) and improved data quality (self-calibration capabilities). A MODIS sensor is mounted simultaneously on two platforms – the TERRA and AQUA satellites – which have been operating since 2001. MODIS imagery has generally replaced AVHRR for applications that don't pre-date 2001. However, in many applications that require fine spatial resolution (paddock and sub-paddock), Landsat is still the imagery of choice.

(- Use of imagery has been stand-alone, and prospectively (historical analyses).)

7.1.3 **Current state**

The use of RS, in general, is currently undergoing rapid transformation, and this is true in agricultural applications. This is due to a combination of advancements in multiple areas including in our increasing abilities in sensing, computing, transmitting, storing and analysing. New and increasing numbers of RS sensors and platforms are becoming available, including the rise of data from proximal sensors (such as sensors mounted on drones and UAVs).

New-generation RS sensors are making it possible to have both high spatial resolution and high repeat frequencies, making paddock and sub-paddock-scale analyses of temporal dynamics and change feasible. This is largely due to the Copernicus programme of the European Space Agency (ESA), which is launching the Sentinel series of satellites.

The Sentinel-1 satellites are C-band radars, which operate at wavelengths responsive to plant structure and moisture. They were launched by April 2016. For the first time for a radar sensor, this will provide (≤6 day) frequent and high resolution (10 x 30 m) imagery (which, by the way, is not affected by cloud cover). This will provide completely new capabilities and applications.

The Sentinel-2 satellites, both of which were launched by March 2017, are high resolution (10 x 30 m), high frequency (≤5 day) optical sensors. Effectively, these sensors combine the strengths of Landsat and MODIS sensors and allow the traditional methods and applications to be continued but simultaneously at sub-paddock scale and with sub-growing season temporal precision.

While these new sensors will provide new RS capability, Landsat and MODIS imagery will continue to be important data sources especially where historical context is required. To benefit from the strengths of each of these, 'blending' activities are becoming more common where the spatial detail of Landsat and the temporal detail of MODIS are combined to produce a synthetic high-resolution/high-frequency information product. Integrated application of RS in agricultural applications is becoming more common. Multiple data sources (often of the same variable) are combined or assimilated using models to produce a best-available representation or estimate of a particular variable of interest – for example, crop yield or soil moisture.

Associated with this trend is the emergence of the use of RS imagery in a predictive capacity, rather than just the prospective (historical) capacity that has traditionally prevailed.

Examples of typical current applications of RS in agriculture include:

- crop-type mapping, crop yield estimation
- clearing and land cover change detection
- pasture biomass, quality and growth estimation
- drought and resilience/health analyses (that compare relative anomalies in greenness against historical statistics or some desirable 'benchmark' state)
- irrigated area mapping, soil moisture modelling, transpiration and crop water use
- bare soil mapping for soil health, soil carbon and erosion potential assessments.

7.1.4 What the future state should look like

The trend towards increasing numbers of sensors and platforms with higher spatial, temporal and spectral resolutions will result in increasing data volumes. The future has to accommodate the flow, storage and processing of substantial volumes of image-based and other spatial data.

The emergence of new data streams, particularly from proximal sensing technologies (such as drones and unmanned aerial vehicles (UAVs), and ground-based sensor networks) is expected to accelerate. It is easy to imagine a future where property (or a collective of properties) has its own fleet of autonomous drones that launch several times a day to provide high-accuracy, high-resolution sensing of the full estate. These will combine with ground-based and animal-based sensor networks. RS imagery will then be just one part of a whole, integrated information ecosystem that provides seamless, real-time and management-relevant information products.

Big data analytics and data assimilation schemes will be the core of such an information ecosystem. These will also involve automated data analytics, artificial intelligence and fully integrated user-interface networks.

A key characteristic of these information ecosystems – one that is in contrast to current practice – is predictive capacity. Real-time assessments will be the bare minimum standard in information; predictions into the near and medium future will be the main game.

There will be an increase in 'bespoke' satellite missions that have specific foci (as opposed to current missions which are generalist). This includes the current trend in micro-satellites that are cheap and provide full and rapid coverage – but only for a narrow and specific set of observations. This also includes specialist missions, such as ESA's 'biomass' and 'fluorescence explorer' missions, which are sensors tailored to the observation of tree biomass and photosynthetic activity, respectively.

7.1.5 What needs to be done to get there

Investment into this *information ecosystem* will be a critical step into the future. This means research into, in particular:

- the evaluation of new sensing systems, the information they may provide, and the value that they offer to the agricultural industry
- reception, storage and workflows of the data such that near-real time and predictive capacity can be utilised (timeliness of results)

- how to optimise the integration/assimilation of multiple RS data streams, and how to optimise the integration/assimilation of these with proximal sensors, sensor networks, personal technology, and data analytics
- predictive modelling capacity that is built around the information ecosystem.

7.2 Soils

7.2.1 Introduction

Knowledge of soil and land resources is a foundation for achieving productive and sustainable agriculture. However, the distribution and characteristics of soils across a farm, district or nation are neither obvious nor easy to monitor. As a consequence, understanding whether farming systems are well-matched to the qualities of the soil requires some form of diagnostic system both to identify the most appropriate form of management and to monitor how the soil is functioning. Three important components of the diagnostic system are:

- an understanding of how soils vary across the farm and broader landscape (e.g. maps of soil properties and functional types)
- an ability to detect and interpret soil-change with time (e.g. availability of nutrients, pH, organic carbon, plant-available water)
- a capacity to forecast the likely state of soils under specified systems of land management and climates (e.g. through the use of simulation models).

This section provides an overview of the Australian soil information system and its evolution. Unlike the USA and some European countries, Australia has not had a long-term and detailed soil survey program. As a result, Australian farmers do not have access to comparable soil information, although the situation has improved in some jurisdictions in recent decades (e.g. Western Australia, South Australia and Tasmania).

It is worth noting that all member states of the United Nations Food and Agriculture Organization, including Australia, have recently reaffirmed their commitment to sustainable soil management (e.g. FAO 2015, 2017). In doing so, they have also agreed that all nations require coordinated soil information systems similar to those that exist in many countries for economic data, weather and water resources. Furthermore, these national soil information systems are to be integrated with the emerging global soil information system (FAO 2017).

7.2.2 Current state

The first *State of the World's Soil Resources Report* by the Intergovernmental Technical Panel on Soils (ITPS 2015a) concluded that 'human pressures on soil resources are reaching critical limits. Further loss of productive soils will amplify food-price volatility and potentially send millions of people into poverty. This loss is avoidable. Careful soil management can increase the food supply, and provides a valuable lever for climate regulation and a pathway for safeguarding ecosystem services.' The ITPS went onto to state that 'while there is cause for optimism in some regions, the overwhelming conclusion from the report is that the majority of the world's soil resources are in only fair, poor or very poor condition. The most significant threats to soil function at the global scale are soil erosion, loss of soil organic carbon, and nutrient imbalance. The current outlook is for the situation to worsen unless concerted actions are taken by individuals, the private sector, governments and international organizations.'

Australia is one of the countries that gave the ITPS some cause for optimism. However, even in Australia, soil acidification, unsustainable rates of soil erosion, loss of soil organic carbon and nutrient imbalances (deficiencies and excesses) are recognised as significant threats to soil function and remain difficult to ameliorate (ITPS 2015b; SoE 2016). If left unchecked, these problems will constrain Australia's ability to take advantage of agricultural opportunities created by a growing population and demand for exports. A concerted effort to further improve soil management is required and this needs to not only include better diagnostic systems for determining when and where soil function is being compromised but also effective systems for developing and implementing farming management practices that restore or enhance soil function. The benefits of achieving sustainable soil management are substantial and they include:

- increased income for farmers and other players within the food supply system
- increased economic activity through the development of service industries that support sustainable soil management
- improved intergenerational equity, particularly for farming families
- more efficient and effective mitigation and adaptation to climate change
- greater food security
- positive externalities including improved water quality and landscape amenity.

It is difficult to estimate the likely return on investments into sustainable soil management. However, the National Committee on Soil and Terrain (NCST 2013) estimated that an annual investment of AUD$100 million into the national soil information system could generate economic benefits worth AUD$2 billion per annum by 2020. These benefits arise primarily from increases in agricultural productivity and avoidance of costs in other soil-dependent industries (potentially hundreds of millions of dollars per year). This estimate does not include the equally large societal and ecosystem service benefits associated with better soil and land management, particularly carbon sequestration (e.g. Minasny et al. 2015). These potential benefits are significant for the Australian economy; however, a far more thorough analysis is necessary to confirm the scale of returns and to identify priorities for investments.

7.2.3 **Institutional evolution**

The evolution of institutions for managing soil resources (and soil information systems) parallels the history of land use in Australia. The initial European impact on soils in most parts of Australia was profound and in some areas catastrophic. Severe soil degradation, particularly in the 100 years after 1850, resulted in declining crop yields and the dust bowl years of the 1930s and 1940s (Bolton 1981; McTainsh and Boughton 1993; McKenzie et al. 2004; Angus 2010). The large economic, social and environmental costs led to a range of institutional responses that have shaped how soil information is obtained and managed to this day.

At the Conference of Commonwealth and State Ministers in 1936, it was agreed that each state would establish a committee to study the problems of soil erosion and conservation, and suggest solutions; the Council for Scientific and Industrial Research (now CSIRO) was to co-operate with these committees (Soil Conservation Committee 1938). State soil conservation authorities with supporting legislation were subsequently established and coordination was eventually achieved through the Standing Committee of Soil Conservation established in 1946. This Standing Committee reported to the Australian Agricultural Council which had a remit to ensure consultation amongst Australian governments on economic aspects of primary production. Variants of this arrangement endured for more than 60 years with the responsibility for soil resources eventually passing to the Natural Resource Management Ministerial Council which had responsibility for land and water management.

The Collaborative Soil Conservation Study (1978a, 1987b) by the Australian, state and territory governments provided a comprehensive overview of the technical and institutional issues affecting soil management across the country. It laid the groundwork for the establishment of the National Soil Conservation Program in 1983. This coincided with continuing public concern over the extent and severity of land degradation which was brought into sharp relief by the large dust storm that engulfed Melbourne in February 1983. The concern did not abate and it contributed directly to the rise of the Landcare Movement with its strong emphasis on participative engagement and local action (Campbell 1992). The strength of Landcare lay in the community groups and networks that, with government and corporate support, conceived their own visions and set goals for local and regional environmental action (Youl et al. 2006).

Unprecedented Commonwealth investments into natural resource management were associated with the rise of Landcare. Several large natural resource management programs built upon the National Soil Conservation Program. The National Landcare Program (1989), Natural Heritage Trust (1997) and Caring for Our Country (2008) invested billions of dollars into natural resource management. It is difficult to accurately assess the impacts of these programs (e.g. Auditor General 2008; Australian Government 2013; Pannell et al. 2012). However, significant improvements in natural resource condition have been achieved although it is acknowledged that the scale of management actions may only be slowing, rather than reversing, the negative impacts that would occur without intervention.

While major land-use conflicts over the use of high quality soils have figured prominently during the last decade (e.g. Williams 2015), the scale of investment into general natural resource management programs has declined. The reasons are complex but the following factors are significant:

- There have been major improvements in soil and land management during the last 25 years (e.g. SOE 2011; ITPS 2015b). This has quite likely contributed to a perception that soil and land management problems have been solved.
- The difficulty of demonstrating returns on investment from large natural resource management programs resulted in public funds being directed elsewhere (e.g. health, education, national security).

- Concerns over some major problems such as dryland salinity lessened partly due to seasonal climate shifts and also because the initial projections were overstated.
- The end of the Millennium Drought (van Dijk et al. 2013), water reforms and significant improvements in water resource information systems contributed to a sense that water problems had been solved.
- The global financial crisis and end of the resources boom forced governments to reduce expenditure.
- Government agencies responsible for natural resource management struggled to find a compelling narrative and mode of operation that was competitive with other government priorities. One indication of this was the abolition of the Natural Resource Management Ministerial Council and Land and Water Australia.

Despite these developments, many of the less obvious but chronic issues affecting the soil resources of Australia remain. However, it is unreasonable to expect governments and industries to invest in sustainable soil management (and the supporting soil information systems) unless there is compelling evidence that these chronic issues require a response. Ironically, such evidence will not be forthcoming until there is an overhaul of Australia's soil information system.

7.2.4 **Australia's current soil information system**

Most reviews of the soil-knowledge system in Australia highlight the institutional complexity, inconsistency of technical methods, limited economies of scale, ineffective mechanisms for funding and lack of a long-term strategy (e.g. Taylor 1970; Beckett and Bie 1978; Collaborative Soil Conservation Study 1978a, 1987b; McKenzie 1991; Campbell 2006; Wood and Auricht 2011). Some of these problems have been solved but significant institutional constraints remain and they were summarised by McKenzie (2014) as follows:

- All levels of government need reliable information on soil resources, but no single level of government or department has responsibility for collecting this information on behalf of other public-sector agencies.
- Public and private interests in soil are large and overlapping, but mechanisms for co-investment by public and private agencies have not been developed.
- Market failure in relation to the supply and demand of soil information is a significant and widespread problem. In the simplest case, beneficiaries of soil information do not pay for its collection and this reduces the pool of investment for new survey, monitoring and experimental programs.
- Partly as a result of the above, most soil-information gathering activities are currently funded through short-term government programs, private companies (e.g. fertiliser companies), individuals, or in response to specific regulatory requirements (e.g. environmental impact statements). These have not produced the enduring, accessible and broadly applicable information systems that are needed to meet the requirements of nearly all stakeholders.

Despite these significant challenges, the Australian soil information system is internationally recognised for being innovative, collaborative and responsive to contemporary issues. This is largely due to the enduring and effective partnerships between operational agencies and research groups that have been responsible for a range of innovations including digital soil mapping, proximal sensing and web-based delivery of information services (McBratney et al. 2003; Arrouays et al. 2014a, 2014b; Hicks et al. 2015; Grundy et al. 2015).

7.2.5 The collaborative model

Despite several previous proposals for the establishment of a national soil information agency (e.g. Taylor 1970; Collaborative Soil Conservation Study 1978b), a strategic review of soil survey and land evaluation activities by McKenzie (1991) concluded that a voluntary and collaborative model was most appropriate for addressing the technical and institutional problems apparent at that time. As a result, the Australian Collaborative Land Evaluation Program (ACLEP) was established to develop a coordinated approach to land resource assessment across Australia. The program included all commonwealth, state and territory agencies involved with land resource assessment. ACLEP was jointly funded by the Australian Government (initially through its National Landcare Program) and CSIRO. In many ways, the model was a continuation of the original institutional arrangements established in 1936.

ACLEP promoted better procedures for acquiring and using soil and land resource information in government and private industry. This was achieved by setting national standards for soil and land resource assessment, providing a forum for communication between technical specialists, attempting to develop a network of soil and land reference sites across Australia and encouraging research into methods for land resource assessment. ACLEP received strategic direction from the National Committee on Soil and Terrain and for most of its existence had a formal line of reporting through to the relevant Ministerial Council of the day.[3] ACLEP had three main phases:

1. 1990–2000: This coincided with the Decade of Landcare when state and territory agencies, with partnership funding from the Commonwealth, undertook the ‘Accelerated Program of Land Resource Assessment’. Some states (e.g. South Australia and Western Australia) were able to complete new soil surveys across their agricultural lands. Other states and territories adopted different strategies. During this period, ACLEP focused on supporting the partner agencies through capacity building, development and publication of standards, and testing of new survey methods.
2. 2000–2010: The focus during this period was on the communication of soil and land resource information to a broad range of users while at the same time providing technical support for new methods of digital soil mapping (e.g. Henderson et al. 2005; McKenzie et al. 2004, 2008). The national Australian Soil Resource Information System (ASRIS) was upgraded to become one of the world’s first online national soil information systems. Collaborations were pursued with other technical groups to provide assessments and

[3] Initially the Australian Soil Conservation Council, then the Natural Resources Ministerial Council and more recently the Primary Industries Ministerial Council until its disbanding in 2013. It now reports indirectly to the Standing Council on Primary Industries (SCoPI) but the scope of the NCST extends well beyond agriculture.

information at the continental scale (e.g. NLWRA 2001, 2002; Peverill 1999). ACLEP was also heavily involved in developing technical recommendations and guidance on monitoring the condition of Australian soils (e.g. McKenzie et al. 2002; McKenzie and Dixon 2007; Grealish et al. 2011). This period also saw initial steps taken to build stronger links between technical programs and proposals for a national soil policy (Campbell 2008).

3. 2010–2015: With the exception of Tasmania and the Northern Territory, most field survey and monitoring programs had been curtailed by this time and the focus for ACLEP was on improving online access to existing soil information. Opportunities in geospatial technologies led to the development of new standards for soil data systems and web-based services. Ongoing support was provided for synoptic assessments (e.g. SoE 2011; ITPS 2015b), and a major upgrade of the National Soil Archive was completed (Karssies and Wilson 2015). The latter activity was especially significant because it allowed new methods of proximal sensing to be deployed on archived samples and in the process, generated large new datasets for the country including a new baseline assessment of soil carbon stocks (e.g. Hicks et al. 2015; Viscarra Rossel et al. 2014). The most significant achievement of this period involving all partners was the development of the Soil and Landscape Grid of Australia (Grundy et al. 2015). This was an internationally significant achievement because it was the first continental-scale implementation of the *GlobalSoilMap* Technical Specifications (Arrouays et al. 2014b) which is a key component of the emerging global soil information system (Global Soil Partnership 2014).

Some aspects of the collaborative model have been effective; for example:

- users of soil information now have unprecedented access to harmonised soil data and information collected over more than 50 years
- major technical advances and major new products have been delivered because of the network and collaborative arrangements fostered by ACLEP
- ACLEP provided a pathway-to-impact for research teams in universities (e.g. The University of Sydney) and CSIRO.

Despite these achievements, the collaborative model forged by ACLEP is no longer viable for several reasons:

- Most state agencies have stopped their field programs of soil survey and monitoring. As a result the map coverage is now out of date and monitoring networks are not being established or maintained.
- A closely related issue relates to the demographic profile of the current cohort of experienced pedologists.[4] Most were trained in the 1980s and 1990s and they participated in the 'Accelerated Program of Land Resource Assessment'. The expertise, and especially the field knowledge, held by these experts is not being passed onto a new generation of soil and land resource specialists.

[4] Pedology is the branch of soil science that studies the formation, distribution and potential use of soils.

- The formal programs for funding research (e.g. via the rural research and development corporations and the Australian Research Council) are more enduring and better organised than those for operational programs of land resource survey and monitoring. At present, there are very few sources of funds for the latter.
- ACLEP and its related activities have been funded through the major natural resource management programs listed earlier. However, none of these programs is compelled to fund operational survey and monitoring programs and there are no jurisdictional mandates to compel governments to continue such programs. This is in contrast to other areas such as weather and climate where data collection is mandated by legislation.
- There has been a general trend towards smaller government and state and territory agencies – the traditional homes for land resource survey and monitoring – have disinvested in the area.
- CSIRO has maintained its long tradition of supporting land resource survey but the investment is considerably less than in previous decades when several divisions were actively involved (e.g. the former Division of Soils and the Division of Land Use Research and its successors). While there is a role for CSIRO to undertake research and development to support the survey and monitoring programs, it has no formal mandate to provide resources for the ongoing operational activities that are necessary if Australia is to have the information services it needs to ensure sustainable soil management.

7.2.6 **Barriers to putting soils on the national agenda**

Institutional reform is necessary if Australia is to have a coordinated and federated soil information system that meets the needs of farmers and other users while being compatible with the broader global effort. Any significant institutional reform requires public support and engagement by policy makers, politicians, industry groups and civil society. However, significant barriers limit public awareness of soil issues and these include the following:

- Most people do not have a clear view of the condition of the soil resources upon which their lives ultimately depend. One cause is increasing urbanisation and the reality that the proportion of human labour devoted to working the soil has steadily decreased through the past century (ITPS 2015a).
- Most threats to soil function are chronic and long-term. For example, soil erosion, acidification or depletion of carbon and nutrients occurs over decades. Some of these changes can be difficult to detect and there is a risk that management responses will not occur until critical and irreversible thresholds have been exceeded.
- Institutional responses to natural resource problems are often triggered by major polarising events (e.g. droughts, fires and floods). Apart from dust storms (which are now much less frequent than during the 1930s and 1940s (SOE 2011)), changes in soil condition rarely rate a mention in the mainstream news media although soil contamination is an occasional exception because it may directly affect human health and food quality.
- For most primary industries (e.g. cropping, grazing, forestry, horticulture), soils are a means to an end. Management systems tend to focus on the final product or readily

measured indicators along the supply chain (e.g. yield, market price). Soils are acknowledged as important but they are often prioritised after other factors that have an immediate impact on profitability. As a consequence, insufficient investment into research, development and extension can easily occur.

- Soil scientists drawing attention to the lack of investment into soil activities can be readily dismissed as self-interested. The recent emergence of independent public advocates on soil issues has started to address this problem (e.g. Former Diplomat and Governor of Queensland, Penny Wensley, and Australia's current national Advocate for Soil Health, Major General Michael Jeffery).
- There have been major improvements in soil and land management during the last 25 years (e.g. conservation farming, controlled traffic, cell grazing, and the more general achievements of the Landcare Movement (e.g. Natural Decisions Pty Ltd 2015)). This has quite likely contributed to a perception that soil and land management problems have been solved.
- Australia is a food exporter and citizens have access to plenty of cheap, high-quality food. Issues relating to food security do not figure in public discourse except in relation to international affairs and when famines occur in distant countries.

Some other factors further limit the consideration of soils by policy makers. These include the lack of ready access to the evidence needed for policy action and the challenge of dealing with property rights for a natural resource that is often privately owned and at the same time an important public good (ITPS 2015a). All these factors contribute to our current lack of institutional preparedness both domestically and internationally.

7.2.7 What the future state should look like

Despite the issues outlined above, understanding and managing soil change across Australia has been recognised as a priority by the Australian Government (e.g. in its Science and Research Priority on Soil and Water). It is central to the Soil RD&E Strategy (e.g. Priority Three) and important to a wide range of industries, governments and communities. A recurring issue has been provision of the enabling infrastructure for collecting, curating and analysing soil information. The need for new arrangements to achieve more open access to information has been recognised in a range of reviews and reports (e.g. Campbell 2008; NCST 2013; McKenzie 2014; ITPS 2015; Keogh and Henry 2016). However, the often-proposed option of establishing a new national agency has not received support partly because of the cost and difficulty of finding a suitable business and institutional model. However, it is now clear that the digital revolution has created exciting new possibilities that overcome past obstacles.

In Australia, several domains have made great strides in developing new and integrated national observing systems and forecasting capabilities *without* having to establish new agencies (e.g. Integrated Marine Observing System (IMOS), Atlas of Living Australia (ALA)). Common to each of these activities is some form of national facility – hosted by an existing institution – that provides the necessary infrastructure for information management and computing. These facilities are notable for their clear strategic outlook, effective collaborative arrangements, and technical excellence.

In this section, we build on proposals by the NCST (2013) and the Australian Soil Network (ASN) to create a soil information system for Australia that supports the best features of the current system and that takes advantage of new technologies. In particular, the proposal for developing the Australian National Soil Information Facility (ASIF). This directly addresses Priority Three of the national Soil RD&E Strategy and it also responds to the recommendations made by Keogh and Henry (2016) in their analysis of global developments in digital agriculture and the steps that Australia needs to take to ensure benefits are quickly realised (e.g. Recommendations 3, 5, 7 and 9). The Facility can fill a critical gap in Australia's overall system for monitoring and managing its natural resources, and in particular, its agricultural landscapes. Before exploring what ASIF should look like, it is worth recapping on some of the key technological developments.

7.2.8 Technological opportunities for improving the delivery of soil information

The sensor revolution

The sensor revolution is transforming every aspect of measurement in soil science and the biophysical sciences more generally. This includes:

- miniaturisation and field deployment of analytical instruments that were once solely for laboratory use (e.g. gamma-ray detectors, infrared spectroscopy and X-ray fluorescence) – these can replace current qualitative methods for characterising soils in field surveys
- dramatic increases in the spectral, spatial and temporal resolution of airborne and satellite-based sensors that are producing images and datasets of widespread value (e.g. high-resolution digital elevation models, sensing of elemental composition and soil water content, actual evapotranspiration)
- revolutionary new measurement techniques in molecular biology that promise new opportunities for plant breeding (e.g. large-scale phenotyping) and understanding of ecosystem function and condition
- rapid advances in communication technologies that enable the development of inexpensive sensor networks that are web-enabled.

Advances in computing power and simulation modelling

The digital revolution and large increases in computing power have opened the way for new approaches to spatial data analysis and simulation modelling. Not only are models more numerically intensive, their ability to handle high-resolution spatial and temporal inputs and outputs is leading to realistic representations of biophysical systems. This is most evident in the climate sciences and it is now extending to simulation modelling for farming systems, landscape hydrology and ecological systems.

Methods for analysing multiple lines of evidence

Arguably the most significant methodological advance for reducing uncertainty in estimation and prediction has been steady formalisation of methods for analysing multiple lines of evidence. While the logic is as old as science itself, the recognition that independent lines of evidence can place bounds on the likely state of a system (e.g. crop growth, catchment discharge, water balance) in the past, present and future opens promising lines for reducing uncertainty.

Analysing multiple lines of evidence is most advanced in weather forecasting and the modelling of climate change. Well-developed mathematical treatments for model-data assimilation allow multiple streams of observational and simulated data (generated by models that ensure mass balance and consistency of physical processes) to be used as constraints on the likely state of the system. Forecasting, now-casting and hindcasting are used to regularly update predictions. This style of modelling is starting to be applied to soils and agriculture and it has great potential. However, model-data assimilation and related approaches are technically and scientifically complex. They are by nature interdisciplinary ventures and require substantial investment into observational networks and simulation modelling. ASIF is an important part of the strategy for developing this capacity in Australia and it provides a foundation for developments in digital agriculture.

Enabling tools and technologies

It is one thing for scientists to develop a detailed understanding of how agricultural and biophysical systems are responding to changes in management practices and environmental change. It is another thing to provide farmers and decision makers with the tools and information systems necessary for good planning and management. Fortunately, the digital revolution has created some remarkable new possibilities to allow these steps to be taken. The design of web-based information systems is evolving rapidly. The resulting tools and technologies are changing how agricultural research, development and extension are done. Two of the proposed lines of business in ASIF (1 and 4) directly address these opportunities.

7.2.9 Roles and responsibilities of the public and private sectors

The decision in 1991 to establish ACLEP using a voluntary and collaborative model was appropriate at the time, particularly given the technical strength of some state and territory agencies. However, the situation has changed and a more enduring and self-sustaining system is required not only for soils, but for natural resource information more generally.

Craemer and Barber (2007) outline some of the market-failure arguments relevant to the development of a 'business case' for public investment in soil information. These relate to the presence of externalities, importance to basic research and development, and information failures within markets. They also note the significance of information as infrastructure and the importance of soil information being collected once but then used for many different purposes. Craemer and Barber (2007) provide a valuable starting point for developing the economic case for investing in soil information but more work needs to be done. It has been assumed here that there is a legitimate role for the public sector in gathering and providing soil information. However, given the private and public-good nature of soil resources, it is also assumed that some form of public-private model would be appropriate.

Craemer and Barber (2007) summarise the market-failure and public-good arguments for public investment in soil information and the following draws heavily on their analysis. The private-sector component of ASIF is also significant and it's expected to grow over time because of the enabling public-sector investments.

7.2.10 Criteria for public-sector engagement

The 'market for soil information' in both the public and private sectors is fragmented for a variety of reasons. It is partly due to the diverse requirements that end-users have for information (e.g. in relation to the scale of information in space and time, the soil properties of interest and the preferred formats for delivery). Other causes of fragmentation include the different reasons why governments invest in soil information. Here we recognise four main reasons for public investment in soil information.

Reason 1: Address transaction costs and information failure

While poorly recognised at present, one of the most important reasons for public involvement is the potential to reduce transaction costs and overcome information failure in existing markets. These inefficiencies have several causes.

Coordination failure: This arises when end-users of information cannot coordinate themselves to commission the acquisition of the information that they need for a known purpose. A district soil map is a good example. Even though there are various end-users who will benefit from the map, they typically have no easy mechanism for coming together to commission the survey early enough to allow delivery of information in a timely fashion. Governments often take on the task of doing the survey but they run the risk of paying insufficient attention to the requirements of end-users and this can reduce the utility of the information. The establishment of ASIF directly addresses coordination failure because it provides enabling infrastructure to support strategic soil mapping, monitoring and modelling.

Economies of scale: Some forms of soil information only generate benefits when a particular economy of scale has been reached. For example, producing a consistent and complete soil survey coverage for a jurisdiction has traditionally involved the completion of many individual district surveys that are then synthesised to generate the final state-wide or continent-wide product. Distinct benefits are generated by these products but they require significant economies of scale. ACIL (1996) document the benefits associated with the digital version of the Atlas of Australian Soils and several state agencies (e.g. Western Australia and South Australia) have been able to generate valuable new information products but only when they have completed their regional survey coverage.

Another aspect of economies of scale relates to the scientific, technical and computing resources needed to generate some forms of soil information. For example, the recently released Soil and Landscape Grid of Australia (SLGA) required a large team and significant investment that was well beyond the capabilities of private-sector soil information providers (Grundy et al. 2015) or any single public institution. The rapid uptake of the SLGA by users in the public and private sector is evidence that a real barrier existed prior to the public-sector investment. It is worth noting that an information product such as the SLGA can be incrementally improved once established. This may involve private-sector investment and some opportunities are identified in the four lines of business proposed for ASIF (see Tables 9 to 12 in Section 10.4).

ASIF will overcome several current barriers associated with economies to scale. Most notably by providing access to cloud computing services, advanced analytical systems and secure archives. The latter is especially important for the long-term monitoring of soil change.

Incomplete information: This arises when potential end-users are unable to determine the information they need and as a consequence they make sub-optimal decisions. The complex and technical nature of some soil factors in agricultural production or environmental management suggest that this is a widespread problem. For example, soil nutrient testing has conventionally focused on the top 100 mm of the soil profile even though significant constraints to production are often deeper in the profile (e.g. soil acidity, dense subsoils, toxicities such as boron). The reasons for the incomplete information may simply be a lack of appropriate agricultural extension services or it could be the inability of soil scientists to communicate complex topics at the requisite level of simplicity. In such cases, strategic public investment into improved information services can overcome significant inefficiencies or costs in the land management system. Lobry de Bruyn and Andrews (2016) confirm the extent and seriousness of incomplete information specifically in relation to soil testing and soil health in Australia.

Reason 2: Identify and respond to externalities

Some actions by land managers generate spillovers that affect other individuals. If the land manager has to pay for the cost of positive spillovers then the generation of these benefits will be below the optimal rate (e.g. an individual farmer is unlikely to bear the full cost of biodiversity plantings that may be needed to increase pollination services across a much larger district). Conversely, if the land manager does not pay for the costs of negative spillovers (e.g. off-site pollution) then a less than optimal outcome is also produced. In both cases, the spillovers are external to the market and government intervention is justified on the grounds of efficiency and equity.

Two nationally significant forms of externalities that require soil information are those associated with the off-site impacts of soil erosion by wind and water, and the production of greenhouse gases especially when soils are cleared and cultivated. Australian governments continue to invest in soil information in relation to both forms of externality; for example, through programs that aim to reduce sediment transport to the Great Barrier Reef, and through inputs to Australia's national carbon accounts and activities that increase carbon sequestration in soils.

A third externality of major importance that has received less attention is the intergenerational inequity associated with soil acidification. In essence, the failure to achieve a zero net acid addition rate in many farming systems is creating a cost for future generations because land will either become worthless or require expensive amelioration. Failure to pay for some of the short-term costs of production (i.e. the cost of liming) results in a much larger cost in the longer term (typically 20 to 50 years later) especially when subsoil acidification occurs. The problem is effectively irreversible once this threshold has been passed.

Identifying and responding to externalities is widely recognised as a primary role for governments. However, it is sometimes unclear which parts of government are responsible for the monitoring of externalities and for developing appropriate responses. This typically causes under-investment into soil information because mechanisms for co-investment by different agencies and tiers of government are rarely available.

Reason 3: Support regulatory and reporting requirements

While not directly considered by Craemer and Barber (2007), this role for government is closely related to the previous two. Governments have reporting responsibilities that range from legally enforceable requirements set by international treaties through to voluntary and discretionary reporting that supports the national or jurisdictional interest. Examples include the following:

- legally enforceable: UNFCCC reporting requirements including those relating to the Kyoto Protocol and the Paris Agreement
- UN Convention on Biological Diversity requirements for national reporting
- 2030 Agenda for Sustainable Development (particularly SDG 15.3)
- World Heritage Convention
- State of the Environment reporting
- less effective conventions and voluntary agreements: (e.g. UNCCD, Revised World Soil Charter)
- contributions to assessments that are in the national interest (e.g. those that may be used for market access). ...

Another area where government regulation requires individuals or businesses to collect soil information is in relation to approval processes associated with planning and environmental legislation. Most such processes have limited requirements for the underlying soil data to be retained in databases to enable reuse for other purposes. A notable exception is the requirement in New South Wales where soil data used for mapping of strategic agricultural lands have to be entered into the NSW Soil and Land Information System (ref).

Reason 4: Enable research and development

Direct public investment by governments into scientific observing and forecasting systems is a key enabler for increasing research capability, supporting innovation and achieving larger returns on investment. This is most clearly articulated by the National Collaborative Research Infrastructure Strategy which has been fundamental to, among other things, improving scientific understanding of Earth-system processes. The latest articulation of the strategy builds on the successes of earlier investments into facilities such as the Integrated Marine Observing System, the Atlas of Living Australia, the Terrestrial Ecosystem Research Network and AuSCOPE.

Public investment is also justified when major scientific investigations are needed. Significant recent examples in soil science include the National Soil Carbon Program, the National Agricultural Nitrous Oxide Research Program, the Soil and Landscape Grid of Australia and the Biome of Australia Soil Environments project.

The fourth line of business for ASIF focuses on the provision of infrastructure to enable research and development. It involves:

- further development of the SLGA as the primary means for mapping soil properties across the continent
- development of an improved scientific framework for extending research results (e.g. crop variety trials, tillage experiments, studies of greenhouse gas emissions) from individual locations to the broader landscape
- providing a key element in Australia’s earth and environmental-systems observational research infrastructure. This has high priority in the National Research Infrastructure

Roadmap (2017) and ASIF could directly support the objective of 'predictive modelling to strengthen environmental management, risk assessments, primary production, and resource development whilst sustaining biodiversity'.

7.2.11 **Private-sector engagement**

Effective government policies and investments can overcome many of the issues outlined above and the establishment of ASIF forms part of the strategy. Effective engagement with the private sector can improve the efficiency of data collection in the following ways:

- capture of data associated with the several hundred thousand soil tests that are undertaken annually by commercial soil testing services provides a mechanism for monitoring soil change (e.g. Arrouays et al. 2012; Rawlins et al. 2017)
- capture of data collected for environmental impact assessment and planning approvals
- stimulate the development of soil information service providers in the private sector (see Business One in Section 10.4 below) that can contribute to ASIF.

Web services provided by ASIF can also form the basis for new businesses in the knowledge economy. Basic services can be provided free of charge and customised services could be provided via a subscription service. New business opportunities are associated with the development of these customised premium services.

A much broader benefit for the private sector relates to accreditation of production systems and supply chains. The ability to demonstrate that sustainable soil management practices have been used in the supply chain is of increasing importance for market access especially for premium products. Most stakeholders (e.g. farmers, food industry, governments) stand to benefit from accredited soil management.

Finally, the most obvious and potentially largest benefit to the private sector is through the provision of soil information that enables farmers in particular to overcome soil constraints to production and improve soil and water use efficiency. The increases in profitability can be large (e.g. Dang and Moody 2016). The establishment of ASIF will improve the provision of such information to farmers and other land managers.

7.2.12 **What needs to be done to get there**

Engage the key partners and agree on roles and responsibilities

ASIF provides the starting point for improving soil information delivery to support agriculture in Australia. However, the initiative is unlikely to proceed unless leaders of the key partner agencies convene to agree on their respective roles and responsibilities. Some of these key agencies include: lead state and territory agencies, the Australian Government, rural research and development corporations, CSIRO, The University of Sydney, Geoscience Australia, and the new CRC for High Performance Soils

More importantly, a key lesson from the last 30 years of collaborative activities is that the roles and responsibilities of agencies involved in ASIF need to be agreed via a formal legal agreement, preferably with legislative backing. The nature of this agreement, at its simplest, could be a register of agreed data services and products that will be provided by member organisations. Such an agreement should build on the advances made in recent years in relation to the adoption of open data standards. New mechanisms for establishing this formal mandate are also starting to appear. The draft reforms on data availability and use proposed by the Productivity Commission provide good solutions to several of these institutional issues, particularly those relating to the National Data Custodian, Accredited Release Authorities and the declaration of National Interest Datasets. While these proposals are at an early stage of development, they appear to provide the necessary institutional framework for ASIF.

Establish links with other facilities and key networks

ASIF also needs to be closely integrated with existing national facilities and operational agencies in related fields. The former include the Integrated Marine Observing System (IMOS), the Atlas of Living Australia (ALA), the Terrestrial Ecosystems Research Network (TERN) and the Australian National Data Service (ANDS); and the latter include Geoscience Australia, the Bureau of Meteorology and the Australian Bureau of Statistics. The success of ASIF also depends on effective engagement with three collaborative networks:

1. The Australian Soil Network and more specifically, the National Committee on Soil and Terrain
2. The Australasian Soil and Plant Analysis Council (ASPAC): this network provides access to private-sector soil-testing companies and associated data sources
3. The International Network of Soil Information Institutions which has been established by the Global Soil Partnership (GSP) and is responsible for delivering the global soil information system. Australia has been a significant contributor to the GSP and engagement via ASIF will bring a range of benefits and, in particular, enable integration with activities in the Asia-Pacific region.

Secure long-term funding

It was suggested earlier that new investment of approximately $5M is required to establish ASIF. This would complement existing investments by existing agencies (e.g. state and territory governments, CSIRO, Australian Government Department of Agriculture and Water Resources). This funding base needs to be broadened and made more secure.

Confirm priorities for mapping and monitoring of soil change

The mapping and monitoring of soil change by ASIF needs to be based on agreed specifications that address the required accuracy and precision for different systems of land use and locations. A suggested initial focus is on the following components noting that the Facility is intended to serve both public and private-sector interests.

<u>*Soil nutrients*</u>: Nutrient imbalances are widespread throughout the more intensively managed landscapes of Australia. Intensification of agriculture in many districts is causing significant environmental impact, particularly due to the large increase in fertiliser use and ruminant animals. In other districts, nutrient mining and decline is occurring due to insufficient replacement of nutrients removed through harvest or other loss pathways.

Existing land resource surveys, the Soil and Landscape Grid of Australia, and several large data compilations by individual projects (e.g. Better Fertiliser Decision project, National Land and Water Resources Audit) provide a starting point for developing better data streams relating to nutrients. However, a major opportunity is to integrate these sources with the large quantities of soil test data collected by farmers, agribusinesses and the fertiliser industry (most of which is currently inaccessible).

Acidification: Soil acidification is a widespread and serious problem that has the potential to cause irreversible damage to soils, particularly across southern Australia, in select tropical landscapes, and in areas where product removal and leaching are contributing factors.

Data sources are similar to those for soil nutrients. However, improvements are needed to ensure estimates are up-to-date and to enable more accurate estimation of the Net Acid Addition Rates of different farming systems. Again, integrating public and private data sources and maximising data accessibility are essential.

Carbon: Understanding trends in soil carbon stocks is essential for achieving sustainable soil management. It is increasingly required for accreditation and monitoring for a range of purposes including market access, official statistical reporting (e.g. Sustainable Development Goal 15.3), carbon trading and other emerging international schemes (e.g. the 4-per-1000 initiative).

Data services on soil carbon need to include a regular update of the Soil and Landscape Grid of Australia and mechanisms for integrating local farm measurements with broader-scale measurements across the landscape.

Soil-water balance: Real-time measurement and estimation of the soil-water balance are the current focus of several major national projects. Advances in proximal sensing (e.g. Cosmos probes, sensor networks) and time-series remote sensing have improved the spatial and temporal resolution of data streams. The use of the resulting information is widespread and includes drought and flood forecasting, pasture management, crop-yield forecasting, fertiliser decisions and agricultural management more generally.

Soil microbial populations: Major advances in molecular biology and activities such as the BASE project are providing completely new insights and potentially the basis for new interventions relevant to carbon and nutrient management in agricultural systems. The soil biological component of the ALA and activities such as the BASE project are both a source and user of new soil data services. A major opportunity for ASIF is to ensure data services and the supporting computing infrastructure are closely aligned with existing systems for biodiversity. This will generate economies of scale and accelerate the rate of discovery and innovation in the management of soil biology cross the Australian landscape.

7.3 Weather

7.3.1 **Introduction/history**

Many of Australia's early farming systems originated from European farming systems and were poorly adapted to local climate conditions. There was little understanding of the operating farming environment. Consequently, these early farming systems performed poorly in Australia.

Traditionally, farmers collected on-farm historical weather information to: a) critique the effectiveness of their management practices, b) better understand the operating environment, c) help predict how certain crops would perform in certain seasons, and d) understand production potential in a season.

Weather information was also collected for determining whether a farmer was entitled to special financial assistance due to an extreme weather event – governments had to determine if a farmer's circumstances were due to poor management or due to the weather. This consideration goes back over a hundred years. In 1901, a Royal Commission was held into the impact on farming from an extended drought period in the 1890s. In their report *Pasture Degradation and Recovery in Australia's Rangelands: Learning from History*, McKeon et al. (2004) review eight major degradation episodes in Australia which have occurred from the 1890s to the 1980s (https://www.longpaddock.qld.gov.au/about/publications/pdf/learning_from_history.pdf).

Post offices were central locations where early weather stations were located. In 1908 the weather service became a federal responsibility, when state-based weather services transferred their weather-reporting responsibilities to the Bureau of Meteorology (BOM). Early data were collected manually, and measurement platforms were not standardised until the late 1970s. In 2012, BOM listed over 700 automatic weather stations in its network.

Initially, weather data were used for historical purposes; that is, to look back on a season. There was limited understanding and limited tracking of pressure systems over the Australian continent. The capacity to forecast weather based on the movement of weather systems did not begin until the late 1970s – a similar time to the standardisation of measurement platforms.

Early weather forecasting was based on historical evidence. In the 1930s and 1940s, scientists began to realise that rainfall was not a completely random process. Scientists started to form connections between the Walker circulation, the El Niño-Southern Oscillation and ocean temperature, and to investigate their effect on rainfall variability. Research activity in this area increased exponentially with the advent of satellite information in the late 1960s and 1970s when these slower-moving drivers could be better tracked.

7.3.2 **Current state**

Rural industries are heavily reliant upon weather information. The value of this information is even higher when there are key on-farm decisions to be made. For example, key decision points can involve purchasing inputs (when and how much of important, high-value inputs such as fertilisers, pesticides and seed for a particular season), and/or scheduling operations (access to heavy equipment for end-of-season harvesting or other processes when a window of fine weather is needed). Primary industries generally rely on BOM for 1-day to 7-day forecasts. However, this information is highly aggregated. It is aggregated at the BOM's regions of interest – climate zones.

Dynamic models have given us the ability to forecast the weather reliably out to 5–7 days. These dynamic models are more deterministic than probabilistic, as compared to climate models that are more probabilistic than deterministic. ACCESS-R and ACCESS-G are the regional and global numerical forecast models, respectively, currently operated by BOM. The dynamic models are gridded and provide bias-corrected grid averages for specific locations. They run four times and twice daily (ACCESS-R and ACCESS-G, respectively) and provide forecast data out to 72 and 240 hours, respectively, with a horizontal resolution of approximately 12 and 25 km, respectively, at 70 vertical levels. The models are based on the UK Met Office Unified Model and published on the BOM website. Forecasts for major cities and some regional centres are published using the ACCESS-C model, capable of forecasting out to 36 hours. The resolution of the ACCESS-C model is approximately 4 km and the model is run four times daily.

There are a large number of weather stations that are still not fully automated or that don't provide data at a routine time step. BOM is trying to move towards real-time automated stations, and a majority of stations are, but there is still limited coverage.

Some agribusiness companies are moving into this space – for example, Elders produces heat-stress and cold weather warnings for livestock (http://www.eldersweather.com.au/). It is early days for commercial products as well as for rebroadcasting the BOM synoptic maps. There is a marketing element for cropping but the real value at present is for livestock – dairy and feedlots in particular.

Over time, there have been no fundamental changes in the type of weather data being collected; however, the measurement devices themselves have advanced. For example, traditional weather measuring devices included a Stevenson-screen with a max/min temperature, wet bulb, rain gauge, evaporative pan, and a device to measure sunlight hours – a glass ball with a strip of paper on a mechanical mechanism. Now, weather measuring sensors collect data on short-wave and long-wave radiation, and there are devices to collect wind data.

The CSIRO's Yield Prophet application is a web-based decision-support tool for grain growers (http://www.yieldprophet.com.au/yp/Home.aspx). It is a good example of where historical and current climate information (including information from producers' private weather stations) is being harnessed across the information chain. Farmers put information into the application, this information goes into the model and the model makes predictions. The farmers act on these predictions from which new information is gained and put back into the model for better predictions. The tool is based on the Agricultural Production Systems sIMulator (APSIM), with farmer input and a nice web interface.

The adaptive value chains self-assessment tool (https://adaptivevaluechains.com/) uses climate data at a 5-km resolution to help understand and evaluate the climate risk exposure of a business or company. Using the tool, a national or multi-national company can map out its supply chain in Australia and look at the potential impacts a set of climate extremes might have on their supply chain. This is done using historical data and the company is given a risk-exposure report. For example, if you are a lettuce grower in southern Queensland that sends produce to NSW and have a supply chain with five nodes, then the report will help you understand where your greatest risk exposure is along that five-node supply chain. Companies and producers can also use the tool to investigate the impact of implementing different logistical scenarios.

7.3.3 **What the future state should look like**

In the future, Australia should be producing weather information at a higher spatial resolution. BOM has relied heavily upon high quality data from weather stations with a long history as their primary data source for model prediction. However, there is now a huge amount of data from additional sources (such as data collected intermittently, data collected from weather stations (say on-farm) with a short history, or instantaneous data collected from phones). As data flow increases, dynamic models, such as those used by BOM, are still going to be used for weather forecasting and climate projections, as they have been, at a higher resolution; however, increasingly, we are going to see data collected at the farm level impacting the lower resolution forecasts.

There is an opportunity to improve assimilation and interpolation methodologies for weather forecasting. There is also an opportunity to move towards regionally robust forecasts based on methods for down-scaling and bias correction that make better use of short-term records. On-farm weather data are not currently being fed back to BOM. BOM has some operational constraints – for instance, it can only use interpolation methodologies that have been rigorously reviewed. There is a benefit in embracing more novel bias-correction and interpolation methodologies that could better harness the data that are being collected on farms.

Weather balloons are still used to collect three-dimensional data through the atmosphere, but now we also have radar and satellite information. The USA has a sophisticated system for three-dimensional reporting on what is happening at the land surface and into the atmosphere across the whole of the US. It has much better data coverage than Australia does. In terms of what the USA is doing now, Australia could be at a similar place in 20 years' time.

There are gaps in our understanding of the impact of extreme events. For example, what is the impact of a frost event that falls in a period of time when the wheat crop is starting to flower? The answer to this question would have a significant impact on production. Farmers do not have an efficient way of assessing this impact. Researchers are currently working on sensors mounted on UAVs that farmers can fly around their property to assess the damage of frost and ascertain the impact a weather event has had on the crop or animals. This information could feed into decision-making tools – should a paddock be harvested, does a paddock need additional nitrogen to combat the effects of the frost event? Currently, this type of technology does not exist. Satellite information is getting us closer, but the data are challenging to interpret and also need down-scaling to be relevant at the farm level.

BOM does not customise its rainfall maps for individual producers/farmers. It provides a publicly accessible resource that producers may or may not use. There is an initiative in BOM to have more context-relevant products, but the production of bespoke products is extremely time consuming and it has limited capacity to do this. So, BOM forecasts are produced for standard variables.

There is an opportunity to be smarter about how we are using satellite information. For example, we could use a greenness index from satellite imagery to determine when a crop might be close to harvest ready.

Precision agriculture is another area of opportunity. The use of remote sprayers and harvesters is becoming standard operating procedure but we are not routinely collecting the data that allow precision agriculture to be used to maximum benefit. For example, if we had satellite information that showed the farmer where nitrogen/phosphorus deficits were, then a tractor could be programmed to address these deficits. With satellite information, remote tractors could also respond to weeds that are not easily seen from the road.

Extending and improving the reliability of a forecast period beyond 7 days would allow farmers to be more flexible in their time of planting, or avoid performing critical operations when rainfall events are predicted. However, of greater potential benefit to a farmer is weather forecasting at the seasonal time scale. For example, if a farmer knew that the next 6 months were going to have high rainfall, then the farmer might go for a higher value, higher risk crop that needs more rain (such as canola or sunflowers), instead of a lower risk, lower value crop such as wheat.

7.3.4 What needs to be done to get there

- When considering the use of data in agriculture, the Commonwealth's *Privacy Act 1988* (Privacy Act) covers issues around where data can and cannot be used. This is a potential barrier to how easy it is going to be to integrate spatial data in real time. For example, in the frost study discussed earlier, one of the farms opted not to participate in the study because they were planning on selling their property and didn't want potential buyers to know the level of frost risk on the property.
- It is going to be very difficult to manage, process, store and deliver data-derived products in real time to farmers. This is a significant challenge. We need to build systems that are expandable to meet future demand and to cope with the large amounts of data that are coming.
- As more data becomes available, there is a growing demand for point-specific information. There is also increasing demand for improved resolution of data. The analytical tools developed for big data environments need to be considered for existing models.
- What is relevant to a farmer in terms of decision-making tools will be different to what is relevant to a policy maker. For example, consider the use of 'zero-till' or 'no-till' practices. Suppose the federal government was trying to decide if it should financially support zero till equally in each state, that is, should the policy be a simple, one-policy-fits-all model? However, some smart modelling could reveal that zero till is not useful in areas of high rainfall such as in certain areas of WA and parts of NSW. So, with smart modelling we can move away from this one-policy-fits-all idea and tailor better, more targeted, cost-effective policy. Better weather and climate products could be developed to help policy makers to make more informed decisions.

Case Study
SENSOR GRIDS

Researchers are taking a landscape view for collecting information on the presence of frost. They have been using iButtons to track how cold air pools in the landscape. This gives us the ability to see which properties are more prone to frost than others under different synoptic events.

Built in the USA and cheap, iButtons were originally designed for the transport industry to track temperature and/or humidity spikes when goods were being transported. With their small size and in-built computer chip, iButtons are a way of increasing the density of data collected without being cost prohibitive.

Industry stakeholders have been excited by this technology and its potential for giving us a better understanding of production risk.

7.4 Climate

7.4.1 **Introduction/history**

Working with the climate is only part of the multifactorial operation that is Australian agriculture. Information on climate, even if it includes a climate forecast, doesn't solve all the producers' problems. For example, if it was possible to accurately forecast the climate in QLD at individual-farm scale, this information wouldn't make all the decisions for a QLD producer; it is just one part of a huge, integrated system.

Producers need to consider the whole system, including climate information, in a way that suits their particular operation. In wheat production systems, producers start each season afresh and past climate doesn't influence the new crop in the way it might for producers in northern beef production systems. For example:

1. In domains such as beef cattle there is a history to the system. This year's success is based on how the cattle have fared so far, the current condition of pasture, the current financial situation etc. In contrast, for wheat the story largely starts anew each year – success is largely determined on this year's rainfall alone, independent of previous years.
2. While climate is important, there can be much bigger factors that determine success in some production systems and that outweigh any impact from climate variability – such as fluctuations in market prices in the case of beef cattle operations.

Climate, as opposed to weather, is driven by the general circulation of the atmosphere and oceans. Main climate influences in Australia include – but are not limited to – tropical cyclones, trade winds, East Coast lows, blocking highs, frontal systems, El Niño/La Niña events and sub-tropical ridges.[5] The Southern Oscillation Index (SOI) measures the changes in air pressure and rainfall patterns between the eastern Pacific Ocean and the Australian/Indonesian region. Rural productivity in Australia can vary with fluctuations in the SOI.[6]

In the past, and still currently, a lot of agricultural forecasting was based on statistical climatology as opposed to climate model forecasts. This forecasting involved SOI phases, and considered the El Niño–Southern Oscillation (ENSO) as the sole contributor to climate variability. For example, SOI phases drive the AussieGRASS (Australian Grassland and Rangeland Assessment by Spatial Simulation) model to predict what pastures will grow given seasonal conditions. Developed in the early 1990s, AussieGRASS monitors key biophysical processes associated with pasture degradation and recovery, at regional scales (e.g. local government areas or bioregions).[7]

The 1982 El Niño event changed climate forecast thinking when sea surface temperatures in the Pacific Ocean could be tracked using satellite imagery. Changes in ocean surface temperatures

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[5] Bureau of Meteorology, 'Australian Climate Influences', accessed 28 July 2017, http://www.bom.gov.au/watl/about-weather-and-climate/australian-climate-influences.shtml

[6] Bureau of Meteorology, 'El Niño, La Niña and Australia's Climate, accessed 28 July 2017, http://www.bom.gov.au/info/leaflets/nino-nina.pdf.

[7] Queensland Department of Science, Information Technology and Innovation, 'Australian Grassland and Rangeland Assessment by Spatial Simulation', accessed 28 July 2017,

https://www.longpaddock.qld.gov.au/about/researchprojects/aussiegrass/.

affect tropical rainfall patterns and atmospheric winds over the Pacific Ocean, which in turn impact ocean temperatures and currents. The ability to track sea surface temperatures meant it was then possible to predict seasonal climate a few months out.

Following this time, in addition to sea surface temperature observations, dynamical models were introduced to see how El Niño patterns emerged. Unfortunately, the reliance on El Niño models in climate forecasting was challenged in the early 2000s when there was a change in the pattern of development of El Niño events.

The availability of data from the Sea Surface Temperature (SST) Satellite Remote Sensing Facility and ARGO profiling floats (for subsurface (to a depth of 2000 m) temperature measurements) has also made a substantial impact on climate and weather modelling.

In climate forecasting now, consideration has shifted towards how to use the dynamical models and the Niño3.4 index (a region in the Pacific Ocean located along the equator, from 5°N to 5°S and 170°W to 120°W) and the Indian Ocean Dipole (IOD) index.

7.4.2 Current state

Beyond the familiar 1 to 10-day weather forecasts, current seasonal climate models generate average conditions and a probability spread of what is likely to occur in the next 6 months.

The Predictive Ocean Atmosphere Model for Australia (POAMA) of the Bureau of Meteorology (BOM) is a seasonal climate model that operates at a low-resolution (250 km) grid. Freely available data from POAMA, such as temperature, radiation and rainfall on a grid, are used to feed crop models like Agricultural Production Systems sIMulator (APSIM) to produce grain production estimates across regional Australia.

BOM is in the process of upgrading their current POAMA-2 system with a new seasonal-forecasting system referred to as ACCESS-S (the seasonal prediction version of ACCESS). ACCESS-S will operate at a higher resolution (60 km) than POAMA-2, and incorporate the latest developments from local and overseas sources. There are a number of global models but BOM is focusing on using the UK Met Office products.

The Managing Climate Variability Program (http://managingclimate.gov.au/) involves five rural research and development corporations: Grains Research & Development Corporation, Cotton Research & Development Corporation, Meat & Livestock Australia, Rural Industries Research and Development Corporation and Sugar Research Australia. MCV's project 'Rural R&D for Profit – Seasonal forecasting' focuses on improved use of seasonal forecasting to increase farmer profitability. The MCV group has contributed funds toward enhancing the ACCESS-S forecast model. Hindcasts are free to model past crop performance. For forecasting, there is a limited number of weather variables currently available and BOM do charge to provide that information.

The MCV program also manages the 'Climate Kelpie' website (http://www.climatekelpie.com.au/) which is a 'one-stop shop' for information and decision-support tools that producers can use for climate risk management.

'The Break Newsletters', by seasonal risk agronomist Dale Grey (http://agriculture.vic.gov.au/agriculture/weather-and-climate/newsletters), are aimed at Victorian farmers. These monthly summary reports on oceanic and atmospheric climate drivers and model predictions for rainfall and temperature are presented as short videos. The video format seems popular. They draw on information about El Niño, the SOI and IOD index as well as Australian and US models for a model consensus.

The form of the available data from POAMA is meant for app developers not for end users. In contrast, the app Yield Prophet Lite (YPL) is meant for farmers. It is available free of charge through the Birchip Cropping Group. Based on a producer's personal information, grain and nitrogen inputs, and rainfall probability deciles, YPL provides the yield potentials (t/ha) with and without additional nitrogen. For example, it could tell the producer that if rainfall is forecast to be low, there would be little benefit in adding nitrogen; but if rainfall is not limiting, there would be potential benefit in adding nitrogen.

The YPL app has been developed from the Yield Prophet (YP) online platform. YP takes raw information from models such as POAMA, performs some data cleaning and processing to feed the information into a tool like APSIM and then restates the results in a form acceptable and meaningful to the producer.

Other tools use historical weather information, not forecast information, to run simulation models. This tends to result in a more conservative forecast. For instance, Queensland's CropARM tool is an agricultural risk management (ARM) tool that uses 115 years of climate records and the APSIM model to predict variability in yield, rainfall, temperature effects and crop growth. CropARM is one of a number of ARM tools developed to assist producers manage risk related to climate, nitrogen and phosphorus application, and fallow period length (http://www.armonline.com.au/#/).

However, currently, the climate models tend to be overly influenced by auto-correlation components, generating longer-than-expected runs of dry or wet periods. This may be due to spatial averaging over a large grid cell.

For multivariate data, the forecasting ignores correlation among weather variables, treating each forecast separately. There needs to be more research directed towards calibrating forecast data with crop yields.

Forecast accuracy depends on the forecasting period, and the information for different forecasting horizons is presented differently. For periods of up to 3 months, the models are good. Between 3 and 6 months, forecasting is more difficult. The likely weather is provided in terms of deciles. Forecasting for 12 months is imprecise.

In terms of 10 years out, climate forecasting is specified in more quantitative expressions such as 'likely to have more El Niño years than La Niña years' or 'more dry than wet conditions'. The statements become less precise the further the forecast horizon.

7.4.3 What the future state should look like

Although better climate models are needed, including better down-scaling, investment is also needed in better understanding how the models are to be used. We don't know how to provide the climate information in a way that is useful for producers. For example, what climate information is needed to affect change in agriculture?

The data may exist currently in a form that is not interpretable to the farmer. There is an opportunity for app development that performs the necessary post processing of forecast data into a form that is relevant to the producer. The core software requirements are similar across multiple industries.

Uncertainty is generated in the forecast by multiple runs of the climate forecasting tool POAMA with the same initial conditions with a small amount of noise and the generated forecasts are reported in terms of deciles. Although the YPL tool is popular with growers, it requires more development to improve its accuracy. Use of ACCESS-S may solve some of the bias-correction issues related to down-scaling that POAMA suffers from.

The farmer is wondering 'should I spray?', 'should I fertilise?', 'should I harvest?' However, the forecasting question the farmer needs answered is 'what is the chance of any rain in the next five days?' Current forecasting metrics are not stated in a way that directly answers the questions asked by the farmer. The information is available, but not in a form suitable for the producer's needs.

Agricultural climate apps need to be targeted efficiently. Producers are reluctant to purchase apps. Perhaps the app should be distributed, not to the grower, but to someone further up the supply chain.

BOM set high standards around the quality of data they collect for their models. Although there is an increase in non-BOM weather stations, it is difficult for BOM to accept this data because of these quality standards. Other weather data providers may accept data from a broader base. This is important because it allows them to down-scale their data. The benefits of incorporating data of lower quality is weighted against the possible benefits of more spatially appropriate information.

If an awesome, able-to-be-down-scaled climate forecast was available, how could it be made relevant to producers?

When farmers are asked what they want, the replies might be 'a better forecast' or 'is it going to be a good year or a bad year?' It is necessary to unpack this by asking what the farmer meant by this. It may mean the farmer wanting to know about a weather event occurring or not at a particular stage of crop development. It may mean knowing if there will be a frost or rainfall at a particular time. If specific weather features that affect crop or animal development can be elucidated by the producer, then the information needed to answer these questions can be extracted from the climate models by the forecasters. Understanding what producers really want to know would allow for bespoke forecasting.

7.4.4 **What needs to be done to get there**

The issue of climate forecasting needs to be part of the broader set of concerns, constraints and issues facing the producer. Modellers and forecasters need to know what specific climate-related information is required by users.

Climate forecasts need to be integrated into the broader digital agriculture space. At the moment this isn't happening, and the decisions are made by sensing current conditions. The space needs to be opened up to allow the forecasting of the future.

Climate does not stop at national boundaries and as a result seasonal climate models are run globally. There are a range of international models that can be used to predict Australia's climate. The details from the full spread of models are often used to give an overview of possible El Niño forecasts on the BOM website and other information sources for climate.

Australian researchers, of course, focus on the climate features relevant to our region and attempt to improve them in ACCESS-S. This will feed back to the UK model (that is the basis for ACCESS-S) to improve the model and eventually benefit Australia.

Funding for the forecast models is giving precedence to developing the models and away from furthering the models' use in agricultural applications (e.g. for specific applications to specific industries such as sugar, grains, livestock, cotton). End-user applications are not being considered. Issues surrounding ownership of intellectual property (IP) may stifle progress on developing tools or apps.

BOM produces POAMA and ACCESS-S, however, Australian industry has access to other seasonal forecast models, including European and US models. Using input from many sources should improve forecast accuracy.

It is important that the BOM establish a funding model for their products as this impacts the development of tools and apps for agricultural industries. Given that forecast information is available from Europe and the US, there is a real possibility that tool providers will look overseas for their data needs.

There is a role for educating producers in the development of agricultural climate metrics. If producers know more about climate drivers and forecasting, then models can be tailored to meet their needs. In going back to the example of the northern beef producer, market prices may dominate the success of a year's production, but that doesn't mean climate is unimportant. It might be that there is an aspect of climate forecasting that could be incorporated into improving the beef value chain if the producer could sit down with a climate modeller. In another example, mango growers in northern Australia might want to know about the climate in Melbourne so they can anticipate windows of opportunity for getting their product to market – when it's hot in Melbourne, people want to eat mangos.

More emphasis is needed in the cross-disciplinary space of climate and ag. Climate scientists tend to focus on their own metrics to improve models. More discussion between the two disciplines would allow agricultural scientists to explain the parts of the climate that are relevant to them, those parts that they need forecast well. The discussion would also allow climate scientists to explain which aspects of the climate are possible to model and forecast and which are not.

If a piece of climate information doesn't affect a change in behaviour then is it really that useful? Finding the decision points in agriculture that relate to climate is an underdone area of research. A simple example – improving an ENSO forecast by increasing correlation values from 0.65 to 0.7 won't change a farmer's behaviour; on the other hand, improving a producer's understanding of the weather systems most likely to result in a frost might do it.

Researchers should be urged to develop a metric for 'farmer happiness'. Climate forecasts don't always result in a profit increase. Sometime the benefits are harder to pinpoint – should a producer wait around to see if the wet season finishes early or just take the family on holiday? An early warning forecast of frost/pest/disease outbreak allows for a mental preparedness to deal with catastrophes, a preparedness that isn't there if a farmer simply wakes up one morning and the crop is ruined. Producers are quite devastated by seeing their stock in pain or underfed and climate forecast information may give them scope to improve animal welfare – but may not necessarily increase the underlying profit.

7.5 Land boundaries

7.5.1 Introduction

7.5.2 Current state

7.5.3 What the future state should look like

7.5.4 What needs to be done to get there

7.5.5 Recommendations

8 The role of decision-support tools: turning data into insight

8.1 Introduction

Decision-support tools in agriculture comprise a wide range of applications as well as a wide range of complexity and product type. Examples range from onboard algorithms for control auto-steering, weed removal and precision placement of fertiliser to milking robots, from control of greenhouse and livestock housing conditions and dynamical modelling for climate forecasting to analytics that optimise yield and profit-harvesting data using multiple sets of private and public data.

Telemetry equipment suppliers offer plug-and-play systems that are now incorporated into virtually all agricultural equipment. Apart from global positioning system (GPS) data, onboard sensors can monitor fuel level, temperature, pressure and tank levels with data connectivity provided via a CANbus (controller area network) system and processed using proprietary software.

The amount of information that can be collected in both crop and animal production systems has increased in recent times, especially since the 1970s, with the use of satellites and now UAV platforms. Both technologies are increasingly being used to monitor crop performance and animal behaviour and health. The spatial and temporal frequency of data capture has increased dramatically with the use of imaging equipment carried by UAVs. Cheaper sensor technologies, borrowed from other sectors, have permeated the agricultural scene. Sensor networks are now being used in research and commercial environments. These devices allow streams of data to be captured. Issues surrounding data standards and interoperability have been a stumbling block and producers have been wary of being trapped into proprietary systems. Many applications incorporate data of different types including imagery and spatial information.

The challenge to process these large amounts of data and turn the data into useful information for producers is an ongoing challenge. Research is still needed for improving the calibration and rectification of streaming data in real time, assembling data of different types, formats and scale from multiple sources and data imputation and then mapping that information to a decision framework meaningful for the end user. To help turn information into decisions, current predictive and inference tools generate either point or probabilistic estimates of possible production levels using historical and forecasted conditions.

The Australian Farm Institute report titled 'The Implications of Digital Agriculture and Big Data for Australian Agriculture' serves as a good review of the current state of digital technology used by some sectors of the agricultural industries.

8.2 Current state

The current agricultural decision-support tools have many different pedigrees. Some started as management information systems, some came from machinery providers, and others are extensions of research tools (often from projects funded by rural research and development corporations (RDCs)). Climate Corp has come from another stable. It uses cutting-edge data analytics to mine mostly publicly available data to deliver a crop prediction model and backs these predictions with crop insurance should an unpredicted weather event occur.

The large platforms are built around databases for recording events such as crop and animal management actions, as well as other forms of data such as GIS data, images and text information, and financial records. They try to be the Swiss knife of farming enterprise management systems. They integrate information from many sources, including synchronising data from mobile devices. Information is fed back to the producer often in the form of a visual dashboard displaying heat maps and charts of various forms – depicting for example, current and future weather conditions or weather warnings. The information presented to the producer is often complex, and often requires a specialist advisor to help interpret.

Recently, a large number of proprietary data-conversion plugins have become available. Some of these are available via subscription to commercial farm management information systems but the Agricultural Data Application Programming Toolkit (ADAPT) system provides many plugins free of charge.

The predictive tools tend to be less user friendly and aimed at specialists or experts. Often tools are produced from a research environment. An example of turning a research tool into a more approachable product is demonstrated by Yield Prophet Lite. This app provides a simpler to use, more applied interface to the more daunting Agricultural Production Systems sIMulator (APSIM) program. GrainGrowers' ProductionWise is another example of providing a grower-friendly decision-support tool, also based on an APSIM backend.

With ever-increasing amounts of data being collected and available, decision tools along with much of the data are migrating to cloud-based processing and file servers. This ensures a more secure data-storage environment than personal desktops or mobile devices, and a processing environment that supports the power and data-handling capabilities needed to process big data. A web-based server model simplifies the support for different operating systems for applications. This also allows mobile devices to be easily interfaced into the application platforms as well.

8.3 What the future state should look like

More of the North American-based commercial providers of agricultural decision-support tools will expand their operations in Australia. Once local datasets of the necessary quality become available in Australia and some of the differences in operations are dealt with, the analytics will transfer to the local environment, making their products more useful to local producers.

Increasingly, data mining companies will develop interest in delivering applications for agricultural industries. The interest for these products may come more from financial and insurance industries and distributors if not from the producers. In general, there is a large expectation of the benefits of using machine-learning techniques on big data and there is no reason to believe that this will not be attempted in agriculture. Improved algorithms based on image data for disease monitoring, animal and plant health diagnostics, animal and plant performance assessment, and soil nutrient monitoring would be achievable using existing machine-learning tools.

Precision agriculture has, amongst other things, reduced the decision making once performed totally by the farmer. There is little reason to doubt that more and more decisions faced by the farmer can be made by devices supported by smart analytics. Platforms like UAVs and terrestrial robots with access to the internet can both monitor and act in response to a threat to a production system. Like self-steering vehicles in which the controlling software lies within the GPS-enabled agriculture vehicle, the algorithms that classify disease and pest risks and take corrective actions can reside on the device – a device that can communicate and interact to enable automatic responses. For example, a drone that is monitoring crop or animal health can direct a terrestrial robot to address a problem.

The increased use of intelligent personal-assistant apps like Google Assistant, Microsoft Cortana and Apple Siri will be applied to agricultural situations. These tools will proactively deliver timely and relevant information to the user that makes predictions based on farm records, farmer behaviour, social networks, scouting robots, weather data, equipment maintenance sensors, predictive tools and other data sources. For example, crop sensors may detect the early stages of a pest and then, incorporating current forecasted weather conditions, the app may suggest the need for an application of pesticide and provide recommendations on type, formulation and timing based on the weather forecast.

Increasingly, decision-support tools will present results in terms of risk (i.e. probabilistic information presented in a palatable form for users so they understand the uncertainty associated with any recommendation or prediction).

Prediction models with 'self-learning' capabilities will be commonly used. Bayesian updating models can incorporate real-time information and update models and decisions. Deterministic models provide future production trajectories; however, observational data is continually updating these trajectories in real time. Model data fusion reconciles the uncertainty associated with predictions with that associated with observational data.

More tools that allow producers to benchmark themselves against other producers will increase, should data-sharing arrangements become available and acceptable to farmers. This is available now to producers aligned with some of the commercial agri-service providers. With good data-sharing legislation in place, data sharing should be available to a wider user base.

Currently most if not all decision-support tools focus on particular variables on interest, for example yield or profit. Associated side effects and possible long-term negative effects can be incorporated into predictive tools. The information presented goes beyond that requested by the user (e.g. a farmer querying a tool to find that the addition of more nitrogen may improve profitability but is warned that there is a defined risk of polluting a nearby water course compromising environmental regulatory or food safety requirements).

Current decision-support tools are based on biophysical models of agricultural production. These are not the only elements of a broader set of decisions that farmers face. Computer support for optimising productivity should incorporate farmer's constraints on the biophysical system as well as other elements. This allows more flexibility for producers to incorporate lifestyle choices into their production planning.

Product traceability along the production chain will be demanded by retailers and the public who show an increasing concern around fair work conditions, food safety and animal welfare issues, among others.

On-farm experimentation will help farmers trial various management options geared towards their own environment. Using existing information, these experiments would allow producers to test various treatments and help the producers make inferences from the trials. Tools and scripts need to be developed to enable producers to design their own on-farm trials as well as the analytical tools to present the results of the experiments in a straightforward way.

8.4 What needs to be done to get there

- Producer-owned devices will produce more of the data than in the past. A framework enabling control of data ownership and use needs to exist to maximise the benefits of the collected data.
- Cheaper and smaller sensor devices and new sensor types will enable more measurements to be made. Properly calibrated, the data from these devices will be implemented to provide quality information on soils and weather properties.
- Weather forecasting models need to have greater accuracy and a finer spatial resolution.
- Highly accurate GPS systems are needed to locate points of interest and control devices with high precision.
- Sensors can accumulate large amounts of data. This data needs to be uploaded in real time to the analytics server. The infrastructure technology to enable this needs to be available to all enterprises and locations.
- Education and clarity is needed on data-ownership law. The data needed for digital agriculture are gathered from many sources. Systems are required to manage and track sharing of information among different stakeholders.

- Communication infrastructure on-farm and backhaul bandwidth to support the necessary data transfer rates are needed to support advances in sensor technology and automation.
- The benefits of harmonising remote sensing with in-situ sensor technology need to be exploited to improve the accuracy of sensor-based data. Calibration of these technologies is paramount in defining the value of these data.

9 Discussion

Data is streaming onto the farm and other agricultural enterprises from public DBs and out of the farm from sensors producing weather, climate, soil and other types of information. Platforms are available from many agri-service providers providing a range of capabilities based primarily around data management systems. Many of these platforms incorporate some predictive tools based on publically available and producer sourced data.

[concerns about cost and locked-in contracts] There is pressure from agri-service providers on producers to purchase sensors of various types, weather stations, soil testing, electromagnetic resonance services, and subscribe to platforms. The financial commitment and concerns about being locked in to service contracts and data ownership and confidentially have been raised by producers. To address these concerns many of the platform providers provide translation tools to allow their data to be exported in a variety of formats.

[data sharing of sensitive info] Some producers are unconvinced of the benefits of data sharing and their enthusiasm dependant on the sensitivity of the information. Where data sharing platforms are available, there seems to be confusion over the level of protection offered to the producer. It is unclear how an effective and simple system could be developed to overcome these concerns. A solution may be available using new technologies like homomorphic encryption which allows computation on encrypted data without having to decrypt the data first.

[data sharing and competitiveness] Producers in some industries use competitive advantage as a reason not to share data.

[concern that data will be used for litigation or environmental legal action by authorities against the producer]

[Data veracity] Despite the increase in volume, variety and velocity of information provided by different providers and technologies, the biggest challenge that determines the usefulness of information relates to its veracity. Exaggerated or inaccurate claims produced by decision support tools using unreliable data will impact the uptake of any of these tools. Producers need to trust the information on which they make decisions. The cost of ensuring highly accurate data is significant and institutions such as Australia's Bureau of Meteorology and Geosciences Australia place high priority on efforts directed towards data quality.

[private sector engagement and public funding] The major cross-sectorial data sets useful to producers include information about soils, weather and climate forecasting and other data available as images. Much of these high quality datasets are provided by public institutions such as the Bureau of Meteorology, Geosciences Australia, the CSIRO, and other federal and state bodies. Who should pay for these services?

Assimulation, downscaling, bias correction and interpolation of weather data from multiple sources.

Increasing numbers of producers are purchasing weather stations with the ability to capture various weather variables at regular times and easily upload the information over the internet. This information can be invaluable for retrospective studies and model building at a fine spatial scale. Who does it as it may be difficult for BoM?

Will the climate model products provided by European and USA based organisations disrupt the role of the BoM?

[predictive tools have some way to go] Tools like Yield Prophet Lite are useful but require more research.

[user needs and interfaces] There are still opportunities in providing the information that is relevant to a producer and in a more convenient form. Many of the dashboards provided as part of the platforms present a plethora of graphics and tables. It is uncertain how these data are mapped into decisions. If producers can articulate their needs, can the data answer these questions directly? The technology employed in mobile assistants like Apple's Siri, Google's Assistant and Microsoft's Cortana can drive search engines as well as analytical tools to provide producers with appropriate and timely information.

Monitoring of soil change in particular soil nutrient depletion, acidification, trends in soil carbon, soil-water balance and soil microbial populations. Existing soil information represents a snapshot in time.

Precision agriculture requires accurate spatial information using GPS technology that is accurate to 1 metre. Because of plate tectonics and continental drift, Australia's datum needs updating to ensure Australia's plate-fixed maps are in sync with devices with accurate positioning capabilities. Role of government (GA) to implement the required updates.

10 Appendices

10.1 Workshops: how they were run and findings

Eight workshops were held in various regional locations in Australia. Participants included producers and agri-services and industry representatives. Potential participants were identified through communications through the RDCs, contacting peak producer groups and personal networks. The workshops were held over the course of four hours and were facilitated by two facilitators supported by seven to eight members of the research team. Numbers of participants at the individual workshops ranged from 12 to 25.

For the workshops, a set of questions was constructed to determine the more important decisions producers make in their enterprises and the sources and tools that were used to support these decisions. To determine the perceived gaps in producer needs, participants were asked what information and/or support tools they thought were missing. The participants were placed into one of 4 small groups to facilitate open contribution to the data-gathering exercise.

After completing the first four workshops, the process was altered to a more 'global café' approach where members of the research team lead groups of attendees through the same questions. The change in format was necessitated by the low numbers of producers compared to agri-services and industry representatives, and the concern that producers were reluctant to raise certain issues.

The schedule of workshops along with their main industry focus is shown in Table 1.

Table 1. Location, date and main focus of workshops to identify datasets and decision-support tool use in agriculture

Workshop	Location	Date	Focus industries
1 (pilot)	Gatton, QLD	5 Dec 2016	Horticulture/vegetables
2	Townsville, QLD	1 Mar 2017	Horticulture, sugar, plus other industries
3	Tamworth, NSW	2 Mar 2017	Meat, grains, cotton
4	Northam, WA	16 Mar 2017	Grains, wool
5	Wagga Wagga, NSW	28 Mar 2017	Pork, grains, rice
6	Tatura, VIC	29 Mar 2017	Dairy, plus other industries
7	Launceston, TAS	30 Mar 2017	Forestry, plus other industries
8	Tanunda, SA	27 Apr 2017	Grapes and wine

10.1.1 **Summary of issues raised**

Table 2 presents the number of times a specific topic related to data use in agriculture was raised at each of the workshops.

Table 2. Summary of major topics raised across the eight workshops

Topic	Topic
Data literaracy (entry to interpretation)	Soil data needs to be at finer scale
Relunctant or opposed to sharing of data	Weather data needs to be at finer scale
Lack of data integration	Data quality/accuracy
Datasets not fully utilised	Storage and security of data
Low adoption of sensor technology/precision agriculture tools	Software no intergrated (interoperability)
Lack of predictive tools	Soil testing too slow
Interest in economic value of data	Lack of trust in data
Sensors used extensively	Farm management tools useful
Need for industry expert	Willing to share some data
Precision ag equipment use is commonplace	Need for crop disease forecast tool
Real time data for smaller areas/individual animals	Questions around value of some technologies (e.g. VRF)
Traceability is increasingly important and relies on good data systems	Lack of skilled labour and flexbility in employment
Need for better water allocation information	Too much paper-based data entry systems

VRF = variable-rate fertiliser

10.1.2 **Consistent issues**

- The major decisions for cropping industries were to do with predicted weather and climate, soil moisture status, soil nutritional status, and pest and disease status.
- Both producers and agri-service providers voiced concerns about the accuracy of sensor technologies; in particular, for soil moisture sensors and biomass/yield sensors on harvesters. Calibration of sensors is rarely performed.
- The willingness to share data among other producers varied with the industry. Agronomists and agri-specialists would/could combine data from clients to provide feedback to producers.
- Producers, particularly large producers, are heavily reliant on expert advisors to make decisions across a range of aspects of their business.
- There are multiple digital agriculture platforms in the market with no consistent platform emerging. Data format conversion tools exist depending on the platform.
- Many data entry systems for various platforms and regulatory tools used by producers rely heavily on manual entry, which is a major impediment to information use and quality. This agrees with our review of the how-to descriptions from a sample of applications.
- Producers raised the need for weather and climate information at paddock scale for forecast periods appropriate to planning and growth periods. This scale may be from years for forestry and tree crops down to hours for livestock and other crops. This was echoed by industry experts and interviews with producers.
- Producers raised the need for historical and current soil property information at crop scale. The soil experts would support this and initiatives for a national collection of soil survey data have been proposed.
- Producers raised the need for soil moisture and physical-chemical data at a finer spatial scale.
- Concerns were raised about how varietal performance translates to specific soil and climate conditions. The varietal performance information is well researched (e.g. GRDC NVT[8] information and SRA's QCANESelect[9]) which provides accurate comparative information for different varieties across a range of environments. The issue seems to be in establishing which environment is applicable to an upcoming season for a grower. When any benefit of genotype expression is marginal compared to the impact of nutrition, available soil moisture and weather events such as heat stress, the worth of the information provided by these initiatives may be decreased. To reduce the producer's risk, they may choose the varieties that perform best across a range of environments. However,

[8] Grains Research and Development Corporation, 'National Variety Trials', *Grains Research and Development Corporation*, accessed 19 June 2017, https://grdc.com.au/research/trials,-programs-and-initiatives/national-variety-trials.

[9] 'Varieties', *Sugar Research Australia*, accessed 19 June 2017, https://sugarresearch.com.au/growers-and-millers/varieties/.

the criteria used by growers to choose varieties is multi-factorial and the risk associated with various options needs to consider the physical, social, and financial environment.

There seems to be a lack of available skills in geographic information system (GIS) and agronomy/husbandry.

10.1.3 Divergent issues

- Rural research and development corporations (RDCs) provide a lot of tools. Noticeable at workshops was the minimal mention of these tools made by producers. Many of these tools are aimed at researchers or highly skilled specialists and consultants.
- During the workshop at Northam, WA, participants raised the usefulness of land use information. Participants at other workshops did not raise this topic.
- In the fishing industries, much of the data collected is directed at managing the fisheries for sustainability.
- The willingness to share data varied among workshops and among participants within some workshops. Sometimes the differences were around the types of data being shared (geophysical versus financial) while in some situations reluctance to share data was due to maintaining a competitive advantage.

10.1.4 Key datasets that are not currently available

- Fine spatial and temporal data of moisture and physical and chemical properties of soils
- Fine spatial and temporal data for weather information. However, as weather stations become cheaper with greater connectivity, producers are placing more weather-recording instruments on their properties.

10.2 Current agriculture-based decision support tools

Table 3 presents our register of common software tools for turning agricultural data into a decision. Many of these tools were identified from our engagement with farmers, producers, and industry experts. Our goal was not to identify every available software tool but only those tools of importance.

Many of the agricultural software platforms presented in Table 3 have one or more of the following components:

- Robotics: Robotics represent a large component of precision agriculture. The technologies include self-steering tractors, variable rate fertilisers and sprayers, and robots (Agbots) for weed removal, disease detection and treatment and harvesting of fruit.
- Logistics: Logistics particularly in determining the supply of inputs such as chemicals and seeds as well as the scheduling of harvestings. Some of the larger software platforms are sold by input suppliers.

- Record keeping: The platforms are often built around a database management system that is housed on a web-based file server or cloud. This module takes data from a number of sources: different sensors, keyboard entry, downloads from public or private data repositories and output information via webtools, SMS messaging services, and scripts for machinery or other devices. Information can be exported to allow producers to share and compare for benchmarking or other purposes.
- Optimisation of processes: An example of process optimisation is prescriptive planting whereby yield is maximised by regulating planting and fertiliser rates depending on soil and weather conditions.
- Product tracking: The ability to track food through the production chain provides processors, retailers and consumers with information about product source and processing with respect to food safety, working conditions, sustainability or other environmental issues.
- Market analytics: Market predictions based on supply and demand data allow producers to produce the type of product that maximises profit at time of harvest.
- Deterministic agricultural production systems: Software tools such as Agricultural Production Systems sIMulator (APSIM) and Yield Prophet are crop simulators that use the essential components of growing a crop using soil, weather, climate data and crop type to allow farmers to make decisions around crop yields.
- Retrospective studies: Producers can look at historical information from different sources to look for patterns or associations to better understand the potential drivers, factors and decisions that have impacted on their past production. Data sharing allows producers to benchmark their performances.

Table 3. Register of major software products used by agricultural industries

When known, the use of a particular data type by a product is marked with an 'X'. The use of data may relate to a platform broadly or to a particular tool so the ‘X’ may appear beside the platform and not a particular module when applicable.

Company and product	Soils	Weather	Climate	Imagery	Boundaries	Other major
Ag Leader						
Agfinity	X			X	X	Yield
Directcommand						
Incommand						
Intelliscope						
Seedcommand						
SMS						
Yield Monitoring						
AgData Phoenix						
Financial (lite/financial/pro)						
Production	X	X		X	X	Yield

Aggateway						
ADAPT						Record keeping
Tools						
AgriDigital	X	X		X	X	Yield, financial
AgriDigital						
Agworld		X	X			
Agworld Everywhere						
Ausveg						Industry statistics
Ausveg						
Back Paddock Company						
Adviser						Financial record/analysis
CornerPost						Record keeping
Manager						
Mobile						
Reader	X					
SoilMate						
Climate	X	X	X	X	X	
FieldView						
Fairport	X	X		X	X	Yield
gpMapper						
Grape Forecaster						GIS layers
MindMyAssets						On-farm map info
PAM						On-farm grape samples
PDP						Vehicle records
PocketPAM2						
Grapelink	X	X		X	X	Financial
ChemCheck						
Grapeweb						Spray records
Grapeweb						
GRDC						Spray records
APVMA						
Crop Disease Au		X	X			Factsheets
Field Pea						
GrowNotes						
Insect ID						
Lentils App						
MyCrop						
SoilMapp						
SoilWaterApp						
Weed ID						
WeedSmart						
Winter Cereal Nutrition						
John Deere						
APEX						
Connect Mobile	X	X		X	X	Equipment data
Harvest Identification						
Harvest Mobile						
HarvestLab						

JDLink						
Mobile Data Transfer						
Mobile Farm Manager						
Operation Center						
Yield Documentation						
Modular Information Systems						
Rocket SystemBuilder						
Rocket UniData						Fishing log
Rocket UniVerse						
OLSPS Marine						
Data Logger						
Data Manager				X		
Electronic Monitoring						
Production Wise	X	X	X	X	X	
NDVI Satellite Imagery						
SA Gov		X	X			
aginsight						
Sense-T	X	X		X		Yield
Pasture Predictor						
SST Software						Fishing log
SST Summit (Basic/Pro)						
SuccorfishM2M						
Catch App						
SC2	X	X				Inter-row distance
SC4						Variety performance data
Syngenta and CSD – Fast Start for Cotton						
Planting Green Light						
Planting rate						
Replant Calulator						
Soil Temp Net (broken)						
Variety Perf'nce (VP)	X	X				
VP Comparison						
The Yield		X				
Sensing+						Disease risk
Vinehealth Australia						
Biosecurity Assessment Tool	X	X	X			Variety performance
Risk Assessment Tool						
Yield Gap Australia						
Yield Gap map for wheat and canola	X	X	X	X		

To visualise how these different software components are at play on a typical farm, see Figure 1 (figure produced by Open Ag Data Alliance). The core of the system is the database residing in the farmer's clouds. Much of the robotics processing resides on the various pieces of farm machinery (harvesters, fertilisers, planters, sprayers, irrigators) with additional external control coming from the script (Rx Map) that controls the machinery.

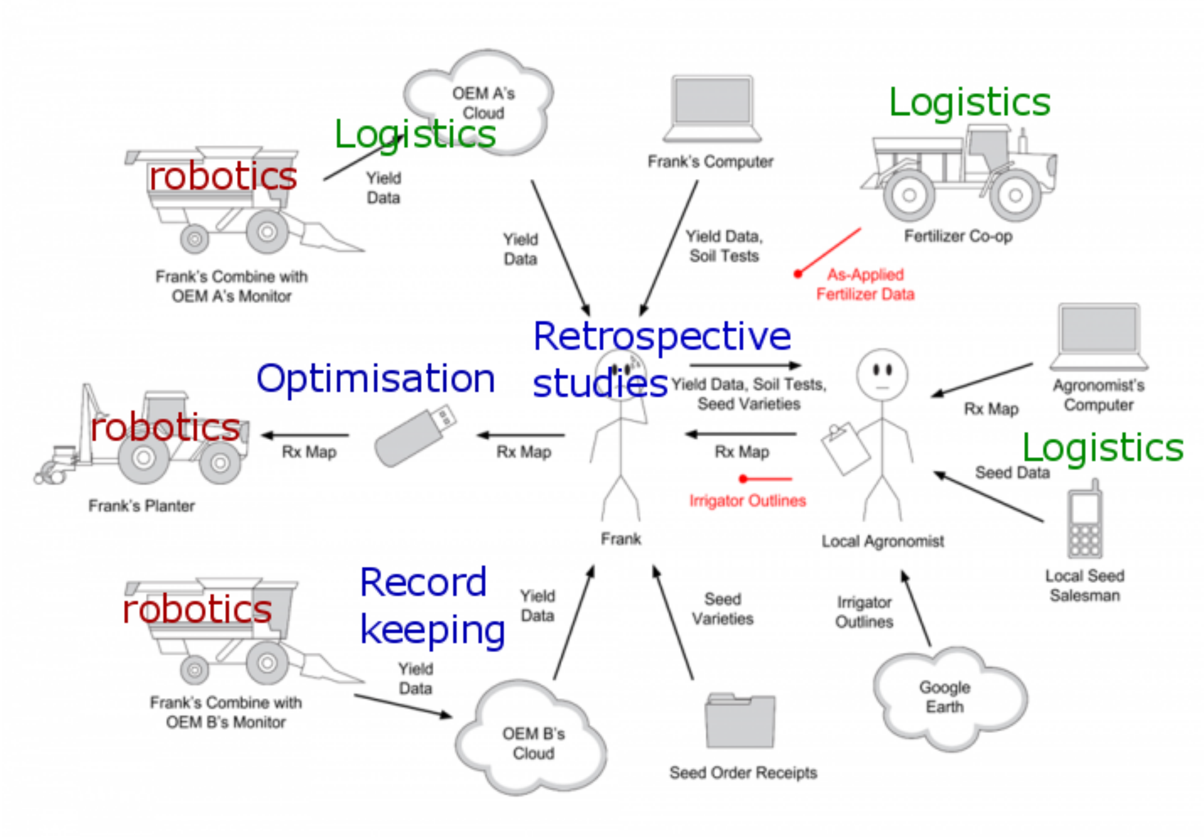

Figure 1. The agricultural data industry ecosystem [based on Open Ag Data Alliance Figure 1 (http://openag.io/about-us/principals-use-cases/)]

10.3 Current cross-sectorial data resources

The data register presented in this section was created by desktop research, from interviews with experts, industry providers and workshop participants. The purpose of creating a data register is to elucidate the available datasets that may be relevant to Australia's agricultural industries.

The data register has been separated into five areas based on the interviews and the need to focus on those data that represent cross-sectorial interest. The five areas are:

1. Soils
2. Weather
3. Climate
4. Imagery
5. Land boundaries.

The extent, coverage, reliability and accuracy of the data within these datasets vary according to the purpose of their collection. Some represent primary or raw datasets while many are products generated by substantial pre-processing to a form useful for users. Many datasets have a spatial aspect with web-based tools to view the available spatial layers.

Within each area, the listing of datasets is aggregated by source and organisation responsible for the dataset.

10.3.1 **Soils data**

The current major dataset for soil information in Australia relevant to agricultural production is the Australian Soil Resource Information System (ASRIS).

ASRIS provides online access to the best publicly available information on soil and land resources in a consistent format across Australia. It provides a hierarchy of mapping units with seven levels of generalisation:

- The upper-three scales (L1–L3) provide general descriptions of soil types, landforms and regolith across the continent.
- The lower scales (L4–L6) provide more detailed information in regions where mapping is complete. Information relates to soil depth, water storage, permeability, fertility, carbon and erodibility. Most soil information is recorded at five depths.
- The lowest scale (L7) consists of a soil profile database with fully characterised sites that are known to be representative of significant areas and environments.

The level of detail depends on the survey coverage in each region. The upper three levels provide descriptions of soils and landscapes across the complete continent while the lower levels provide more detailed information, particularly on soil properties, for areas where field surveys have been completed. The lowest level (L7) relates to an individual site in the field (10 m mapping window). The data for the ASRIS Level 5 (finest scale) soil units can be downloaded in an APSIM-compatible format for crop modelling.

Table 4. The number of available datasets containing information on Australian soils categorised by source and organisation

Source and organisation	Count
aurin	**13**
Government of New South Wales – Department of Planning and Environment	3
Landgate	9
Regional Australia Institute	1
csiro-dap	**94**
databroker-oznome-csiro-au	**18**
data-gov-au	**408**
ACT Government	1
Australian Bureau of Statistics	1
Australian Institute of Marine Science	88
Australian Seabird Group	1
Bioregional Assessment Programme	27
Brisbane City Council	1
Centre for Tropical Biodiversity & Climate Change, James Cook University (CTBCC/JCU)	1
City of Hobart	1
City of Melbourne	2

Commonwealth Scientific and Industrial Research Organisation	14
CSIRO Oceans and Atmosphere – Information and Data Centre	2
Department of Agriculture and Water Resources	29
Department of Primary Industries, Parks, Water and Environment (Natural Values Conservation Branch)	1
Ecosystem Sciences, Commonwealth Scientific and Industrial Research Organisation (CSIRO)	8
Geoscience Australia	122
Logan City Council	1
Moreton Bay Regional Council	1
New South Wales Datasets	3
School of BioSciences, The University of Melbourne	1
South Australian Governments	87
State of the Environment	9
Torres Strait Regional Authority (TSRA)	7
data-melbourne-vic-gov-au	**2**
data-nsw-gov-au	**3**
Department of Finance, Services and Innovation	1
Department of Planning and Environment	1
DPI – Water	1
data-qld-gov-au	**15**
Environment and Heritage Protection	1
Natural Resources and Mines	1
Science, Information Technology and Innovation	13
data-sa-gov-au	**83**
Dept of Environment, Water and Natural Resources	82
Dept of the Premier and Cabinet	1
data-vic-gov-au	**31**
Department of Economic Development, Jobs, Transport and Resources	22
Department of Environment, Land, Water & Planning	6
Environment Protection Authority Victoria	1
Geoscience Australia	1
Sustainability Victoria	1
data-wa-gov-au	**41**
Department of Agriculture and Food WA	26
Department of Environment Regulation	10
Department of Parks and Wildlife	1
Department of Water	4
nci	**26**
nsw-oeh	**126**
Environment Protection Authority (EPA)	6
Office of Environment and Heritage (OEH)	118
Office of Environment and Heritage (OEH) – Office of Water	2
nsw-seed	**12**
Department of Planning and Environment (DPE)	2
Environment Protection Authority (EPA)	1
NSW Resources and Energy (DRE)	1
Office of Environment and Heritage (OEH)	8

(blank)	**3**
Geoscience Australia	1
(blank)	2
Grand total	**875**

10.3.2 **Weather data**

The major weather and climatic datasets are produced by the Australian Bureau of Meteorology (BOM). The Australian Digital Forecast Database (ADFD) contains official weather forecast elements produced by the BOM, such as temperature, rainfall and weather types, presented in a gridded latitude and longitude based format covering the next 7 days with a 6 km grid resolution (3 km in Victoria and Tasmania). This set of weather elements is updated around 6 am and 6 pm Eastern Standard Time each day. Less frequent recording is done at more than 18,000 sites around Australia with more frequent observations recorded at the 560 automatic weather stations.

However, increasingly, local weather records are being collected by state authorities as well as by producers and agribusinesses. Affordable weather stations are available to record direct measurements such as rain, wind speed, wind direction, air temperature, relative humidity and solar radiation as well as derived measures such as dew point, heat stress index for livestock, thermal work limit and wind gust and wind vector calculations for spray and odour drift.

Some state authorities and institutions augment the BOM's stations. For example, the WA Department of Agriculture and Food manages a network of 180 automatic weather stations throughout the state to provide timely, relevant and local weather data to assist growers and regional communities make more-informed decisions. This data includes air temperature, humidity, rainfall, wind speed and wind direction, with most stations also measuring incoming solar radiation to calculate evaporation.

Commercial weather networks are emerging. The Discovery Ag Water and Weather Network (DAWWN) consists of a network of 68 automatic weather stations and soil moisture probes, strategically positioned across the length of the NSW cropping belt. DAWWN provides data on rainfall, air and soil temperature, wind speed and direction, solar radiation, humidity and barometric pressure. A series of soil moisture probes will be installed throughout this network to complement the weather station data offering underground telemetry connectivity. Each soil moisture probe site records soil moisture at 20 cm intervals to a depth of 2 m and includes soil temperature, as well as having an automatic rainfall gauge at each site. The network operator provides weather information to growers and agronomic service providers.

Table 5. The number of available datasets containing information on Australia weather categorised by source and organisation

Source and organisation	Count
aurin	**1**
Government of the Commonwealth of Australia - Bureau of Meteorology	1
bom-gov-au	**2612**
csiro-dap	**3**
data-gov-au	**1435**
Australian Antarctic Division	2

Australian Institute of Marine Science	1310
Biophysical Oceanography Group, School of Geography, Planning and Environmental Management, University of Queensland (UQ)	7
Bioregional Assessment Programme	44
BlueNet	1
Bureau of Meteorology	13
Bureau of Meteorology (BOM)	1
CSIRO Oceans and Atmosphere - Information and Data Centre	7
Department of Finance	1
Geoscience Australia	23
New South Wales Datasets	2
Space Weather Services - Australian Bureau of Meteorology	1
State of the Environment	22
(blank)	1
data-nsw-gov-au	**2**
NSW Rural Fire Service	1
Transport for NSW	1
data-vic-gov-au	**2**
Department of Environment, Land, Water & Planning	2
nci	**5**
neii	**2**
nsw-seed	**2**
Water New South Wales (WNSW)	2
(blank)	**5**
Australian Institute of Marine Science	2
(blank)	3
Grand total	**4069**

10.3.3 **Climate data**

The difference between weather and climate is time. The same primary meteorological data is used for both purposes. The derived data products, however, will differ in their definition and the algorithms used to generate them. Climate information will define the weather that occurs on the scale of seasons, years or decades, or longer periods. Changing weather is something we experience on a day-to-day basis, while climate change is concerned with how long-term weather statistics vary across longer expanses of time. The BOM utilises the Predictive Ocean Atmosphere Model for Australia (POAMA) for several products including forecasts of the state of the El Niño–Southern Oscillation (ENSO), Indian Ocean Dipole forecasts, and seasonal rainfall and temperature outlooks.

Scientific Information for Land Owners (SILO) is an enhanced climate database hosted by the Science Delivery Division of the Department of Science, Information Technology and Innovation (DSITI). SILO contains Australian climate data from 1889 (current to yesterday), in a number of ready-to-use formats, suitable for research and climate applications. In addition, SILO provides users with access to climate change projections data for 2030 and 2050 in a daily format. The DSITI site produces a range of products under various topics:

- Seasonal climate outlook

- monthly climate statement – DSITI monitors sea-surface temperature (SST) anomalies in key regions of the Pacific Ocean over autumn, winter and spring, and provides objective outlooks for summer (November to March) rainfall on this basis. This is presented as a textual report
  - Southern Oscillation Index (SOI) – these data are presented as maps
  - rainfall probabilities – based on 'phases' of the SOI

- Rainfall and pasture growth maps. The features presented in these maps include forecast cover anomaly, forecast curing anomaly, pasture biomass, pasture biomass relative (to historical records), pasture growth, pasture growth relative (for various windows of time), pasture growth seasonal probability, pasture curing index, pasture grass fire risk, relative rainfall (for various windows of time) and rainfall total. Also related to rainfall and pasture growth are:
  - current rainfall and pasture growth maps
  - archived rainfall and pasture growth (from 1890 onward).

In agriculture, climate data is also used to define the likelihood of extreme weather events such as droughts and floods occurring. In relation to crop yields, the timing of an extreme weather event with respect to the growth stage of a crop can be critical. Agriculture is highly sensitive to climate variability and weather extremes, such as prolonged drought, floods, severe storms, heat waves, and untimely frosts.[10]

Attempts to introduce traditional yield insurance products in Australia have consistently failed, although in developed countries, traditional yield insurance products are common. A 2012 ABARES report[11] reviewing the options of insuring Australian agriculture concluded that although the case for government underwriting of risk products is weak, improved information at the shire level and improvement of crop simulation models is warranted.

Table 6. The number of available datasets containing information on Australian climate categorised by source and organisation

Source and organisation	Count
ala	**7**
aurin	**6**
Government of New South Wales - Department of Planning and Environment	1
Regional Australia Institute	1
University of Newcastle - Centre of Full Employment and Equity	4
bom-gov-au	**1**
csiro-dap	**242**
CSIRO	242
data-gov-au	**2290**
ARC Centre of Excellence for Coral Reef Studies, James Cook University	8

[10] Motha, Raymond P., 'Chapter 30: The Impact of Extreme Weather Events on Agriculture in the United States' (2011). Publications from USDA-ARS / UNL Faculty. 1311, accessed 24 July 2017, http://digitalcommons.unl.edu/usdaarsfacpub/1311.

[11] Hatt, M, Heyhoe, E & Whittle, L 2012, Options for insuring Australian agriculture, ABARES report to client prepared for the Climate Change Division, Department of Agriculture, Fisheries and Forestry, Canberra, September. CC BY 3.0, accessed 24 July 2017, http://www.agriculture.gov.au/SiteCollectionDocuments/ag-food/drought/ec/nrac/work-prog/abares-report/abares-report-insurance-options.pdf.

Atlantic Oceanographic and Meteorological Laboratory (AOML)	779
Ausgrid	2
Australian Antarctic Division	25
Australian Institute of Marine Science	72
Australian National University	12
Bioregional Assessment Programme	64
British Oceanographic Data Centre (BODC)	30
Bureau of Meteorology (BOM)	4
Centre for Microscopy and Microanalysis, University of Queensland (UQ)	8
Centre for Tropical Biodiversity & Climate Change, James Cook University (CTBCC/JCU)	5
Centre for Tropical Environmental & Sustainability Sciences, School of Marine and Tropical Biology, James Cook University (JCU)	1
China Second Institute of Oceanography (CSIO)	6
City of Melbourne	1
Commonwealth Scientific and Industrial Research Organisation	1
CSIRO Marine and Amospheric Research	7
CSIRO Oceans & Atmosphere	1
CSIRO Oceans & Atmosphere - Hobart	20
CSIRO Oceans and Atmosphere - Information and Data Centre	69
Curtin University	1
Department of Agriculture and Water Resources	5
Department of Applied Geology, Curtin University	1
Department of Biological Sciences, Macquarie University	8
Department of Finance	1
Department of Industry, Innovation and Science	1
Department of Primary Industries, Parks, Water and Environment (Natural Values Conservation Branch)	1
Department of Water (DoW), Western Australian Government	1
Ecosystem Sciences, Commonwealth Scientific and Industrial Research Organisation (CSIRO)	4
Environment Protection Authority Victoria (EPA), Victorian Government	1
French Institution for Exploitation of the Sea (IFREMER)	87
Geoscience Australia	249
Global Change Institute, University of Queensland (UQ)	6
Indian National Centre for Ocean Information Services (INCOIS)	35
Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)	1
Integrated Marine Observing System (IMOS)	523
Japan Agency for Marine Earth Science and Technology (JAMSTEC)	40
Japan Meteorological Agency (JMA)	94
Korea Meteorological Administration (KMA)	3
Korea Ocean Research and Development Institute (KORDI)	21
Land Tasmania	1
National Environmental Information Infrastructure (NEII)	1
New South Wales Datasets	2
Ocean Technology Group (OTG), The University of Sydney (USYD)	1
School of Civil, Environmental and Mining Engineering (CEME), The University of Western Australia (UWA)	1

School of Marine and Tropical Biology and the Australian Centre of Excellence for Coral Reef Studies, James Cook University	6
South Australian Governments	49
State of the Environment	20
Sustainability Victoria	1
TropWATER, James Cook University	8
TropWATER, James Cook University (TropWATER/JCU)	1
(blank)	1
data-nsw-gov-au	**2**
Ausgrid	1
Office of Environment and Heritage	1
data-qld-gov-au	**16**
Agriculture and Fisheries	1
Environment and Heritage Protection	3
Science, Information Technology and Innovation	12
data-sa-gov-au	**40**
Adelaide City Council	1
Department of Planning, Transport and Infrastructure	1
Dept of Environment, Water and Natural Resources	37
Dept of the Premier and Cabinet	1
data-vic-gov-au	**17**
Department of Economic Development, Jobs, Transport and Resources	2
Department of Environment, Land, Water & Planning	10
Department of Justice and Regulation	1
Department of Treasury and Finance	1
Mallee Catchment Management Authority	2
Sustainability Victoria	1
data-wa-gov-au	**7**
Department of Agriculture and Food WA	7
nci	**105**
NCI	105
nsw-oeh	**47**
Office of Environment and Heritage (OEH)	47
nsw-seed	**5**
Department of Planning and Environment (DPE)	1
Office of Environment and Heritage (OEH)	4
(blank)	**7**
Department of the Environment and Energy	1
(blank)	6
Grand total	**2792**

10.3.4 **Imagery data**

Measurements from sensors located in remote platforms, regardless of whether these platforms are located on satellites, airplanes or even closer to the ground, are used to infer canopy parameters such as digital elevation model (DEM), weather information, soil properties, vegetation cover, biomass, leaf chlorophyll content, change detection, vegetation health monitoring, weed optical spot spraying and three-dimensional (3D) surface mapping.

Precision farming requires information on crop condition throughout the growing season at high spatial resolution which has been lacking.

Imagery product types include electromagnetic (including satellite), LIDAR, radar and geophysical.

The major features of satellite data that define its suitability for precision agriculture is the revisit frequencies, range of providers with varying restrictions on its use, spectral range and the range of spatial resolution and formats, accuracies and reliabilities.

The Australian Centre for Remote Sensing (ACRES) archives data from both the US-based Landsat and France-based SPOT satellite imagery sensors for most agricultural production areas in Australia. Geoscience Australia (GA) produces a large number of Earth science products derived from satellite imagery.

Table 7. The number of available imagery datasets categorised by source and organisation

Source and Organisation	Count
aurin	**7**
Government of Queensland - Department of Natural Resources and Mines	3
Landgate	1
Melbourne Water Corporation	3
csiro-dap	**5**
CSIRO	5
data-gov-au	**583**
Australian Antarctic Division	15
Australian Government Department of the Environment and Energy	1
Australian Institute of Marine Science	53
Biophysical Oceanography Group, School of Geography, Planning and Environmental Management, University of Queensland (UQ)	7
Bioregional Assessment Programme	56
BMT Oceanica	1
Bureau of Meteorology	3
Centre for Microscopy and Microanalysis, University of Queensland (UQ)	1
Centre for Tropical Biodiversity & Climate Change, James Cook University (CTBCC/JCU)	1
City of Gold Coast	1
Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin-Madison	1
CSIRO Oceans and Atmosphere - Information and Data Centre	5
Department of Agriculture and Water Resources	3
Department of the Environment and Energy	1
Geoscience Australia	375
Glenorchy City Council	2
Integrated Marine Observing System (IMOS)	5
James Cook University (JCU)	7
Land Tasmania	1
Murray-Darling Basin Authority	1
National Aeronautics and Space Administration Jet Propulsion Laboratory (NASA JPL)	1
New South Wales Datasets	5
Office of Environment and Heritage (OEH)	1

Remote Sensing and Satellite Research Group (RSSRG), Curtin University	1
School of Earth and Environmental Sciences, James Cook University	14
School of Plant Biology (SPB), The University of Western Australia (UWA)	1
Science, Information Technology and Innovation	1
South Australian Governments	4
State of the Environment	3
TropWATER, James Cook University	9
TropWATER, James Cook University (TropWATER/JCU)	1
(blank)	2
data-nsw-gov-au	**6**
Australian Institute of Marine Science	1
Department of Finance, Services and Innovation	4
NSW Rural Fire Service	1
data-qld-gov-au	**30**
Environment and Heritage Protection	1
National Parks, Sport and Racing	2
Natural Resources and Mines	16
Science, Information Technology and Innovation	11
data-sa-gov-au	**3**
Dept of Environment, Water and Natural Resources	2
Unleashed 2014 Industry and Community Data	1
data-vic-gov-au	**42**
Department of Economic Development, Jobs, Transport and Resources	3
Department of Environment, Land, Water & Planning	39
data-wa-gov-au	**24**
Department of Agriculture and Food WA	2
Department of Transport	3
Department of Water	1
Landgate	17
State Library of Western Australia	1
nci	**8**
NCI	8
nsw-oeh	**84**
Environment Protection Authority (EPA)	11
Geoscience Australia	1
Office of Environment and Heritage (OEH)	71
(blank)	1
nsw-seed	**6**
Department of Primary Industries (DPI)	1
Office of Environment and Heritage (OEH)	3
Spatial Services (DFSI)	2
(blank)	**1**
auscover	**13**
(blank)	13
bom-gov-au	**2**
(blank)	2
Grand Total	**814**

10.3.5 **Land boundary data**

Property boundaries can be merged with yield and profit maps and accurately locate weather events and floods for insurance and government assistance programs.

The US Department of Agriculture (USDA) has set out to establish the Common Land Unit (CLU) as a standardised GIS data layer that will allow mapping to be integrated easily on a nationwide basis. The objective of providing this layer is to include all farm fields, rangeland, and pastureland in the USA. In conjunction with digital imagery and other data, the CLU data layers will be used to support farm service programs, monitor compliance, and respond to natural disasters. The layer can be compared to the IKONOS (a commercial Earth observation satellite) 1-m satellite imagery for crop production forecasting and retrospective studies.

In Australia, land use mapping is conducted broadly at two scales: national scale and catchment scale. Both land use mapping methods use the Australian Land Use and Management (ALUM) classification system[12] which combines state cadastre databases. The description of each scale is as follows:

- **National scale** (1:2,500,000) uses a modelling approach to integrate agricultural commodity data, satellite imagery and other land use information. It is relatively inexpensive, statistically rigorous and is amenable to relatively frequent update to enable the assessment of trends.
- **Catchment scale** land use mapping can vary from 1:25,000 (where 1 cm on the map = 250 m on the ground) for irrigated and peri-urban areas, to 1:100,000 scale (1 cm = 1 km) for broadacre cropping regions, and 1:250,000 (1 cm = 2.5 km) for the semi-arid and arid pastoral zone. Catchment-scale land use data is produced by combining state cadastre, public land databases, fine-scale satellite data, other land cover and use data, and information collected in the field.

Table 8. The number of available datasets containing information on Australian property boundaries categorised by source and organisation

Source and organisation	Count
aurin	**63**
Government of New South Wales - Department of Planning and Environment	1
Government of Queensland - Department of Natural Resources and Mines	2
Government of the Commonwealth of Australia - Australian Bureau of Statistics	2
Government of the Commonwealth of Australia - Geoscience Australia	1
Government of Victoria - Department of Environment, Land, Water and Planning	2
Government of Victoria - Department of Health and Human Services	1
Grattan Institute	2

[12] Accessed 24 July 2017, http://www.agriculture.gov.au/abares/aclump/land-use/land-use-mapping.

Landgate	20
Melbourne Water Corporation	3
PSMA Australia Limited	19
Queensland University of Technology - Smart Transport Research Centre	7
University of Queensland - eResearch Group	2
Yarra Valley Water	1
bom-gov-au	**4**
BOM	4
csiro-dap	**25**
CSIRO	25
data-gov-au	**1889**
ACT Government	1
Australian Antarctic Division	24
Australian Communications and Media Authority	1
Australian Electoral Commission	1
Australian Government Department of the Environment and Energy	1
Australian Institute of Marine Science	113
Australian Research Council Centre of Excellence for Coral Reef Studies (JCU)	7
Bioregional Assessment Programme	288
Brisbane City Council	3
Bureau of Meteorology	7
Centre for Microscopy and Microanalysis, University of Queensland (UQ)	1
City of Casey	2
City of Gold Coast	4
City of Greater Bendigo	2
City of Greater Geelong	2
City of Hobart	1
City of Launceston	1
City of Melbourne	6
Colac Otway Shire	2
Crawford School of Public Policy (CSPP), The Australian National University (ANU)	1
CSIRO	4
CSIRO Land and Water Flagship	9
CSIRO Oceans & Atmosphere - Hobart	16
CSIRO Oceans and Atmosphere - Information and Data Centre	11
Department of Agriculture and Water Resources	3
Department of Biological Sciences, Macquarie University	1
Department of Communications and the Arts	1
Department of Employment	4
Department of Environment, Land, Water & Planning	1
Department of Environment, Land, Water and Planning (DELWP), Victorian Government	1
Department of Health	2
Department of Infrastructure and Regional Development	2
Department of Parks and Wildlife (DPaW), Western Australian Government	1
Department of the Environment and Energy	13
Department of the Prime Minister and Cabinet	30

Department of Environment	1
Ecosystem Sciences, Commonwealth Scientific and Industrial Research Organisation (CSIRO)	1
Geoscience Australia	1159
Golden Plains Shire Council	1
Government of New South Wales - Department of Planning and Environment	1
Hydro Electric Commission	1
Integrated Marine Observing System (IMOS)	17
Land Tasmania	18
Moreton Bay Regional Council	6
Murray-Darling Basin Authority	5
National Native Title Tribunal	1
New South Wales Datasets	16
Nillumbik Shire Council	1
Noosa Shire Council	1
Office of Environment and Heritage (OEH)	1
Oregon State University (OSU)	2
Regional Australia, Local Government, Arts and Sport	2
School of Animal Biology (SAB), The University of Western Australia (UWA)	1
School of Civil, Environmental and Mining Engineering (CEME), The University of Western Australia (UWA)	1
School of Earth and Environmental Sciences, James Cook University	2
School of Earth and Environmental Sciences, James Cook University (JCU)	1
School of Environmental Systems Engineering, The University of Western Australia (UWA)	1
School of Humanities and Social Sciences (SHSS), Deakin University	1
South Australian Governments	36
State of the Environment	11
Surf Coast Shire Council	1
Tasmania Fire Service	1
Torres Strait Regional Authority (TSRA)	7
TropWATER, James Cook University	5
TropWATER, James Cook University (JCU)	7
Wet Tropics Management Authority	6
Wimmera CMA	1
Wyndham City Council	1
(blank)	5
data-melbourne-vic-gov-au	**5**
(blank)	5
data-nsw-gov-au	**12**
Ausgrid	1
Australian Institute of Marine Science	1
City of Sydney	1
Department of Finance, Services and Innovation	4
Department of Planning and Environment	1
DPI - Water	1
Office of Environment and Heritage	2
Transport for NSW	1
data-qld-gov-au	**76**

Agriculture and Fisheries	17
Communities, Child Safety and Disability Services	1
Education and Training	3
Environment and Heritage Protection	4
Housing and Public Works	1
Infrastructure, Local Government and Planning	6
National Parks, Sport and Racing	2
Natural Resources and Mines	26
Police	3
Queensland Fire and Emergency Services	3
Queensland Health	1
Science, Information Technology and Innovation	1
State Development	3
Transport and Main Roads	5
data-sa-gov-au	**40**
Adelaide City Council	5
Department of Planning, Transport and Infrastructure	12
Department of State Development	1
Dept for Communities and Social Inclusion	3
Dept for Education and Child Development	3
Dept for Health and Ageing	1
Dept of Environment, Water and Natural Resources	10
Dept of Primary Industries and Regions	2
Port Adelaide Enfield Council	1
State Library of South Australia	1
Unleashed 2014 Industry and Community Data	1
data-vic-gov-au	**528**
Ambulance Victoria	2
Department of Economic Development, Jobs, Transport and Resources	57
Department of Environment, Land, Water & Planning	464
Department of Planning and Community Development	1
Department of Premier and Cabinet	2
Geoscience Australia	1
VicRoads	1
data-wa-gov-au	**99**
Aboriginal Affairs Coordinating Committee	2
City of Perth	10
Department for Child Protection and Family Support	1
Department of Aboriginal Affairs	1
Department of Agriculture and Food WA	3
Department of Education	1
Department of Environment Regulation	1
Department of Fire and Emergency Services	2
Department of Mines and Petroleum	2
Department of Parks and Wildlife	11
Department of Planning	3
Department of Regional Development	5
Department of Transport	10

Department of Water	10
Environmental Protection Authority	4
Harvey Water	1
Landgate	26
Main Roads Western Australia	1
National Native Title Tribunal	1
State Library of Western Australia	1
Western Australia Police	2
World Wildlife Fund for Nature	1
nci	**4**
NCI	4
nsw-oeh	**88**
Department of Planning and Environment	1
Environment Protection Authority (EPA)	6
Murray-Darling Basin Commission	1
Office of Environment and Heritage (OEH)	79
Office of Environment and Heritage (OEH) - Office of Water	1
nsw-seed	**13**
Department of Planning and Environment (DPE)	4
Department of Primary Industries - Water (DPI-Water)	1
Department of Primary Industries (DPI)	1
Environment Protection Authority (EPA)	1
Murray-Darling Basin Authority	1
NSW Resources and Energy (DRE)	1
Office of Environment and Heritage (OEH)	3
Spatial Services (DFSI)	1
(blank)	**8**
Bioregional Assessment Programme	1
Geoscience Australia	1
(blank)	6
Grand total	**2854**

10.4 An Australian soil information facility

10.4.1 **Purpose**

The proposed facility would be a distributed network of data providers (primarily state and territory agencies) supported by a small coordination team that manages an advanced and shared spatial-data infrastructure that supports four distinct lines of business (see also Tables 9 to 12).

1. **Sustainable soil management to improve the profitability, efficiency and resilience of Australian agriculture**: This line of business would aim to develop information services that allow farmers to assess their performance against district benchmarks; provide subscription-based services to support mapping of soil condition, nutrients and carbon; and supply subscription-based services for soil data management and mapping for commercial laboratories and agribusiness.

2. **Land-use planning, resource assessment and outlooks**: This line of business would aim to provide consistent mapping of strategic soils across Australia (e.g. high quality agricultural soils); supply land-suitability assessments for regional planning; produce soil resource outlooks (e.g. taking into account climate change, agricultural intensification, urban expansion); and develop subscription services for detailed land-use planning (mainly for local government).
3. **Environmental monitoring, regulation and compliance**: This line of business would aim to establish and maintain harmonised national systems for monitoring soil condition and key threats to soil function. In particular, it will enable formal reporting via international agreements (e.g. Sustainable Development Goals, soil carbon for climate-related agreements) and develop data streams to enable formal accreditation in relation to sustainable soil management (e.g. to assist with trade and market access).
4. **Research infrastructure to support national priorities relating to soils and Earth system science**: This line of business would aim to ensure the scientific community has access to soil information that improves the impact of their research. It would: further develop the Soil and Landscape Grid of Australia; improve systems for extending research results from individual locations to the broader landscape; support for the National Research Infrastructure Roadmap and its planned national predictive modelling system; and provide an efficient national soil archive service.

10.4.2 **Primary activities**

Standards

Online geospatial information systems (e.g. Google Maps) have been a catalyst for innovation with many new businesses being been built on the primary geospatial data services. Ironically, this diversity has only been possible through the development of, and adherence to, rigorous technical standards.

Online soil information systems require much stronger discipline in the collection and management of soil data than soil scientists and their institutions have shown to date. This is particularly challenging because methods of soil measurement, mapping and monitoring are currently in transition and agreement is only now being reached on preferred methods (e.g. for proximal sensing and digital soil mapping). In many ways, the desired soil data services outlined here are conceptually simple – estimates are needed of key soil properties (e.g. water content, carbon, pH, N, P, K) at points in geographic space (including depth) and through time. However, the undertaking is complex because current data holdings have been collected according to different standards and they are held in diverse information systems.

As a consequence, an initial task for establishing the Australian National Soil Information Facility is to agree on standards for soil data collection, exchange and interoperability between national and local data systems. This needs to build on recent initiatives to implement ANZSoilML compliant web services and ensure standardised data flows from different sources.

Data services and application development

The Australian National Soil Information Facility would aim to provide data services that are analogous to those provided by other domains (e.g. weather, climate and water data services provided by the Bureau of Meteorology). Data services would be delivered online and some will be of value to users in their primary form (e.g. soil water content). Others could be used by third-parties to supply value-added services that may be free (e.g. as provided by SoilMapp) or on a subscription basis. As recognised by Keogh and Henry (2016), a range of new business opportunities will develop around these data services (e.g. various forms of carbon trading, farm advisory services, financial products).

Research archives

It's logical for the Australian Soil Information Facility to include the CSIRO National Soil Archive and other state and territory archives that are willing to participate. These archives have proven invaluable in recent years for projects including:

- application of new measurement technologies such as MIR and NIR[13] on specimens to produce improved national maps (e.g. aspects of the Soil and Landscape Grid of Australia)
- calibration of new measurement methods using existing specimens and their accompanying data (e.g. new methods for soil carbon measurement)
- re-analysis of specimens to enable high-precision measurement of soil change (e.g. reanalysis of the National Soil Fertility Program sites from the 1960s and 1970s).
- rapid assessments of soil properties on existing specimens, reducing and sometimes obviating the need for new sampling (e.g. mapping boron concentrations across Southern Australia in the late 1980s to support plant breeding and improved variety selection)
- analysis of baseline variables in specimens collected prior to agricultural development (e.g. contaminants and potentially, molecular biology).

Good progress is being made in integrating physical archives and their associated soil information systems. This has resulted in the development of a demonstration portal for an Australian National Virtual Soil Archive.

[13] Mid-Infrared and Near-Infrared spectroscopy

Table 9. Summary of ASIF Business One: Improving agricultural productivity and profitability

Outcomes

Sustainable soil management makes Australian agriculture more profitable, efficient and resilient. This will be achieved by:

- Closing yield gaps
- Improving water and nutrient use efficiency
- Managing carbon
- Better spatial matching of farming practices with soil conditions.

Opportunities and key interventions

- Develop capabilities to allow easy updating of the Soil and Landscape Grid of Australia as new data become available.
- Improve the coverage of soil surveys tailored towards the needs of agriculture [separate program to ASIF]
- Establish the harmonised national soil monitoring system [separate program to ASIF]
- Improve access to nutrient testing data and integrate public sector and commercial data systems as much as possible
- Improve usability of soil test data
- Provide online tools for mapping and monitoring soils at the paddock scale
- Develop capabilities to undertake district and farm scale benchmarking

Services

- Yield gap estimation and district benchmarking to provide farmers with improved performance measures
- Farm mapping and decision support systems (subscription based)
- Nutrient mapping, monitoring and management service (subscription based)
- Soil carbon mapping, monitoring and management service (subscription based)
- Data management and mapping services for commercial laboratories and agribusinesses (subscription based)

Table 10. Summary of ASIF Business Two: Land-use planning, resource assessment and outlooks

Outcomes

Better matching of land use and management with land capability.

Technical activities

- Production of harmonised soil grids and polygon maps across Australia
- Further development of land-use modelling capabilities (e.g. enhancement of LUTO)
- Improved data capture systems to support surveys commissioned for detailed land-use planning
- Integration of soil information into simulation models used for scenario analysis and outlooks.

Services

- Consistent mapping of strategic soils across Australia (e.g. strategic agricultural lands)
- Land suitability assessment for regional planning (e.g. suitability for urban and industrial land use, agriculture, forestry)
- Soil resource outlooks (e.g. scenario analysis taking into account climate change, demographics, regional development, agricultural intensification)
- Subscription services to local government for detailed land-use planning (e.g. geotechnical characteristics of soils including shrink-swell potential, erodibility, acid sulfate soils; land suitability for defined land uses)

Table 11. Summary of ASIF Business Three: Environmental monitoring, regulation and compliance

Outcomes

Trends in the condition of soil resources are known and land managers, industries and governments have the information they need to respond.

Technical activities

- Establishment and maintenance of a harmonised national system for monitoring soil condition and key threats to soil function.
- Establishment of data capture systems related to field activities and investigations that are mandated by:
    - governments (e.g. environmental impact assessment, planning approvals, other regulatory requirements)
    - publicly funded research (e.g. RIRDCs, ARC, CRCs, Universities, CSIRO).
- Establishment of voluntary industry-based data capture systems that support sustainable soil management and formal accreditation systems.
- Provision of soil archive services as part of the national soil monitoring system.

Services

- Reporting on the status of Australia's soil carbon stocks via international mechanisms including the UNFCCC and the Sustainable Development Goals (particularly SDG 15.3)
- Production of consistent assessments for state, territory and national state of the environment reports.
- Production on a regular basis of consistent, evidence-based national assessments of key threats to soil function focusing initially on soil acidification, soil erosion, soil carbon, nutrient imbalances, soil compaction and sealing.
- Data streams to enable accreditation for sustainable soil management.

Table 12. Summary of ASIF Business four: Research infrastructure

Outcomes

The scientific community has easy access soil information that improves the impact of their research.

Technical activities

- Further development of the Soil and Landscape Grid of Australia so that it provides the authoritative source of information on the functional properties of soils across the continent.
- Development of an improved scientific framework for extending research results (e.g. crop variety trials, tillage experiments, studies of Greenhouse Gas emissions) from individual locations to the broader landscape.
- Integrate ASIF into the predictive modelling system proposed by National Research Infrastructure Roadmap and 'help strengthen environmental management, risk assessments, primary production, and resource development whilst sustaining biodiversity.'
- Provide an efficient national soil archive service and encourage research into new measurement technologies, detection of soil change and instrument calibration.

Services

- High performance web-services connected to the Soil and Landscape Grid of Australia, particularly those that feed into simulation models and schemes for model-data assimilation.
- National Soil Archive.

Organisation and resourcing

The Australian Soil Information Facility needs to be hosted by an existing agency with a capacity to deliver the federated system. It requires an Advisory Board with members representing the participating agencies and key stakeholders including agribusiness and relevant professional organisations. The Facility requires a coordination team including a director, manager of ICT infrastructure, lead soil scientist and support staff. The facility needs to have technical specialists based within the host organisation and across the participating agencies. The structure and governance would be similar in many ways to a Cooperative Research Centre.

Rough estimates indicate that public agencies in Australia currently invest about $10 million per annum into soil information systems and supporting activities. An increase in total investment from the current $10 million to about $15 million per annum is required to support the shared facility.

ASIF should generate direct economic benefits of several hundred million dollars per annum within a decade. There would also be equally significant environmental benefits. This estimate of benefit is based on previous investigations into the benefits and costs of soil information and evaluations of soil constraints on agricultural production. The associated development of capability in science, technology and professional services would boost the fledgling international soil management consulting industry. In agriculture alone this has the capacity to amplify benefits by another order of magnitude and contribute significantly to the pressing global challenges of achieving food security and sustainable development.

While the establishment of ASIF seems obvious, it is important to understand some of the institutional issues that have bedeviled this area for so long. Most important is understanding the case for public and private sector engagement and appreciating some of the challenges in building stable commonwealth-state relationships.

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