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Horizon Scan to Inform NRAR Strategic Management and Planning

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Report to NSW Natural Resources Access Regulator

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Executive summary

In Australia, a continent with a highly variable climate, water is important for the health of the environment as well for the wellbeing and livelihoods of local communities. The recent Millennium drought and the continuing lack of substantial rain in many parts of the country has highlighted that there is a need to continue to do more regarding the management of access to water in rivers, associated waterbodies and aquifers. In addition, studies during and after the Millennium drought have shown that environments reliant on the water in rivers have become highly stressed through over extraction of water for human related uses. It is now well recognised that sufficient water needs to be returned to the environment to restore some level of ecosystem function, as seen by the decision to set sustainable diversion limits in the Murray-Darling Basin. This diversion of accessible water back to the environment requires decisions to be made that takes into consideration competing compelling ecological, social, economic, cultural, ethical and statutory requirements. Correct decisions will ensure the wellbeing of flow-dependent ecosystems linked to rivers, such as within the Murray-Darling Basin, while still securing a viable agriculture and other industry along with ensuring healthy communities.

The on-going variability in Australia's climate, the range of possible impacts from climate change and other future influences such as technology advancements means that decisions made now can conceivably have long term impacts on water availability, agricultural production, community wellbeing and the health of ecosystems. In NSW, the State Government has formed the Natural Resources Access Regulator (NRAR) within the former NSW Department of Industry to regulate water access licences and associated approvals for a range of government and non-government entities. This involves the monitoring of compliance to access of water resources across NSW and undertaking any necessary enforcement remediation. As part of the consideration for future water needs in NSW and NRARs role in supporting all competing needs, a horizon scan has been commissioned to assemble information that can inform and aid strategic planning exercises within NRAR.

The horizon scan reports on six major uncertainties that have been identified as potentially important drivers/influencers that could impact on the ability of NRAR to carry out its responsibilities. The six uncertainties identified are (1) Climate Change; (2) Social Attitudes to Water; (3) Agricultural Practices and Irrigation Needs; (4) Water Technologies; (5) Environmental Requirements; and (6) Data Management and Analysis.

Climate Change

An examination of the potential impact of climate change on water supplies needs to start with a realisation that Australia has a naturally variable climate that experiences periods of dry and wet that can last from only a few years to decades. Climate change modelling has indicated that NSW will continue to be influenced by this natural climate variability until at least 2030 with continuing cycles of dry and wet periods. As such, NRAR's regulatory activities will need to remain linked to the Bureau of Meteorology's short-term climate predictions during this period up to 2030.

After 2030, climate change will become a more dominant impact, particularly in those regions away from the coast. Climate change modelling has predicted that these areas will become progressively drier, particularly in the winter periods in the Murray-Darling Basin. Predictions on the magnitude of any decreases in rainfall, however, remain unclear. There is also less certainty for climate change impacts in coastal regions of NSW post-2030 with climate change modelling currently indicating there could be either a wetter or drier climate in coastal areas. This uncertainty regarding water availability in coastal regions has implications for long-term planning for farming and urban uses in these regions. There could ultimately be potential opportunities for either greater productivity through increased water availability, or increased restrictions due to long-term reductions in rainfall.

While climate change is predicted to have limited influence on rainfall until 2030, the Australian climate is already becoming increasingly warmer, in line with global warming trends, and will continue to do so as climate change impacts become more prominent. Predicted temperature increases in the range of 1.3°C to 5.6°C have been predicted by 2090 although the amount of change will depend on the region within NSW and the global RCP level reached. The resulting increasing temperatures will influence water uses through increased evaporation, decreasing soil moisture and increasing heat stress on urban and rural communities, crops and animals. This increasing heat stress will have direct implications for both rural and urban water demand and use.

Social Attitudes to Water

Research on social attitudes on urban water use during the Millennium drought and subsequent ongoing research into the views and vulnerability of rural communities and farmers in the Murray-Darlin Basin have highlighted the importance of engaging with communities as early as possible in decision-making processes and for those communities to feel that their views are being considered. The opinions and attitudes of communities are a central consideration for NRAR is a core requirement for the organisation to maintain public confidence in water management and regulatory activities. It can also be expected that a high public confidence in NRAR as a regulator and in decisions made can assist with good compliance behaviours.

Experiences from the Millennium drought have shown that communities expect to be engaged in water decision-making and that there will be transparency associated with the development and enforcement of government regulations. A failure to do so can lead to non-acceptance of water sustainability plans and ongoing operations. There is already anecdotal evidence from studies within the Murray-Darling Basin that communities believe that they have not been part of any decision making process which has been implicated in increased levels of stress, anger, and potentially to deliberate non-compliance with regulations. It has also been suggested that there could be a range of other actions undertaken as a form of revenge.

Urban residents have previously demonstrated a willingness to reduce water use through a range of demand management processes as long as it is clear that there is a transparent level of fairness and equity. It is likely that this level of consciousness about the need for water sustainability continues and that urban communities will continue to also be increasingly conscious of problems and issues faced by farmers and rural communities. Research has shown, however, that the level of effort on reducing water consumption in urban communities can be influenced by the level of information provided, with greater persistence of water saving measures occurring in groups that had been provided details on how to reduce water use or comparative information on water usage levels across the community.

In contrast, rural communities have a much more complex range of issues influencing social attitudes as access to water is such an important part of the function and wellbeing of rural communities. Thus, the attitudes of many rural communities cross the bounds of irrigation and farming requirements to include the interlinked needs of small towns that support farming districts, as well as the needs of the environment. There is also a variety of attitudes relating the wide range of rural water issues. Much of the differences in attitudes and resilience can be linked to existing financial stress, level of education and time on the land. Those most at risk due to these stressors are also likely to be a greater potential risk of non-compliance due to desperation, or high levels of resistance to changes to existing water management structures. Farming communities, both farmers and those in supporting communities, also have a high awareness of the risks associated with water availability and on the potential impact shortages of water can have on local regional communities. This has caused impressions of “winners” and “losers” relating to access to water which has the potential to further increase concern and anger within impacted communities.

Regardless of the levels of stress or concern, farming communities are aware of the need for improved water regulations and have indicated that they expect licencing and regulations on water use to be consistent and transparent with clear accountability on water management and regulation. These expectations also include that incidences of non-compliance will be investigated in an open and transparent manner, and that any enacted enforcement measures undertaken are measured and appropriate.

Agricultural practices and irrigation requirements

Agriculture is a large consumer of water extracted from the environment using more than 70% of the water extracted from the environment in NSW in 2017-18. Most of this water was used for the cultivation of cotton, grains and rice. The value from these three relatively water-intensive agricultural commodities, however, was approximately 40% of the value of all other agricultural commodities produced in NSW during 2017-2018. In addition, an analysis of changes in water use over time showed that the volume of water (ML) used per hectare of land was also highest for rice and cotton with water used by both commodities increasing to above 2009 level in 2012. Water use for the production of rice then declined after 2013, (in line with the reduced area irrigated for rice), while the amount of water used to irrigate cotton has remained high up till 2017. In comparison, water use for other irrigated agricultural products such as vegetables and beef cattle have remained relatively constant since 2009.

These levels of water use are likely to become more of an issue as increasing temperatures and decreasing water availability caused by climate change being to take effect. Decreasing soil conditions across many areas of NSW are an interlinked issue caused by over use of water in different regions of the State for agriculture and changes to water levels in local rivers and aquifers. There will therefore need to be a reconsideration on how water use is planned, implemented and monitored. A drying climate is likely to require increased monitoring for compliance issues relating to over-extraction of water and other non-compliance behaviours.

Increasing climate change impacts also are likely to result in the fact situation where relying on the regulation of compliance of water extraction will not be sufficient for helping agriculture to adapt to changes in local conditions. Instead, there will be an increasing need for new forms of adaptation measures that can assist farmers and rural communities. This has already commenced with governments already assisting in the development of improved irrigation water supply efficiencies, irrigation application methods and other technologies that improve the efficiency of irrigation. These adoption efforts will continue to be needed and vary as climatic conditions change. Not all regions will experience the same changes in climate or the same degree of change and therefore adaptation measures will need to be flexible to suit the location and conditions. As the regulator of water access and use, NRAR will have a pivotal role in assisting with these adaption processes but will benefit if it is done in partnership with local communities. These partnerships have the potential to be facilitated through the increased use of automation, robots, sensors and analysis of big data. Advances in these innovations will assist both farmers and regulators such as NRAR to further increase the efficient use of water while improving agricultural outputs. This will be of particular use in more remote regions where regular communication and information sharing is currently difficult.

Water Technologies

Human-based systems are becoming increasingly controlled by a range of technologies that are making work processes, transport, health, communications and lifestyles fundamentally different from what was experienced in previous generations. The advancement of many of these technologies are continuing at an ever-increasing rate, driven, in part by ever-increasing computational capability.

These technology advancements will have broad social and economic impacts and benefits to the Australian community and it can be anticipated that agricultural industries have the potential to benefit from a range of such advances. The success of technological advances, however, will also depend on the market readiness of specific innovations. Technology advances are frequently market driven and therefore difficult to predict, nevertheless, both urban and rural water are large markets and, as such, it can be expected that there will be technologies that will emerge which will have substantial influence on reducing water use while improving overall availability.

In Australian cities, urban water use will decrease through improvements in sustainable housing and improved water demand management, for example the increased use of smart meters. Improvements in treating water will also have a major influence on urban water supplies, increasing the potential for the development of a circular water economy based on water recycling and harvesting of urban stormwater. Potential reductions in the extraction of water for urban demands will provide more water for other users and reduce compliance monitoring requirements of urban centres by regulators such as NRAR.

For agricultural industries there will also be benefits from advances in automation, robotics, real-time sensors and information technology that will assist with the timely, precise application of water to maximise yields within set water allocation levels. The uptake of automation and use of sensors has already been able to improve production efficiencies for farms and have the potential to further influence water use, either by reducing water demand, or conversely by enabling larger areas to be cropped. There will therefore be a need for an improved communication between farmers and regulators on how much water is used to produce a given amount of a crop. The current requirements for irrigators to install smart meters is already demonstrating the benefits of real-time data access and is influencing the market in smart meters with a range of improvements in meter design even now reaching the market. These real-time sensors and smart meters will also be of significant value and benefit for regulators such as NRAR by directly providing information on water extraction and use, at distance, in real time. This can enable NRAR to monitor and detect any non-compliance events quickly and enable enforcement remediation activities to be undertaken in a timely, transparent manner.

Environmental Requirements: Studies have shown there are impacts on the ecology of rivers and waterways being caused by a combination of the naturally variable climate (with an increasing contribution from climate change) and through over-extraction of water for human-based activities. Studies have shown that the ecological condition of the rivers in the Murray-Darling Basin have been declining for some time with consequences for a range of flora and fauna in the Basin, both in-stream and on those reliant on river water. This has been driven by overexploitation of water in the river system which has not only reduced water flows but increased salinity and acidity levels, as well as affecting soil structure which has resulted in the movement of large amounts of sediment and nutrients into waterways. Overfishing and removal of large volumes of floodplain timber resources has also compounded the ecological decline of the Murray-Darling riverine system.

Ecological studies have highlighted the importance of regular flooding for the lifecycle of many native flora and fauna. Where sufficient water has been reallocated back to ecological icon sites within the Murray-Darling Basin, significant improvements in the health of those sites have been recorded. All of these impacts, combined with a changing climate mean that the monitoring of compliance for water extractions will remain vital to ensure there is a fair distribution of water between irrigators, rural communities and the environment.

There are many rivers and groundwater systems that are often interconnected, both within the Murray-Darling Basin and elsewhere in NSW. A combination of continued human use and the influence of climate change will have a detrimental impact on these groundwater-surface water dependent ecosystems through reduced water flows into rivers and lakes, rising sea levels increasing the salinity of groundwater.

Engagement with communities is vital for continuing support to ensure that sufficient water supplies are maintained for local environments. It is easier to gain support for providing water for the environment in drought and at times when there are low water levels in rivers. Recent studies have shown that it will be more difficult to do so when there are larger volumes of water flowing in the rivers during wetter periods. A continual dialogue with local communities, even when water levels are not at extreme low levels, will go a long way towards providing greater transparency and a level of bipartisanship around decisions that provides equity between human-based needs and adequate provision for the environment. Community support can be further enhanced through a united understanding on the greater value of the environment. Economic assessment of the value of healthy environments has shown that improving ecological systems can add millions of dollars in value to regional areas through increased ecosystems services. This information, if discussed appropriately, could assist in engendering good compliance behaviour within local communities.

Data Management and Analysis

The handling of large amounts of data is currently problematic for many agencies, but with technological improvements, there is considerable potential to assist in decision making and compliance monitoring, particularly for important resources such as water. The ability to manage and analyse Big Data from a series of different, disparate sources has the potential to provide better ways to manage water resources, both for water users and regulators. The Australian Bureau of Statistics and the Bureau of Meteorology are already developing methods and tools to analyse large data sets from a range of different sources and stakeholders. Both these agencies already partner with a range of stakeholders in the development of these new methods and tools. Further broadening of these partnerships will inevitably bring benefits across all levels of government.

Having the ability to combine the use of sensor technology to provide real-time data, the provision of information from smart meters, and combining information from a range of other sources such as satellite images, social and financial data from the ABS, and climate projections from BoM will enable NRAR to produce more accurate and transparent regulatory decisions in a timely manner.

The collation and tracking of this data can be assisted and made secure through the use of blockchain technology which could enable NRAR to track compliance with water extraction limits over a range of timeframes. This can be achieved by being able to trace a series of transactions including water extraction, amounts of commodities produced and sold, and any market interactions. The ability to analyse large data sets and any associated distributed ledgers can also help monitor and reduce opportunities for fraudulent activities relating to water extraction, water use and the water market.

In conclusion, the NSW Natural Resource Access Regulator has an important yet difficult task in regulating the access to water for many different users. The success of any long-term management of water is reliant on ensuring that decisions made demonstrate an understanding of the future, long-term needs of users and the environment in a changing climate. Regulatory decisions will become more challenging as climate change starts to have an impact, particularly post-2030. Technology improvements and increased continual community engagement has the potential to enable NRAR to use a more comprehensive risk-based assessment relating to regulatory decisions that considers the full impacts of non-compliance actions by users and around any enforcement decisions taken. Making full use of improvements of improvements in data handling and analysis and reporting from real-time sensors and meters, will assist NRAR with its regulatory functions by enabling a greater transparency of decisions relating to licensing, compliance assessment and any resulting enforcement. Improved transparency will naturally can create a closer engagement with communities and water users which will, in turn, assist with appropriate decisions relating to the regulation of water requirements for irrigators while protecting healthy ecosystems for NSW.

Introduction

The ability to access and use water is fundamental for environments as well as for human wellbeing and industries. In Australia, a continent with a highly variable climate, water is often a limiting factor for the environment and the livelihoods of local communities. The Australian environment has evolved to deal with the "boom and bust" of water availability (CSIRO 2012), however, increased use of water to support a growing population, a range of industries, and more mechanised irrigation farming systems is now placing an untenable strain on rivers and other waterbodies. In some areas, there were licences to extract more water from the rivers than there were normal volumes that flow through the rivers (Williams 2017). As a result of excessive extraction, local environments reliant on the water in the rivers have been seriously impacted. This has been particularly documented in the Murray-Darling Basin, but the impact of climate change and human activities on the ecological health of rivers and water bodies elsewhere is also well recognised (NSW Office of Environment & Heritage 2011).

The impact of the Millennium drought highlighted the fact that there needed to be better control of access to water from rivers, associated waterways and aquifers, and that a portion of water previously removed under water licences needed to be returned to the environment to enhance environmental flows, regional groundwater levels, etc. In NSW, the State Government has formed the Natural Resources Access Regulator (NRAR) within the former Department of Industry to regulate water access licences and associated approvals for a range of government and non-government entities as well as approving controlled activities that are undertaken beside or in NSW waterways and bodies (NSW Department of Industry 2019a).

Decisions relating to water access rights and enforcement can potentially impact the yearly productivity of irrigators, the wellbeing of local communities and the health of local ecosystems. As decisions made now can also influence future activities and licence requirements causing long-term implications, there will be a continuing, and potentially increasing need for transparency of monitoring of water access rights and any related regulatory enforcement. Conversely, a lack of appropriate regulatory decisions and/or enforcement can create a perception of "winners and losers", or a lack of procedural fairness which has the risk of creating unnecessary stress and division within and between local communities. As such, it is important that decisions made are as transparent and balanced as possible.

Due to the potential long-term impacts of decisions made now, it is important that future needs, impacts and drivers are also considered in order to future-proof decisions as much as possible. This is vital due to the widely recognised potential impacts of climate change, advancements in technology data analysis to aid decision-making processes, and the existing and possible future expectations of communities and industries. NRAR will need to take all of these uncertainties into account to ensure that fair and appropriate access to water continues for rural and other industries and urban needs, and that the behaviour of individuals and companies meet required standards within allocated rights. This will assist in the development of a culture of procedural fairness within and across communities, and ensure that water access rights and needs are being balanced with the needs of others, including the environment.

To assist NRAR, this report provides an analysis of six agreed key uncertainties. This horizon scan allows for the examination of the current situation in each uncertainty as well as the potential, plausible future considerations for issues within each uncertainty.

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Research Focus and Methodology

This horizon scan was based on the research focus questions of:

1. What are the current and emerging trends in future water uses, management and regulatory practices that could impact ongoing NRAR regulatory requirements?
2. What current and emerging trends in the future availability and requirements for water will influence NRAR's ability to manage and regulate water use and availability?

Using these research questions, a range of citable references from CSIRO and other credible sources were used to analyse information under six key uncertainties (1) Climate change; (2) agricultural needs and irrigation needs; (3) social expectations; (4) water technologies; (5) environmental needs; and (6) data management and analysis.

Explorations of these six uncertainties helps to provide information on the recent state of water management in NSW, the level of climate change that could be expected in the next 20 and 70 years, and the role that technology and improvements in data analysis could have on the regulation of water resources in NSW. This can assist to ensure maximum possible fairness for all users while maintaining and improving local environments reliant on water in NSW rivers and waterways.

The social attitudes and expectations of local communities, both in urban and rural communities were examined to explore the impacts that could be expected to arise from NRAR's regulatory responsibilities, and actions NRAR could undertake to increase transparency on the design of compliance programs and enforcement resolutions that considers all risks and related social, economic and environmental impacts.

Uncertainty #1: **Climate Change**

Key Findings

1. NSW will continue to be influenced by the existing natural climate variability along eastern Australia up till at least 2030 with continuing cycles of dry and wet periods that could last for periods of a few years through to decades. Thus, NRAR's regulatory activities are likely to remain linked to the Bureau of Meteorology's short-term climate predictions till at least 2030.

2. After 2030, impacts from climate change are predicted to become more dominant, particularly in those regions away from the coast. These non-coastal zones will become progressively drier, particularly in the winter periods in the Murray-Darling Basin (Table 2). The magnitude of rainfall decreases, however, remains unclear.

3. For coastal regions, the current climate change modelling indicates that climate change post-2030 could cause either a wetter or drier climate. The uncertainty regarding water availability in coastal regions could have implications for farming and urban uses by either enabling greater productivity through increased water availability, or become restricted due to long-term reductions in rainfall.

4. While climate change is predicted to have a limited influence on rainfall until 2030, the Australian climate is already becoming increasingly warmer, in line with global warming trends. This increased warming will continue as climate change impacts become more prominent. Temperature increases by 2090 are predicted to be in the range of 1.3°C to 5.6°C depending on the region within NSW and the RCP level reached (Table 1).

5. Increasing temperatures will have an influence on water uses due to increasing evaporation, decreasing soil moisture, and increasing heat stress on urban and rural communities, crop and animals. This increasing heat stress has implications for water demand and use.

6. The extent of the impact of climate change is dependent on global efforts to reduce greenhouse gas emissions. NRAR should use the worst case scenario (RCP 8.5) as the base case for all planning from 2030 and beyond until it becomes clearer on the success of global carbon reduction efforts.

Australia is a continent that has a naturally variable climate and future climate modelling has predicted that this variability will be exacerbated by climate change (CSIRO and Bureau of Meteorology 2015). The amount of impact that will occur will depend strongly on global efforts to reduce emissions and reach the best emissions target possible. As of 2019, the potential success of reducing emissions vary widely from very little reduction to very strong actions. To cover the wide range of potential reductions in greenhouse gas emissions, the international climate modelling community has developed a set of three climate change scenarios entitled Representative Concentration Pathways (RCPs). These three scenarios provide examples of the climate being influenced at three set levels of atmospheric greenhouse gas concentrations. These RCPs are from the lowest RCP 2.5 through the medium RCP 4.5 to the extreme RCP 8.5 (Figure 1). The exact definitions of each RCP are provided in Text Box 1.

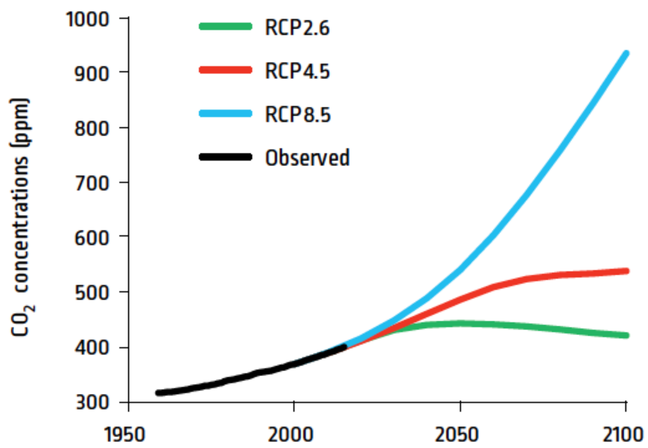

Figure 1. Variations in changes to atmospheric CO2 concentrations under different RCP predictions

(sourced from Bureau of Meteorology and CSIRO 2016).

Regardless of whatever climate change mitigation efforts are put in place by Australia or globally, it needs to be acknowledged that some further warming will continue due to current and past greenhouse gas emissions. This will occur even if all global emissions were able to be immediately stabilised (CSIRO and BoM, 2018). As a result, Australia will need to continue actions in adapting to continuing climate change. While it can be expected that there will be overall increases in temperature and changes to other weather events such as rainfall, due to the size and geographical extent of the Australian continent the impact of climate changes will vary in different regions. Thus, adaptation and mitigation efforts need to be considered at a local scale. Consideration of potential climatic changes and impacts at regional levels will be important for agencies such as NRAR who will need to judge the extent of risks associated with regulatory decisions (both positive and negative) as well as the impact of any non-compliance behaviour to other users of water at a local level.

The Bureau of Meteorology and CSIRO are the lead agencies undertaking future climate modelling for Australia and undertake modelling at different scales through the use of "NRM clusters" which are set geographical and climatic regions of the Australian continent (CSIRO and Bureau of Meteorology 2015). The model clusters in which NSW land areas are included are the northern sections of the Murray Basin cluster, the southern part of the Central Slopes and East Coast clusters and the eastern portion of the Rangelands cluster (Figure 2). Using these different cluster levels, the outputs from the models can be continually assessed against current and historical trends in those regions, thus providing an assessment of potential changes in each region (which may be differ significantly from changes in other regions).

TEXT BOX 1.

RCP = Relative Concentration Pathways. This equates to the amount of radiative impact on the climate system by the end of the century caused by increased greenhouse gas emissions (Figure 1).

- RCP2.6 (low) –ambitious global action to reduce emissions
- RCP4.5 (medium) – strong global action to reduce emissions towards end of century
- RCP8.5 (high) – little global action to reduce greenhouse gas emissions

(BOM and CSIRO 2016)

While the modelling of climate impacts examines a range of impacts including extreme temperatures, marine and coasts, fire risk and (where appropriate snowfall), for NRAR's information, only changes in annual temperature, rainfall, drought and extreme rainfall have been considered for discussion.

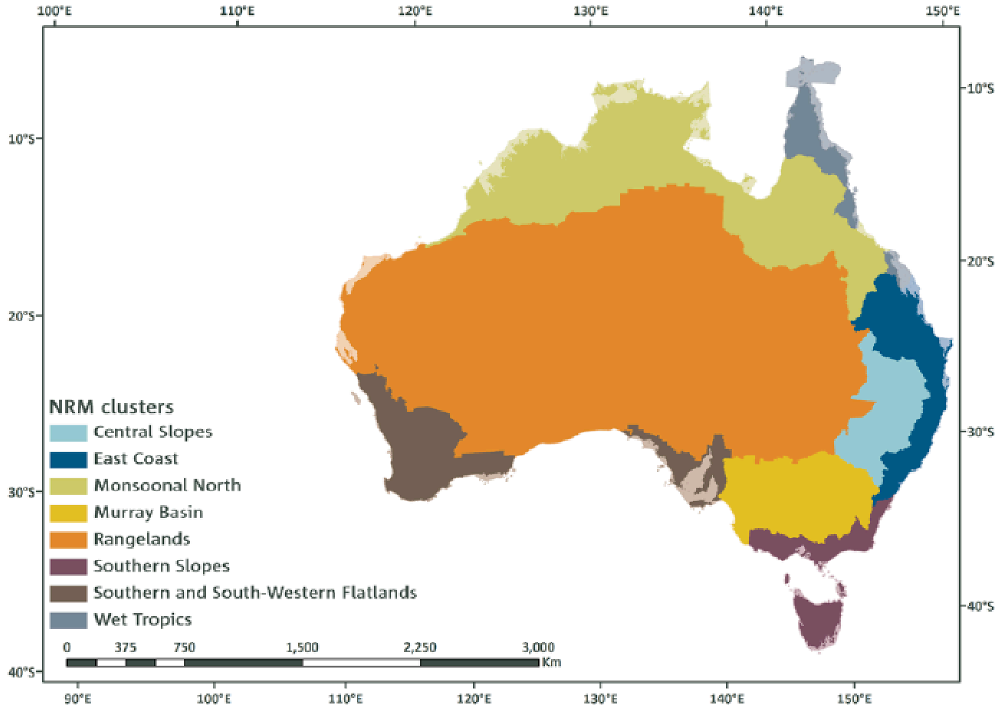

Figure 2. Natural Resource Management clusters.

(sourced from CSIRO and Bureau of Meteorology 2015)

Temperature

The trends in temperature change in NSW is a general increase with observed annual mean increases of between 0.05 and 0.3 °C across the state between 1940 and 2018 (Figure 3). When viewed as yearly mean temperature anomaly (Figure 4) it shows that there were a number of years that were below the running temperature mean (calculated from a 30 year period from 1961-1990) interspersed with years above the mean up to 1996. After that, the temperature across NSW has continued to climb and has been consistently above the mean. Overall, there has been an increase of more than 0.95 °C since 2013 (with all but 2015 being higher than 1°C above the 30-year mean).

Modelling of temperature changes into the future using climate change models has predicted that this increase in average annual temperatures will continue, and potentially accelerate (CSIRO and BOM 2018). The average annual temperature is predicted to increase in all NRM sub-clusters. As detailed in Table 1, in the time up to 2030 the increases are very similar, however, later in the century the Rangelands and Central Slopes NRM sub-clusters will become considerably warmer than the Murray-Darling Basin and Eastern Coast South sub-clusters. All the modelling indicates that temperature increases under the RCP8.5 conditions will be significantly greater than under the other two RCP conditions.

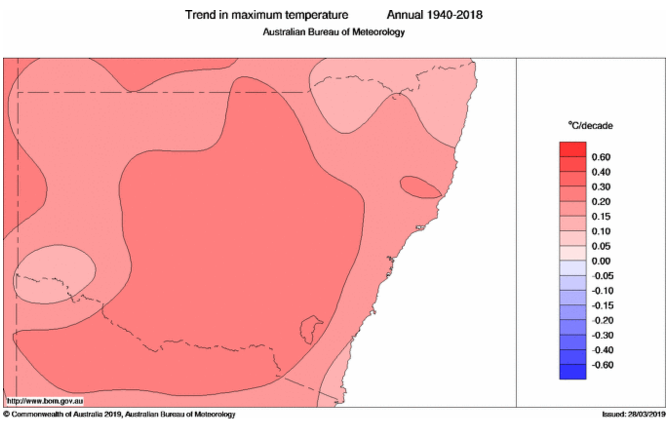

Figure 3. Trend in mean temperatures across NSW 1940-2018.

Source: Bureau of Meteorology website (http://www.bom.gov.au/climate/change/) Accessed June 2019.

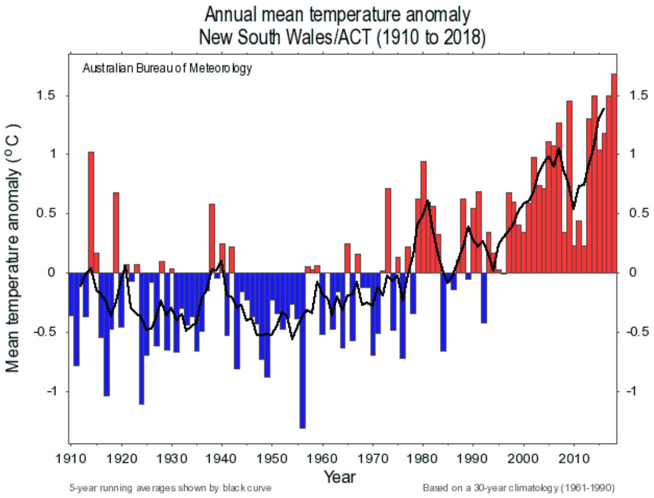

Figure 4. NSW annual mean temperature anomalies 1910 to 2018. (black line is 5-year running average)

Source: Bureau of Meteorology website (http://www.bom.gov.au/climate/change/) Accessed June 2019.

Table 1. Climate model predictions for temperature changes in the NRM sub-clusters that cover the NSW state boundaries.

NRM CLUSTER	UP TO 2030[a]	2090[b] RCP4.5	2090 RCP8.5
Eastern Coast South	0.5 to 1.3 °C	1.3 to 2.5 °C	2.9 to 4.6 °C
Central Slopes	0.6 to 1.5 °C	1.4 to 2.7 °C	3.0 to 5.4 °C
MDB	0.6 to 1.3 °C	1.3 to 2.4 °C	2.7 to 4.5 °C
Rangelands North	0.6 to 1.5 °C	1.5 to 3.1 °C	3.1 to 5.6 °C
Rangelands South	0.6 to 1.4 °C	1.3 to 2.6 °C	2.8 to 5.1 °C

[a] Changes in temperature compared to 1986-2005 climate

[b] The web site does not provide estimates for temperature changes up to 2090 under RCP2.6. It can be assumed that there would be limited difference with the predicted changes up to 2030.

(Source: CSIRO and Bureau of Meteorology 2018)

The observed and predicted increasing temperatures will have an effect on all regions across NSW including urban communities and rural industries. Local heatwaves recorded in 2013, 2014, 2015 and 2018 all caused major impacts on local infrastructure, community health, placed major demands on electricity supplies, and affected transport and agricultural systems. (CSIRO and Bureau of Meteorology 2018). The predicted continual increase in average annual temperature will further increase human health impacts and stresses on rural industries.

Without adaptation and intervention by water utilities and government, it is likely that water consumption in urban areas will increase to deal with the impact of increasing temperatures, particularly relating to urban heat island impacts. Only a portion of the water demand in urban areas is required for consumption (i.e., drinking and cooking) and the majority is used for other household requirements (e.g., flushing of toilets and clothes washing) along with irrigation of gardens, parks and other green spaces. Most water suppliers/utilities have already undertaken considerable effort to separate potable water needs for consumption and non-potable water use for other requirements (for example the increased use of rainwater tanks in and around houses and commercial buildings) and it would be expected that these efforts will continue as part of adaptation efforts to climate change. These adaption efforts in urban areas have a strong likelihood to alter urban water requirements and on how water moves through the urban environment. Increasing urban sprawl will change the rate and manner in which water moves from the land into waterways. Conversely, efforts by government and urban communities on initiatives such as water sensitive urban design (WSUD) and urban greening will influence potable and non-potable water demand (potentially both positively or negatively). This could change overall water requirements in cities and towns. Regulators such as NRAR will need to be aware of what changes are occurring in urban water uses and needs, and understand how these changes differ to changes in needs and behaviours in rural communities who may have less options to deal with water variability in a changing climate.

In contrast, farms and other rural industries are likely to have more limited options to deal with changing water requirements caused by variations in rainfall patterns, increasing evapotranspiration and decreasing soil moisture content. As with urban areas, farms and small regional communities need water for both potable and non-potable needs although there is considerably greater use for non-potable purposes (e.g., irrigation) than in larger urban centres. The climate prediction models tested have all shown a high degree of agreement that there will be an increasing level of potential evapotranspiration. Unlike urban areas, rural districts are less likely to be able to use many of the adaptation options such as capturing excess stormwater from hard surfaces, utilise recycled water, or manufacture water from sources such as desalination due to the need for large volumes for basic farm operations. As such, it is likely that rural communities will be more reliant on changing farming practices and use of efficiencies gained from automation and sensor technologies. For some, in times of high stress there will be an increased temptation to breach water access limits to just survive as viable farms. For a regulator such as NRAR, having better information on local conditions and potential time extents of impacts from climate change (i.e., short-term variation or long-term climate change) could assist in determining the level of harm of non-compliance and thus aid in the determination of appropriate enforcement remedies.

The amount of potential increase in evapotranspiration is linked to the degree of local warming and the relative predicted temperature increases under the different RCP scenarios. The exact magnitude of change under each of the RCP, however, is currently not completely clear (CSIRO and Bureau of Meteorology 2015). Soil moisture is predicted to decrease across all of NSW under all the RCP scenarios due to decreases in rainfall, increases in temperature and potential increase in evapotranspiration. The extent of decreasing soil moisture increases with the higher RCP scenarios. As a direct result of decreasing soil moisture (and other compounding factors of decreased rainfall, increased temperatures and evapotranspiration) run-off into streams is projected to decrease by 2090 under all RCP scenarios (with the severity of the decrease related to the RCP scenario) (CSIRO and Bureau of Meteorology 2015). This will exacerbate issues relating to balancing water supply issues for human and environmental needs, on the motivations for individuals and entities to exceed water extraction limits, and have implications for compliance enforcement (e.g., perceived severity of penalties, implications for stress on farmers and rural communities, etc.).

Rainfall

As with the trend for temperature, rainfall trends across NSW have been influenced by the natural climatic variation of the Australian continent (i.e. the variation in rainfall patterns observed in the last 100 years) (CSIRO and Bureau of Meteorology 2018). Figure 5 shows visually how the natural climate variability has influenced the NSW average rainfall pattern, based on an assessment of 2040 to the present compared to an average rainfall pattern using rainfall data from only 1980 to the present. This second rainfall map highlights the impact of the millennium drought on NSW.

When rainfall is viewed using changes across a 30-year average (Figure 6) it shows that all of the major NRM regions that cover NSW have been influenced by this natural climatic variation up to the present and that there has been no discernible trend across time.

Future rainfall patterns are also a major focus for climate change modelling and forecasting. The model predictions for rainfall provided in the *Climate Change for Australia* web site for all the NRM sub-clusters that cover NSW predict that natural climate variability will continue to dominate over any influences caused by climate change up to 2030 (CSIRO and Bureau of Meteorology 2018). This suggests that NRAR should consider using the short term climate predictions issued by the Bureau of Meteorology for any regulatory planning and decisions up till at least 2030.

After 2030, greenhouse gas driven climate change is predicted to increase the variation between the NRM sub-clusters (Table 2). For example, rainfall, particularly in the eastern coastal regions of NSW is projected to vary little from the current normal variability under all RCP conditions apart from a significant decrease in winter & spring under a RCP8.5 scenario. The situation is similar for western NSW apart from the more southwestern regions which fall within the southern NRM region which has a decrease in rainfall in the winter and spring seasons under an RCP4.5 scenario (CSIRO and Bureau of Meteorology 2015, CSIRO and Australian Government 2019). Under the more extreme RCP8.5 predictions, annual mean rainfall could decrease significantly across the majority of NSW by 2090. This could be somewhat alleviated, however, by the chance of extreme rainfall events also increasing significantly (CSIRO and Bureau of Meteorology 2015, CSIRO and Australian Government 2019). The models predict that this potential increase in the chance of extreme rainfall events, however, will still only occur between longer durations of reduced rainfall (drought).

Flooding has been shown to be an important part of the ecological cycle for many Australian riverine ecosystems. It may therefore be important to consider maintaining some level of restrictions on farm water extractions that have previously been “allowed” during these high rainfall periods, in order to provide as much water for ecological services provisions. This would be a significant change from what has been considered previously acceptable and

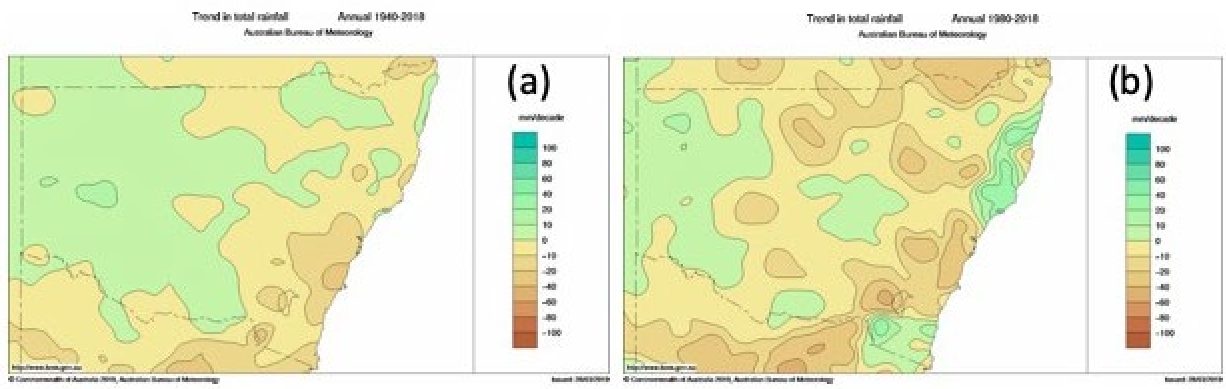

Figure 5. Trends in annual rainfall across NSW (a) 1940 to 2018, (b) 1980 to 2018.

Source: Bureau of Meteorology website (http://www.bom.gov.au/climate/change/) Accessed June 2019.

could increase risks of non-compliance that would need further attention. McGown (2017) noted a perspective with some farmers that it was difficult to see large volumes of water flowing past farms which could be used on farms to increase crop output (even if it's acknowledged that the water in the river is being kept for those further downstream or for the environment). Regulatory enforcement of decisions to reduce extractions during periods of flood will need to be backed by information that has used climate change predictions to consider any alterations to "rights" to extract more water during flood events vs. providing as much water for environmental services to buffer against increasing dry spells.

The lack of certainty on the scope of increases in extreme rainfall events suggests that for the moment at least, it could be considered prudent for agencies such as NRAR to take a precautionary principle that considers that significant decreases in rainfall up to 2090 will be the major condition for NSW.

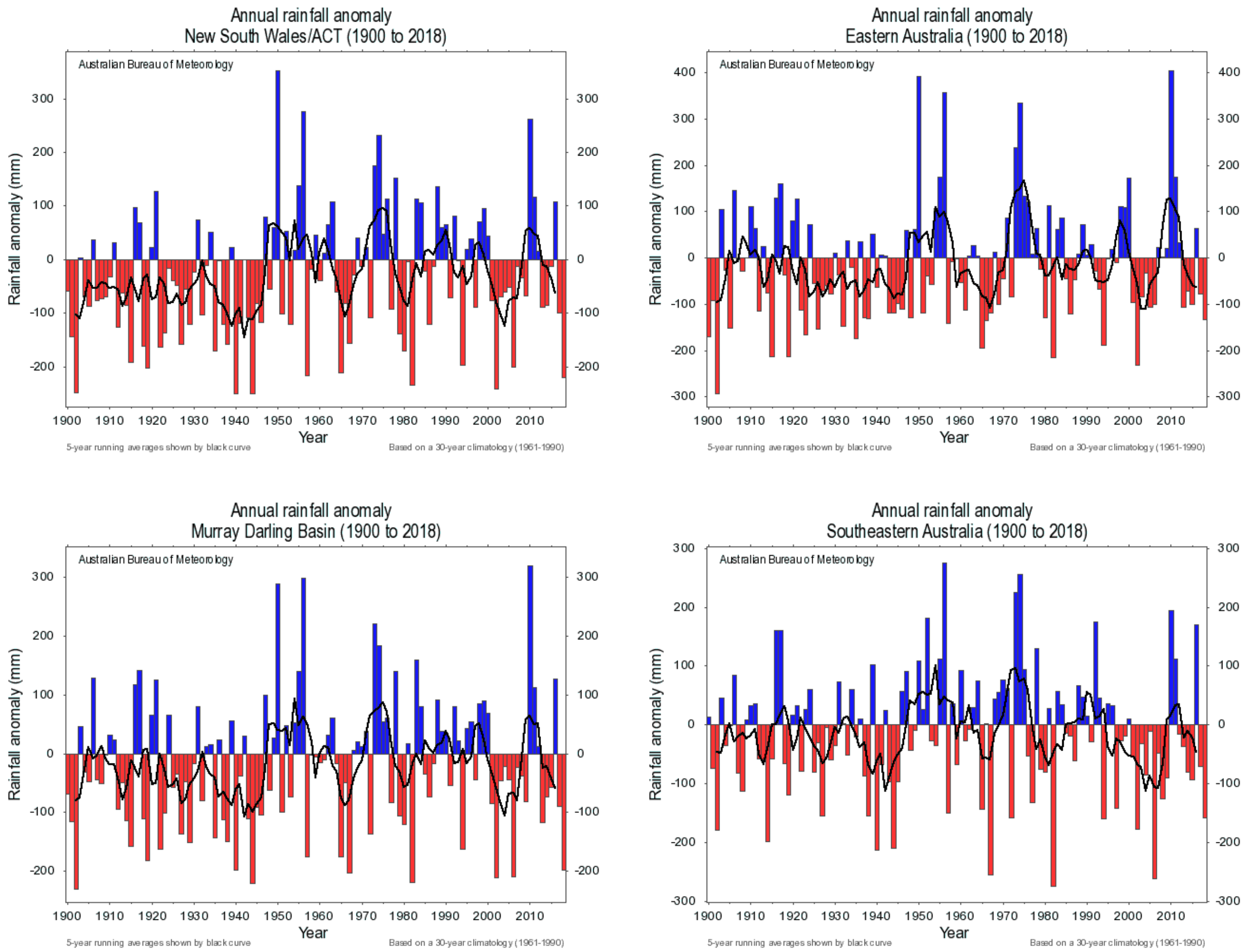

Figure 6. Rainfall anomalies across NRM regions covering NSW. (black line is 5 year running average)

Source: Bureau of Meteorology website (http://www.bom.gov.au/climate/change/) Accessed June 2019.

Increasing rainfall variability means that NRAR would need to consider how climate change is impacting the different sub-regions on a more localised level. In all NRMs apart from the MDB, in the decades towards the latter part of the century, the models indicate that for impact assessments in each region, the risk of both a drier and wetter climate should be considered.

If this increased variability does occur as predicted, then the use of new sensor technologies and analysing of Big Data for climate would be important to detect in real-time local variations in rainfall and subsequent stream flows. In addition, the combining of improvements in data analysis with in-stream real-time sensor technology and smart meters will enable this information to assist NRAR to locate and identify incidences of non-compliance.

Drought and Extreme Rainfall Events

Both drought and extreme rainfall are part of the natural history of the Australian landscape and are a part of the variable trends for both temperature and rainfall. This has included periods of intense drought such as the Millennium drought and other occasions of flooding of regions from either localised intense rainfall or due to major increases in streamflow from impacts further afield (for example cyclones progressing inland and causing flooding through inland waterways).

The climate change modelling predictions provided by CSIRO and the Bureau of Meteorology have indicated that, as for rainfall, up to 2030 the possibility for drought or extreme rainfall events will be driven by

Table 2. Climate model predictions for rainfall changes in the NRM sub-clusters that cover the NSW state boundaries.

NRM CLUSTER	UP TO 2030[a]	2090[b]
Eastern Coast South	Natural climate variability	Consider the risk of both a drier and wetter climate. Only in winter will have a rainfall decrease that is projected with *medium confidence*
Central Slopes	Natural variability is projected to predominate	Decreasing winter rainfall with *high confidence* Decreases are also projected in spring, with *medium confidence* Impact assessment in this region should consider the risk of both a drier and wetter climate.
MDB	Natural variability is projected to predominate	Cool season (April to October) rainfall is projected to decline under both an intermediate (RCP4.5) and high (RCP8.5) emission scenario. Little change in the warm season (November to March)
Rangelands North	Natural variability is projected to predominate	Changes to rainfall are possible, but the direction of change cannot be confidently projected
Rangelands South	natural variability is projected to predominate	Winter rainfall is projected to decline over the century under both intermediate (RCP4.5) and high (RCP8.5) emission scenarios (*high confidence*) Changes to annual and summer rainfall for late in the century are possible, but the direction of change cannot be confidently projected

[a] Changes in temperature compared to 1986-2005 climate

[b] The web site does not provide estimates for temperature changes up to 2090 under RCP2.6. It can be assumed that there would be limited difference with the predicted changes up to 2030.

(Source: CSIRO and Bureau of Meteorology 2018) the existing natural variations in climate that have been observed since climate record keeping was started (CSIRO and Bureau of Meteorology 2018).

Post-2030, however, there is a medium confidence in the model predictions that the time spent in drought conditions will increase across all of the NRM sub-clusters covering NSW (CSIRO and Bureau of Meteorology 2018). Likewise, the models have a high confidence prediction that post-2030, there will be an increase in the intensity of extreme rainfall across of the NRM sub-clusters (CSIRO and Bureau of Meteorology 2018).

The predictions relating to droughts and extreme rainfall, like for changes in temperature and overall rainfall patterns suggest that it remains unclear how much change there will be in rainfall and related streamflow conditions or the implications for different areas within NSW. While the climate models indicate that there will be climate-change driven changes in temperature and rainfall, particularly post-2030, the magnitude and extent of such changes is still unable to be predicted with any reasonable certainty. Thus, at present, regulators such as NRAR will need to remain vigilant to, and respond appropriately to climate impacts on short term horizon timescales. Until future climate predictions that have greater confidence levels become available, it could be worth considering the assistance of new water technologies such as smart real-time sensors and meters combined with the ability to monitor and analyse big data sets as mechanisms that will enable NRAR to be able have improved information on the current, at-that-time water needs of communities, industry and the environment at specific locations. These time points can then be incorporated into how NRAR conducts required regulatory campaigns, and aid in communication with local communities on the rules that are being applied and enforced.

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Uncertainty #2: **Social Attitudes to Water**

Key Findings

1. Experiences from the millennium drought have shown that communities expect to be engaged in water decision making and that there will be transparency in government regulations. A failure to do so can lead to non-acceptance of water sustainability plans and options (e.g., water recycling). Anecdotal evidence is that there is a belief in some communities that they have not been a part of any decision making process which can lead to increased stress, anger and potentially deliberate non-compliance behaviour in relation to regulations, or cause other actions as a form of revenge (McGowan 2017).

2. Urban residents have previously demonstrated a willingness to reduce water use through a range of demand management processes as long there it is clear that there is a transparent level of fairness and equity. It is likely that this level of consciousness on water sustainability will remain and that urban communities will increasingly be also conscious of problems and issues faced by farmers and rural communities.

3. Research has demonstrated that multiple forms of community engagement and outreach can result in reductions in water use by urban communities. The degree to which these reductions in water use remain over time, however, is more influenced by the level of information provided with a greater persistence of water saving measures occurring in groups that had been provided details on how to reduce water use or comparative information on water usage levels across the community.

4. In rural, non-urban communities there is a much more complex range of issues influencing social attitudes that cross the bounds of irrigation and farming requirements, the interlinked needs of small towns that support farming districts, and the needs of the environment. Much of the variability in attitudes and resilience in rural communities has been linked to existing financial stress, level of education and time on the land. Those most at risk due to these stressors can be considered to also be at a higher risk of non-compliance due to desperation, or from higher levels of resistance to changes to existing water management structures.

5. Farming communities, both farmers and those in supporting communities, have a high perception of the risk associated with water availability, and on the potential impact shortages of water can have on local regional communities. This can cause impressions of "winners" and "losers" which has the potential to further increase concern and anger within impacted communities.

6. Farming communities have indicated that they expect licencing and regulations on water use to be consistent and transparent with clear accountability on water management and regulation. These expectations also include that incidences of non-compliance will be investigated in an open and transparent manner, and that any enacted enforcement measures undertaken are appropriate.

Water availability and use in Australia is intimately interwoven in the fabric of Australian society. Australians, new and old are cognisant of the variability of the climate and for the Australian Continent to be "*A land of drought and flooding rains*" (Dorthey Mackellar). Recent experiences and learnings from the 1996-2010 Millennium drought showed that the opinions, attitudes and actions of the general community can have a major influence on water security. The opinions and attitudes of communities are a central consideration for NRAR with a core requirement to maintain public confidence in water management and regulatory activities. It can be expected that high public confidence can assist with good compliance behaviours (and the opposite if there is low confidence).

There are also indirect influences via communities and organisations that can impacted by NRAR regulatory decisions as well as social, media or "political" pressures brought to bear in response to enforcement decisions. Enforcement decisions, in particular those relating to any perceived (real or not) impacts on communities and industries that are considered to be made without adequate consultation or consideration of community needs could lead to public backlash. A lack of public trust increases the risk of non-compliance activities, almost as a form of defiance (McGowan 2017)

As noted in the CSIRO Megatrends "Humans are complex and income growth and class ascendancy can be associated with negative behaviours" (Hajkowicz et al. 2012). By this the authors were implying that the drivers behind people's motivations and behaviours may not always be as altruistic as we think, particularly when there is a perceived impact on personal livelihoods or comfort. McGowan (2017) highlighted the impact on the level of trust for the MDBA as well as Federal and State Governments on the formulation and implication of the Murray-Darling Basin Plan. Some of those interviewed in this study intimated that the resulting grower anger was driving "inappropriate behaviour" as a form of "payback on the Authorities". While there is no firm data on if, or by how much non-compliance activities occurred as a reaction to regulatory changes and enforcement, social research has shown that a loss of trust, particularly for those in positions of authority can be very difficult to reverse and can result in further deepening of disengagement (Nancarrow et al. 2007). Developing and maintaining trust under difficult circumstances (such as the complex environment of irrigation communities and water access rights) still requires considerable research and engagement.

There is considerable information available on social attitudes to water in urban areas (mostly through the activities to increase water recycling and other alternative water sources) but there currently is less available on attitudes in rural areas with the majority of the data available coming from within the Murray-Darling Basin. What information is available is from small regions or council areas within the Basin and there is limited information that provides a view of social attitudes across the entire Basin. The MDBA is currently commissioning a research project on social and economic conditions of communities across the basin and assessing drivers of change (Murray-Darling Basin Authority 2019b). The outputs of this research are still pending (due December 2019). The value of this new research to other agencies such as NRAR remains to be determined and will only focus on the communities within the Murray-Darling Basin. As NRAR has responsibilities across all of NSW, it may need to consider engaging similar social research activities that are either in locations identified as requiring more information or that provides data that is more applicable to NRAR's operational requirements.

Among the lessons from the Millennium Drought was that there were distinct needs, options and attitudes between urban water supply and requirements and rural water needs. As NRARs remit covers licences to Water Utilities and other entities that extract water from rivers and other sources for urban uses as well as those organisations and individuals using water for rural purposes, this section on social attitudes and behaviours has been divided into two sections, one relating to urban supplies and the second on rural requirements.

Urban

Urban water uses and sustainability is usually deemed to be the responsibility of water utilities supplying urban areas. This, however, does not mean that regulators such as NRAR do not at times come under public scrutiny, or be required to give reasons for decisions made on what are the major drivers influencing public attitudes to urban water supplies, even if the decisions made are not the responsibility of NRAR (i.e., opinions are formed amongst community members of what activities NRAR carry out, even if the perceived activities are not, in fact, within NRARs responsibilities or remit).

The impacts of the Millennium drought provided significant learnings relating to the management of urban water supplies. Many different options were trialled and developed ranging from controlling demand for water (demand management) through to more expensive options such as desalination plants, water recycling options and water diversion methods (Spinks et al. 2017).

Demand management was a major mechanism used by urban water utilities to reduce water use. Studies undertaken in Queensland during the millennium drought demonstrated that there was a general willingness to conserve water, but there were a range of factors that could potentially impede reducing water use including the cost of installing water saving devices, and any belief in a lack of equity with other regions (Fielding et al. 2010, 2012). Following a study that investigated a series of different interventions from as little as merely providing information through to providing feedback on water savings at the end of the study it was demonstrated that any form of intervention relating to demand management could significantly reduce water usage in households (Figure 7) (Fielding et al 2012).

The study also showed, however, that after the intervention activities had completed, those in the group who were getting feedback on their water use (end-use feedback) rebounded to higher levels of water use compared to those in the groups where there had been information on water savings (information only) or on comparisons with other similar households (descriptive norm). This demonstrates the complexity of community attitudes and associated behaviour, and that while demand management is a useful strategy, complexity of human behaviours and attitudes mean that there is no simple quick fix for achieving consistent, long term benefits around demand management.

While the public activities demonstrated that processes improving demand management were a major benefit to urban water sustainability and that the public was generally very supportive (and active) in reducing unnecessary water use in times of need, a range of other water sustainability actions such as water recycling schemes, desalination and increased use of roof-harvested rainwater (rain water tanks) and captured stormwater have been employed (Price et al. 2010). While NRAR has a limited role in decisions on the increased use (or not) of alternative water sources, research has clearly indicated that community acceptance of these alternative water sources is strongly linked to perceptions of trust, fairness and equity, and the ability to be engaged in decision-making processes (Alexander et al. 2008). As part of the water supply and regulatory "community", NRAR can assist in promoting good community and corporate behaviour and acceptance on demand management of potable supplies and uptake in the use of alternative water through advocating those activities which can help engender increased trust in the water supply community.

While as already stated most public attitudes towards urban water issues are more focused on water utilities, health departments, and pricing regulators, the Millennium drought has raised community awareness of water issues and there has been an increased expectation of transparency and fairness by water suppliers and governments on decisions relating to urban water supply issues (Alexander 2008, Nancarrow et al. 2007, Price et al. 2010). Again, while having a limited direct role in the provision or control of urban water, NRAR is part of the broader group of government water regulators and authorities and will need to consider that at times, it is likely that it could come under greater public scrutiny as a result of broader decisions made relating to urban water access rights, particularly during times of decreasing rainfall. A transparent corporate position on the role urban centres have on protecting water sources, and on the enacted limitations about the amount of water available to urban centres can be useful as part of the broader urban community engagement.

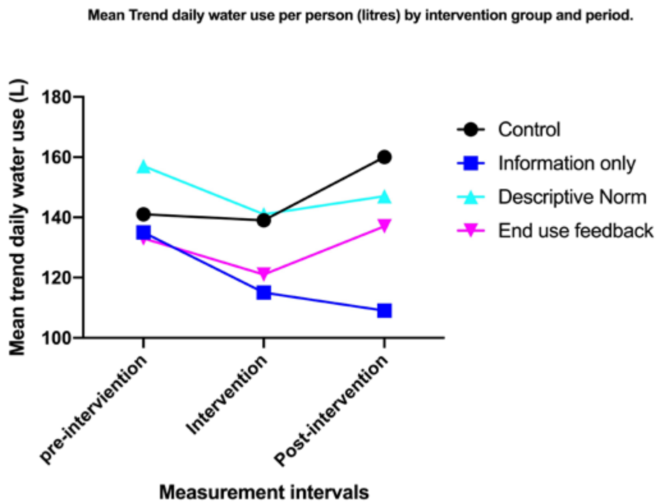

Figure 7. Influence of intervention method on changes in water demand

(sourced from Fielding et al. 2012)

Social attitudes toward water and water savings are not just about targeting individuals to reduce their personal water consumption. Many of Australia's large cities such as Sydney are diversifying demographically and stratifying in terms of accessibility to services such as transport and closeness to other public utilities (CSIRO 2017). As such, public scrutiny around access to water resource allocations is an increasingly complex issue that not only involves issues relating to potential decisions to reduce allocated volumes for urban use, but also on complex issues around fairness and equity (e.g., is one group perceived to get more rights to water than another group/town); environmental protection (e.g., if rivers and streams run dry, is that the fault of over-extraction by users?); and engagement/trust issues (e.g. what level of consultation was undertaken prior to a decision made and if any public inputs were considered?) (Nancarrow et al. 2007). As the water access regulator, NRAR does not make decisions relating to where water is allocated, or how much. However, public scrutiny into decisions relating to investigations into non-compliance and any resulting enforcement remedies does need to be transparent and fully justifiable to demonstrate that the rules have been applied correctly and that fairness and equity have been employed. A perceived failure to do so runs a high risk of damaging public trust in NRAR's ongoing role and activities.

Since the millennium drought and the continuing lack of rain in different regions of Australia, climate change has continued to become more of a focus for the community. There is a higher percentage of awareness of the potential long-term impact of climate change in our urban communities and even when natural climate variations are viewed as possibly caused by climate change (Walker et al. 2017). It can be expected that the community will be more conscious of the impact of climate change on natural resources and will expect agencies such as NRAR to take this into account when making decisions relating to compliance decisions on water extraction. Information provided via polling in recent State and Federal elections during the 2017-2019 period has shown that the majority of urban residents (which make up over 80% of the Australian population) are concerned about climate change and believe that governments (which includes government agencies such as NRAR) will take climate change into account in decision making relating to natural resources. It is likely that communities will also expect these decisions to not have an adverse impact on the environment (NSW Government 2017).

Urban communities are not only demonstrating concern about local urban conditions but also are conscious of problems and issues relating to water allocated to farmers vs. the environment in regions such as the Murray-Darling Basin, if only through the media (Mathews 2017). Urban communities will expect that decisions made relating to urban water allocations and enforcement of water access entitlements are enforced in a transparent and equitable manner (Mathews 2017). This is likely to be one of the areas NRAR will come under urban community observations and expectations and this scrutiny can only be expected to increase as the climate change impacts increase.

Rural

In rural communities there are a much more complex range of issues influencing social attitudes that cross the bounds of irrigation and farming requirements, the interlinked needs of small towns that support farming districts, and the requirements of the environment. Irrigation and farming requirements can also be divided further into that needed for smaller individual/family farms and the activities of larger farming companies and irrigation co-operatives. Studies have shown that there are several regions and communities within the Murray-Darling Basin that could be economically and socially vulnerable to changes in water allocation rights (Stenekes et al. 2012). This could be further impacted by changes in the existing water market although a recent study by McGowan (2017) indicated there were a variety of opinions, both positive and negative, regarding the impact of the water market. It is understood that more is needed to understand the social and economic conditions in the Murray-Darling Basin.

The majority of the available, current information on rural social beliefs and attitudes relies on research undertaken within the Murray-Darling Basin and is predominantly provided at a scale of work undertaken in a few localities or councils. There is very little current data available providing information of social attitudes and beliefs across the entire Basin. As such the MDBA has commissioned an independent panel to report on the social and economic conditions within the different Murray-Darling Basin communities. The panel will also provide updated information on the impact of the temporary water market, including the influence of speculators on water prices and availability (Murray-Darling Basin 2019). This report is expected at the end of 2019 and should provide valuable information for agencies such as NRAR relating to the current social attitudes of communities within and across the Basin. For rural areas outside of the Murray-Darling Basin, there is even less current research data easily available. As such, it will be important for agencies such as NRAR to either directly commission social research in other NRM regions outside of the Basin when needed, or to support broader government undertakings to examine the social impacts of climate change across NSW or Australia (should they be undertaken).

Those studies that have been undertaken in different regions/basins of the Murray-Darling Basin have highlighted the deep and complex attitudes of farmers and towns that are within and reliant on farming districts. Several studies have investigated the vulnerability of different regions within the Murray-Darling Basin to reductions in water, either through drought or reductions in water access due to the implementation of sustainable diversion limits. These studies have all demonstrated that an individual's attitude is linked to a real or perceived level of vulnerability (or not) which is closely associated with factors such as farmer age; level of debt; the type of agriculture practiced and the impact of reduced water on the production of that commodity; level of education; and perception of personal wellbeing and optimism (McGowan 2017, McLeod et al 2011). These social research projects indicate that farming communities, both farmers and those in supporting communities, have a high perception of the risks relating to water availability, and on the potential impact shortages of water can have on local regional communities, all of which can lead to high levels of stress and financial pressure (McGowan 2017). NRAR's regulatory enforcement requirements need to be cognisant of these perceptions and stressors relating to the risk of water limitations on farming livelihood and financial viability. Financial stresses and perceptions of wellbeing can lead some to non-compliance activities through desperation. Additionally, anger at regulators such as NRAR for perceived unfair treatment can also lead some to undertake actions as a form of revenge (McGowan 2017). There is limited quantitative data on non-compliance activities or the drivers for such reactions, however, the chance for these forms of non-compliance occurring can be reduced through:

- direct, long term engagement,
- people perceiving that they are being listen to,
- a demonstration that irrigator concerns have been considered,
- working with irrigators on possible alternatives, and
- maintaining a consistent full and open transparent decision making process.

It will also be important to understand that the levels of stress, anger and concern will vary between communities and may even vary within an individual community under different conditions. Maintaining a continual consistent and open engagement with the different communities will be important in building and maintaining trust with these communities.

Many rural communities that have been surveyed have the impressions that there are "winners" and "losers" relating to water access and rights with a perception that larger farming businesses and those with crops less impacted by variations in water access were better off than the "little farmer" with water sensitive crops. (Bristow and Stubbs 2010, McGown 2017). There was concern that there was a rising level of inequity between those who have good access to water, or have access to on-farm grants (because they had been in the right place at the right time) and the impact that such a belief may have on the broader community.

Agricultural communities are naturally proud of their communities and regions and are concerned about the impact the variability and/or loss of water would have on not only themselves personally but also their surrounding community. This was a relatively consistent trend across much of the Murray-Darling Basin but more pronounced in those areas that had a high reliance on the income coming from the cultivation of highly water-dependant agricultural products such as cotton, rice and dairy. The generation of the water market and the water caps within the *Murray-Darling Basin Plan* and the resultant reduction in certainty on water availability were recorded to increase levels of stress and concern in impacted rural communities. (McLeod et al 2011). Communities have voiced opinions that they expect water use and licencing to be consistent and transparent with clear accountability on water management and regulation (Murray-Darling Basin Authority 2018a). These expectations also include a view point that that incidences of non-compliance will be investigated in an open, transparent and appropriate manner, and that any enacted enforcement measures are effective and fair (Mathews 2017).

Examples of the points raised during a range of interviews within several research projects include:

- A belief that farming communities were not consulted and are excluded from decisions relating to water access and extraction levels or details of the *Basin Plan* (McLeod et al. 2011).
- That the opinions and needs of farming communities are not being listened to (McLeod et al. 2011).
- That farmers believe that non-farming communities have the opinion that farmers are only interested in water for farming and are not interested in their local environments (and the impact of loss of water in those environments) (McGowen 2017).
- Not everyone believe that all farmers would struggle and just *"give up"*. There was also a differing attitude that people in rural areas would always find ways to adapt and survive through strong resilience (McGowen 2017). This was noted to be particularly the case for farmers under the age of 35, and/or having a tertiary education, and those over 65 with low levels of debt (Marsden Jacobs et al. 2010).
- Others in rural towns also voiced an opinion that changes to the nature of farming could provide new opportunities for those regions. This was particularly pronounced if there was some level of government or other agency involvement in trialling new crops or innovative businesses in the area. Others suggested that it would drive irrigators to be smarter with the way they undertook irrigation (McGowen 2017).
- Increasing "red-tape" and having to gain approvals from multiple agencies were listed as a frustration, particularly when legislate requirements appeared to change regularly (McGowen 2017).

It is likely more information will become available over time on the needs and opinions of local communities in rural areas, particularly in the Murray-Darling Basin. For example, the MDBA report due in December 2019 will provide greater information on the changes being experienced by different communities across the Murray-Darling Basin with a focus on the social and economic conditions of these communities and the drivers of change they are experiencing. This report should provide greater insight into the different demographics across the entire basin.

Some of the potential differences may not be just geographic, but also details on farms vs towns, types of agricultural products produced and if there are any clear gender drive differences. McGown (2017) observed that women are increasingly taking a much greater role in running farming businesses (both financial and labour) than may have traditionally occurred. Some interviewed voiced the opinion that women are becoming more informed on water issues in the Murray-Darling and are becoming more involved, taking greater leadership roles in agricultural industries.

The complexities around the social aspects of individuals and communities are one of the most multifaceted issues agencies such as NRAR have to deal with (Williams 2017). The complex, multi-stakeholder requirements and attitudes of rural communities with multiple contested water resource requirements and rights can make it difficult for water allocation agencies and regulators such as NRAR to develop processes that are perceived as equitable and fair. Where there are opinions on the lack of fairness and/or strict controls and processes which demonstrate equity within and across regions, there is always the potential for inappropriate behaviour by a minority as has been explored by the investigations of Ken Matthews (Mathews 2017). This is made even more difficult by the complexities in the diverse range of relevant stakeholder values, understanding of environmental needs and climate change, and the ability of individuals and communities to adapt to change (Abel et al. 2016).

The competing needs of rural communities, farms and their surrounding environment will remain a complex issue. These complexities will not be resolved soon and are likely to become more prominent as climate change becomes more pronounced. This is likely to be particularly prominent in the Tablelands and Western NSW regions where climate change modelling has predicted with confidence a significant reduction in rainfall from 2030 due to climate change. Managing these issues and balancing the needs and rights of a broad diverse community under these conditions will require an on-going relationship between government agencies and regulators such as NRAR with rural community groups and co-operatives closely supported by other State and Federal agencies (e.g. the MDBA) and researchers.

Engaging with communities and monitoring local attitudes will be important when making important decisions around water access rights, compliance programs and targeting regulatory interventions (McGowan 2017).

While there will always be a need to make decisions that will not solve everything for everyone, a feeling of being listened to is considered to be important for all communities and is vital for communities to understand why certain decisions have been made (McGowan 2017). Communities also benefit from being provided with information and being able to, in turn, deliver material that may influence decision making. As climate change takes effect after 2030, on-going discussions and involvement of local communities will become increasingly important to help with at least an acceptance of, if not agreement with decisions that have to be made, even if they cause adverse effects on farms and community.

NRAR will need a responsive regulatory enforcement processes that involves and seeks input from local communities to ensure compliance with non-urban water allocation licences. A failure to do so will create a perception that local communities are not being communicated with or given the opportunity to be involved in important decision-making processes. This is likely to create significant dissatisfaction in impacted communities. With the likely increasing need to make difficult decision on relative water allocations, which may vary across regions, learning from the processes used (and not employed) during the formulation of the Basin Plan and acting upon these learnings will be vital for the best decisions under the conditions experienced at the time.

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Uncertainty #3: **Agricultural Practices and Irrigation Needs**

Key Findings

1. In NSW, agriculture used more than 70% of the water extracted from the environment in 2017-18 (Figure 8).
2. In 2017-18, the majority of water used for agricultural purposes was for the cultivation of cotton, grains and rice (75%). However, the value from these three agricultural commodities was only 59% of the value of livestock to the NSW producers and 40% of the value of all other agricultural commodities produced in 2017-2018 (Figure 10).
3. The volume of water (ML) used per hectare was also the highest for rice and cotton with water use by both commodities increasing to above 2009 levels in 2012. Water consumption for the cultivation of cotton remained higher than 2009 levels up till 2017.
4. Increasing temperatures and decreasing water availability caused by climate change will require planning for dealing with a drying climate that includes monitoring for any increasing incidences of water theft, over-extraction and other non-compliance behaviours.
5. Soil conditions in many areas of NSW are currently rated as being in poor condition through increases in acidification, salinity and erosion, further impacting on crop productivity levels.
6. Regulating compliance will not be sufficient to regulate water extraction in regions impacted by climate change and there will be an increasing need for adaptation measures that can assist farmers and rural communities. Governments are already commencing to assist in the development of improved irrigation water supply efficiencies, irrigation application methods and other technologies that improve irrigation efficiencies.
7. Increasing use of automation, robots, sensors and analysis of big data will also assist both farmers and regulators adapt to climate change by increasing the efficient use of water while improving agricultural outputs. Sensor technology combined with improvements in the analysis of collected data will be especially important in more remote regions for farmers for farming adaption and for regulators to monitor compliance where currently regular communication and information sharing are difficult.

Water is an essential requirement for a range of human activities. In Australia's variable climate providing sufficient water for all, including the environment, is a frequently a concern for regulators and water users. This is particularly an issue for the supply of water for agricultural purposes. As shown in Figure 8, for NSW in 2016-17, agriculture used over 71% of the water allocated for human based activities, with the next two highest water uses, water supply and treatment and domestic use, being less than 20% combined (Australian Bureau of Statistics 2017a).

Agriculture will continue to be an important sector of the Australian economy. Currently, agriculture not only provides food for the Australian market, but is also a significant export earner. The CSIRO Australian National Outlook (ANO) (2015) has projected that prices for agricultural products will continue to trend upwards over the coming decades. The modelling undertaken within the ANO research has predicted that increasing local and global demands for produce will be the main drivers for this increase in the output of food and fibre. This increase in production will occur even if substantial land use changes occur (e.g., more land is turned over for use in biofuel feedstock production or for carbon sequestration) as long as the current declining investment in productivity is halted and sustainable investment is restored. The potential cascading impacts of future climate change and extreme events on farms, sectors, and regions, however, are compounding influences of any levels of agricultural production rates and remain to be further explored (CSIRO 2019). Figure 9 shows the impact on climate variability and low water access in crop production between 2001 and 2015 with declines in crop productivity (up to, and greater than 20%) observed in large areas across the eastern and western regions of Australia, including large tracts of NSW.

As the major use of water resources, agriculture will always be a significant consideration in water regulations and ways to conserve water. The experiences from recent dry spells and drought, combined with concerns over the impact of climate change are increasing the focus on agricultural water demand, water use practices and potential future farm operations. Irrigation practices also needs to be linked intimately with farm soil conditions with much of the agricultural soils in NSW are currently rated as poor for acidification, salinity and erosion (Metcalfe and Bui 2017).

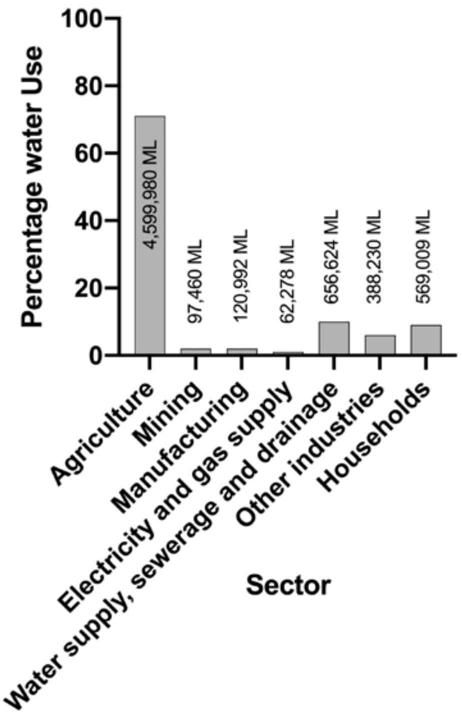


Figure 8. Percentage of water use across different NSW sectors in 2017-2018

(Source: Australian Bureau of Statistics 2017a)

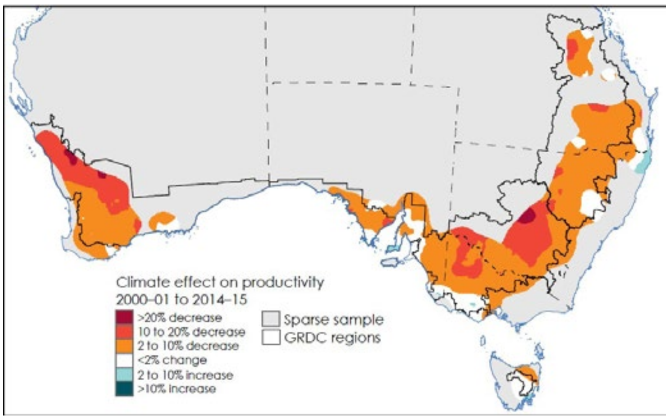
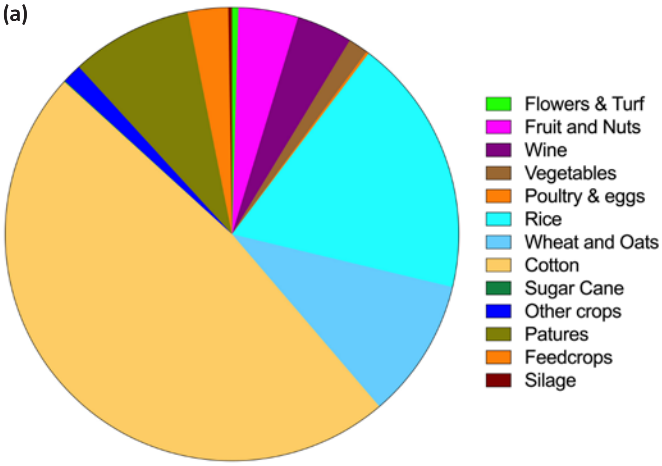


Figure 9. Climate effect on crop productivity levels in 2001–2015 relative to the long-term (1914–2015). [From Hughes et al., 2017]

The amount of water used in different Agricultural sectors and their relative value is presented in Figure 10. As can be observed in Figure 10(a), cotton followed by rice and grains (wheat and oats) were the largest users of the water allocated for agricultural use in NSW. In contrast, the combined meat production in Figure 10(b) was the largest individual earners for all NSW agricultural commodities in 2017-2018.

(a)



(b)

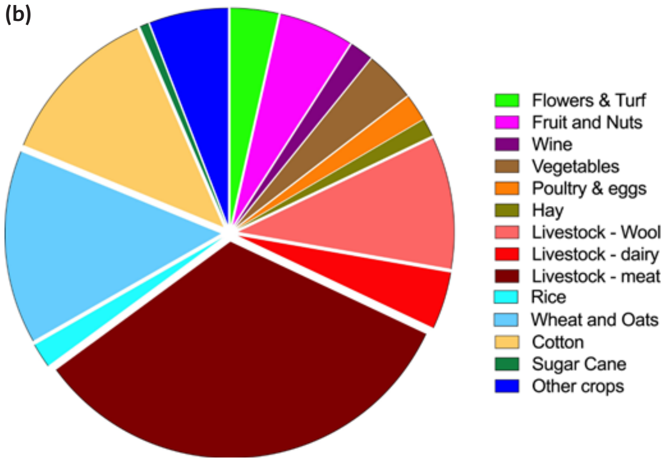


Figure 10. Comparison of (a) the amount of water (ML) used by selected agricultural sectors and (b) the value of for each commodity sector ($million) for 2017-2018 year.

Note that in (a) the Pastures, Feedcrops and Silage sections are used to represent water use for the Livestock sectors detailed in (b)

(Source: Australian Bureau of Statistics. 2018)

When the value of each agricultural commodity was considered as a proportion of water used, however, cotton and rice production was observed to provide significantly less value per megalitre used than the majority of the other agricultural products (Figure 11). This highlighted value of each ML of water for each dollar returned does not suggest that cotton or rice production should necessarily be targeted to be provided less water in more lean times by water allocation agencies, however, it may be that that cotton and rice production could be an area of agriculture that would benefit from greater innovations relating to improved water management practices or new irrigation methods. It should be noted that this information is based on data on water use per each agricultural commodity across the entire state of NSW and the values depicted in Figure 11 may change if applied to specific regions or if other externalities other than total water used and total commodity earnings are also considered.

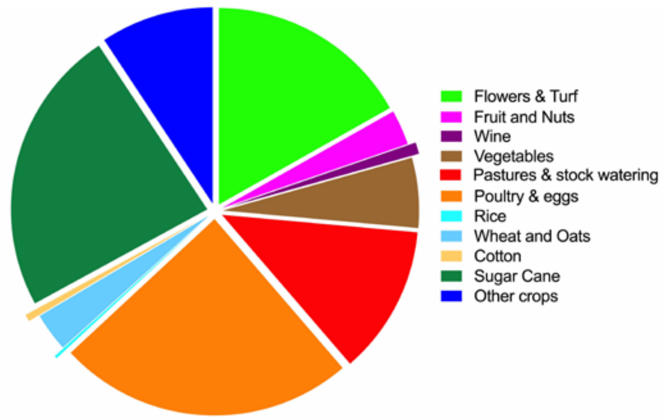


Figure 11. The proportion of value per ML water used across NSW Agriculture sectors 2017-2018

(Source: Australian Bureau of Statistics 2018)

The information on water use above is a snapshot of use in a single year (2017-2018). Figure 12 provides information on changes in the amount of water used (ML) per hectare irrigated between 2009 and 2017. Overall water use per hectare between 2009 and 2017 was the highest for rice followed by cotton. Water use per hectare for beef cattle and vegetables has remained relatively stable over the 2009-17 period while cotton, rice and dairy all had increases post the end of the millennium drought.

Rice and dairy had a large jump in use between 2012 and 2013 that can be linked to significant increases in stream flows at that time but have then declined with dairy having rapidly dropped back to 2009 levels. The decline in water use for rice can be linked to decreases in the amount of rice paddocks irrigated from 203 till 2017 (Australian Bureau of Statistics 2017b). Cotton also increased water use in 2012 and has remained above 2009 levels up till 2017 (which is the latest year of available data).

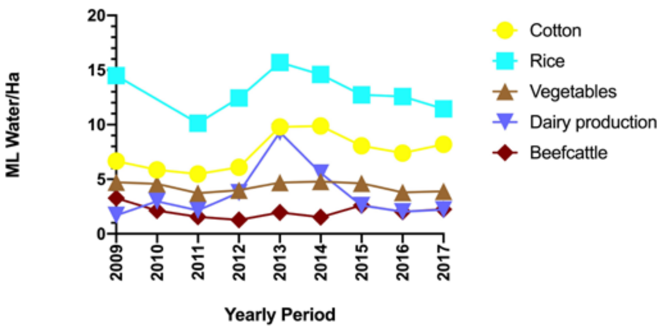


Figure 12. Yearly ML of Water used per hectare irrigated in NSW for selected agricultural commodities 2009-2017.

(sourced from Australian Bureau of Statistics 2018)

As mentioned in the **Climate Change** Uncertainty section, the availability of water in NSW will remain principally dominated by the existing natural climate variability until at least 2030. Water use is likely to be influenced by continuing temperature increases and subsequent higher evaporation rates which could increase the demand for water, however, the amount of water available for extraction from the environment will depend existing current variable rainfall patterns.

Due to the reliance on these climate uncertainties, the amount of water available over periods of one to three years will be reflective of this natural variation. Regulators such as NRAR will therefore need to monitor water use taking water availability over these time periods into consideration. With a predicted drying climate post-2030 particularly in the Murray Darling basin and southern rangelands, along with a high chance of more frequent and prolonged drought across NSW, there will be a need to start planning for this eventuality and the implications for agriculture.

For NRAR, implications of increasing water theft or over-extraction and other non-compliance behaviours become more possible through attempts to “ride out” increasing dry periods or the impacts of increasing ambient temperature. Post-2030 considerations will also need to include short-term vs. long-term needs for agriculture and the environment, and longer term water security issues for commodities sensitive to water access changes (e.g., fruit and nut cropping).

This planning will include adapting irrigation practices to cope with the changing climate or improving irrigation practices as well as using innovations in technologies and data management as discussed below in the **Water Technologies** and **Data Management and Analysis** Uncertainty sections. These same technologies will be important tools for NRAR for real-time monitoring of water use and for comparing to areas/crops being irrigated. As climate change impacts increase, adaption will be become more important than mitigation activities, at least post-2030. The Australian Government has already developed an Intergovernmental Agreement (IGA) on National Drought Programme Reform with state and territory governments to create a focal point for government support that aids farmers preparation for droughts and to manage their business risks proactively (Commonwealth of Australia 2015).

An example of adaptation activities already underway for improving agricultural water use efficiencies is the funding the Australian government has been making available to irrigation cooperatives and groups allocating funding of $917 million for the modernisation of irrigation systems (www.agriculture.gov.au). While there is limited data relating to farm structures in NSW, future considerations should be given to the number of existing or emerging corporate farming systems. The Australian Bureau of Agriculture and Resource Economics and Sciences (ABARES) is currently undertaking research into the structure of farms in Australia which will examine issues relating to changes in farming ownership arrangements, integration of farms into larger businesses, etc. (http://www.agriculture.gov.au/abares/research-topics/surveys/structure-of-farms).

This information will be important for NRAR as monitoring small family farm compliance will be different than that undertaken for corporate sized farms. It is also conceivable that corporate farming businesses will be better placed to take up irrigation initiatives than small, family based farms.

Other adaptation options also being considered include changing or diversifying crop practices (GRDC 2019) to supply more products for biofuels and/or biotechnology (Hajkowicz et al. 2012) as well as new opportunities for farms for carbon pricing, particularly those farms more impacted by climate change. Also farms with reduced availability of irrigation water sources have the opportunity to become financially viable by receiving carbon offset funding from other industries to sequester carbon through long term crops (e.g., tree cultivations) or other new technologies for entraining carbon back into the soil which does not require the intensive irrigation requirements of traditional crops (Bryan et al. 2015). It would be important for regulatory agencies such as NRAR to be aware of these developing adaptation agendas and innovations as they can assist understanding how irrigation practices are evolving and may prevent or reduce any intended or inadvertent unacceptable behaviours by irrigators (e.g., inappropriate water storage).

There will be other broader adaptation methods that have strong potential to influence agricultural farming practices in the next decades including increasing automation, use of robots, sensors and analysis of big data (Hajkowicz et al. 2012). These are discussed in detail in the **Water Technologies** and **Data Management and Analysis** Uncertainties sections.

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Uncertainty #4: **Water Technologies**

Key Findings

1. Technology advances are frequently market driven and therefore the timing and cost of these technologies are difficult to predict, however, both urban and rural water are large markets and, as such, it can be expected that there will be emerging technologies that will have a significant influence on reducing water use while improving sustainable practices.

2. Urban water use will decrease through improvements in sustainable housing and improved water management, including increased use of smart meters. Improvements in treating water will have a major influence on urban water systems, increasing the potential for a circular water economy based on the recycling of wastewater and the harvesting of urban stormwater. Subsequent reductions in the extraction of water for urban demands will provide more water for other users and reduce compliance monitoring requirements by regulators such as NRAR.

3. A surge in the uptake of automation and sensors within the agricultural sector has accompanied a sharp decline in employment in this sector. A possible reason for this apparent linkage is that automation and sensors can reduce labour costs and improve production efficiencies for farmers. Increased use of automation and sensors could either reduce water demand through improvements in efficient water use, or conversely increase water use by enabling larger areas to be cropped with reduced labour.

4. Agricultural industries will also benefit significantly from advances in automation, robotics, real-time sensors and information technology that assist with the timely, precise application of water and fertilisers to maximise yields within set water allocation levels.

5. The use of real-time sensors and smart meters will be of significant value and benefit for regulators such as NRAR by directly providing information on water extraction and use, at distance in real time. This can enable NRAR to monitor and detect any non-compliance events quickly and enable enforcement remediation activities to be undertaken in a timely, transparent manner.

6. The current requirements for irrigators to install smart meters is already demonstrating the benefits of real-time data access and is also influencing the market in smart meters with a range of improvements in meter design already reaching the market.

Human-based systems are becoming increasingly controlled by a range of technologies that are making work processes, transport, health, communications and lifestyles fundamentally different from what was experienced in previous generations (CSIRO 2019). The advancement of many of these technologies are happening at an ever-increasing rate, driven, in part by ever-increasing computational capability. We are in what is colloquially termed the “digital revolution” or the “4th industrial revolution”. Over the next few decades, cities, towns, industries, farms, and even at least parts of the environment will be transformed by new innovative technologies. Many new technologies will unlock massive streams of data about the system they are controlling, monitoring or working in as well as how they are influencing other parts of the local controlled or natural environment. As these data streams are brought together and analysed (see the **Data Management and Analysis** Uncertainty) they have the potential to provide means to improve local conditions.

More and more devices will become connected via the internet becoming part of the ‘Internet of Things’. The ‘Internet of Things’ is where all devices will be connected to the internet, and/or to each other (CSIRO 2017) (Figure 13). The result of this increased connectivity is the potential to change the way governments function, industries operate, and people work and live. For example, government regulations could be controlled through industry demonstrating on-going compliance through connections of smart sensors monitoring a company’s operations, rather than seeking initial approvals (“red tape”). This could save a company time and money waiting to get initial approval or licence and thus, enable them to more easily take up and use new innovations that improve their performance and/or products. Government agencies would gain from this by being able to monitor the actual performance of a company against set performance criteria (e.g., water use, discharge qualities, etc.) in real-time, thus having a greater assurance that essential requirements are being met, while also being able to reduce initial, time-consuming approval processes. This has the additional benefit of creating greater transparency relating to how improved and more efficient uses of resources and networks become (Morgan, 2017). There is the potential risk, however; that an increased reliance on computer generated data to monitor compliance could lead to incidences of fraudulent activities where computer data is used to hide illegal water extraction and uses (as has been observed in other industries such as finance).

This will necessitate agencies such as NRAR to have highly computer literate staff who are skilled in the detection of any fraudulent activity. The increased use of blockchain technology as described in the **Data Management and Analysis** Uncertainty has the potential to reduce the opportunities for data fraud.

As has been described above in the **Social Attitudes** Uncertainty, NRAR may have little influence on, or drive the development of many new water technologies. Many new technologies that are developed for the water industry, however, could have a beneficial impact on NRAR's regulatory environment through the ability to reduce water use, or to improve use and compliance monitoring.

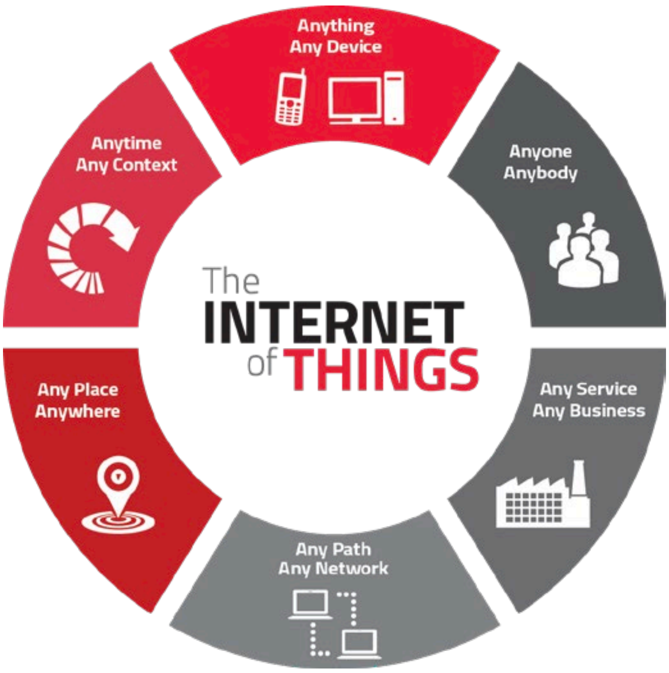

Figure 13. The 'Internet of Things'

Source: http://www.manhattansoftware.us/resources-emea/blog/133-technology/338-top-10-reasons-iwms-2015-4.html

Due to the scale of the markets, urban water systems attract continual improvements in technology. Rural water systems can also benefit from improvements in technology, however, in comparison to urban water systems the scale and uptake of water technologies in rural areas can be greatly influenced by the ability to pay for new technology and/or deal with changes in the regulatory environment. Other issues to be considered that are less of an issue in urban environments which will be experienced by rural users are environmental extremes, remote locations making servicing and repairs difficult, and ensuring reliable power and internet connection services.

Identifying new technologies can be difficult as some take a long time to get to market while others can emerge and have an influence in a much shorter time-period. The rate of uptake and influence can be driven by need (for example responding and adapting to severe drought conditions) or through changes in regulatory requirements (e.g., the use of smart meters). In addition, predicting the ultimate impact of a new technology can be difficult as there are often unforeseen issues that can impact on the influence of new technologies. For example, during the millennium drought, State Governments provided incentives for households in urban areas to install rainwater tanks to reduce demands on potable water supplies, however, subsequent analyses demonstrated that unless tanks were plumbed directly into houses, their influence on overall potable water demand was limited (Beal et al. 2011). This section will instead, highlight several examples of new developing technologies that can provide an understanding of how new technologies could influence water systems in both urban and rural water environments. Developments in data handling and management are covered in Uncertainty #6.

Urban

There are many emerging urban water technologies. A number of these technologies are designed to reduce the costs of treating or delivering water but also can either have an intended, or additional influence on water demand management. Below are three examples of new technologies that are either reaching the market or have significant potential to have an extensive impact on urban water systems if successfully able to be brought to market. To cover the broad scope of urban water technologies, one example is associated with water monitoring software, a second example is on a novel water treatment membrane, and the third is based on advances in low-cost, real-time sensors to monitor water quality.

AdaptWater™

A number of water utilities have partnered together along with a consultancy firm (Climate Risk Pty Ltd), the Water Services Association of Australia, and the Australian Government, to develop a tool (AdaptWater™) that can be used to determine the risk to and adaptation requirements for water utility assets from the impacts of climate change and extreme weather events as well as subsequent impacts on reliant communities (Commonwealth of Australia 2015). AdaptWater™ can be used to fully assess dependencies between water, energy and telecommunication assets to better understand the complete risk profile to a range of plausible impacts (e.g., bushfires causing power failures and resulting loss of telecommunications causing loss of control of remote water assets), rather than just the physical risk to the asset alone.

GraphAir

The treatment of water to produce high-quality water supplies has become increasingly reliant on membrane filtration to remove contaminants and impurities from water. This can overcome many of the uncertainties associated with the performance of traditional water treatment methods. The operation of these membranes, however, can be costly and energy intensive, making processes such as desalination less optimal as a potable water supply mechanism. The use of reverse osmosis membranes in desalination and the production of potable quality recycled water loses a large percentage of the water during filtration and relies on extensive chemical use for regular membrane cleaning. CSIRO has been developing the GraphAir membrane which are a novel form of graphene membrane that is permeable to water vapour, a trait not common for graphene filters which are naturally hydrophobic and have pore sizes too small to allow the passage of water vapour. Testing at the laboratory scale has demonstrated that the GraphAir membrane has been able to be used in membrane distillation processes to produce potable quality water from seawater (Seo et al. 2018). Further studies have shown that the GraphAir membrane is also more efficient and resistant to fouling and temperature gradient issues. Successful upsizing of the GraphAir membranes would allow them to be a significant part of an urban treatment system designed to produce recycled potable water with treatment and cleaning costs significantly less than is required for treatment systems such as dual membrane systems. This could be a major advance in achieving a closed urban water system which can take water from a range of contaminated sources to provide high quality water. This technology has the potential to be useable over a scale of a single household to entire suburbs and towns. It has the potential to decentralise water treatment systems which can then aid urban centres to achieve a significant reduction in reliance on water from the environment. Thus, for regulatory agencies such as NRAR, it provides the opportunity to have less oversight requirements on urban areas as there will be significant reductions in the amount of water needed to be extracted from the environment. This will enable regulators to put more valuable effort into other areas requiring attention.

Water Quality Sensors

To reach a more water resilient future, water will increasingly come from a range of water sources, including; rainwater, surface-, and storm-water, groundwater and recycled water. CSIRO has developed low-cost real-time water quality sensors to assist water utilities in managing potential health risks related to the intrusion of recycled water or contaminated water into drinking water. The technology uses complementary measurements of electrochemical and fluorescence to detect changes in water mixture based on both salt levels and biological components. Trials have been run at two water recycling facilities, demonstrating that the sensors can detect down to 1% intrusion of recycled water into drinking water. The system has been shown to work calibration free for periods of up to 6 months. The potential success of broad uptake of such sensors could engender an increased trust by urban communities and individual residents that water delivered to drinking taps is of the highest quality. This would facilitate a range of water sources and water qualities to be safely distributed and used around water-sensitive cities, de-risking recycled water infrastructure investment. At present this technology is more applied to water treatment and supply. There is potential, however, for these sensors to assist regulators such as NRAR to better monitor the source of water based on chemical signatures (e.g., using persistent contaminants such as artificial sweeteners or naturally occurring fluvic and humic acids as robust markers and tracers).

Rural

Sensors and automation

Globally, the proportion of people employed in the agriculture sector has fallen sharply over recent decades, and in Australia, it has fallen from around 8% of all jobs in the 1970s to less than 3% today (The World Bank 2018a, The World Bank 2018b). This has been accompanied in recent years by a surge in automation and the use of sensors. Together, these technologies help reduce labour costs, increase production efficiency, reduce waste and optimise resource use.

Increasing availability and use of sensor technology and smart meters will enable irrigators to become significantly more efficient in farming practices, including irrigation. Sensors will be able to measure soil moisture and nutrient conditions in real time, which will enable farmers to apply water and fertilisers in a targeted manner helping to reduce costs and maximise yields (Hajkowicz et al. 2012). The sharing of this data with the relevant authorities can help farmers with ensuring that they have adequate water supplies and that these allocations are best fitted under different availabilities of water, particularly in times of stress.

While such sensors have the potential to assist irrigators more precisely manage their farms water needs, the same sensors can assist water regulators such as NRAR by directly providing information on water extraction and use, at distance, in real-time. This can be combined with other on-farm sensors to also provide information on how the extracted water is being used, thus reducing the potential for unnecessary use or storage of excess water. Such real-time monitoring would provide regulators with levels of assessment that are currently not available.

Some water users could be reluctant, at least initially to share data on water use as it could be seen as a higher level of government intrusion into their activities. If approached appropriately, however, the sharing of data can also foster a closer relationship with farmers as the information produced can provide regulators with a greater understanding of a farms water needs. While it is not the role of NRAR to decide water volume allocations, when shared with, and between agencies it can provide a level of partnership between government and farmers that can be of benefit to everyone.

Automation combined with sensors will further improve efficiencies in agriculture (Hajkowicz et al. 2012). Robots do not necessarily need to be mere ways to reduce human labour, instead, robots can be used for routine work such as detecting whether orchards are ready for picking (Hajkowicz and Dawson 2018). Investment in agricultural technology has surged in recent years and is expected to continue growing to become increasingly competitive globally (National Farmers Federation 2018). A current working example is the BoniRob agricultural robot developed by Bosch (http://www.agriexpo.online/prod/bosch-deepfield-robotics/product-168586-1199.html). BoniRob is designed to undertake a wide range of on-farm applications and activities including as weed control, soil tillage, seeding and spraying. Such robots could conceivably be given modules to monitor plant growth in different sectors of a farm, monitor soil moisture and irrigate at a localised level, thus reducing water loss through evaporation, or over or under irrigating depending on conditions at that time, etc.

One of the most recent uptake of new sensor technology is the NSW Government enacting a requirement for the use of Smart meters for licensees extracting non-urban water (NSW Department of Industry 2018a). These meters are required to comply with set telemetry and data logging specifications. It has been noted that not all the approved meters may be suitable under all situations and needs, and that achieving and managing telemetry requirements may be difficult in certain regions (NSW Government 2018). It is likely that these issues, along with potential unforeseen issues with the existing approved sensors will drive the development of newer, improved smart meters that assist not only NRAR but also the irrigators. Current evidence of market response to the demand for smart meters is already providing cheaper meters with improved low cost telemetry are already becoming available. As such it can be expected that smart meter technology will increasingly provide improved capability that reduce costs for both farmers and government agencies.

It will be expected that there will also be an increased availability of water-based systems that integrate with other farm components to manage water availability and efficient extraction and irrigation use. An early example of this technology field is the SenseT process which uses real-time water monitoring with sensors (stream flow and soil water) combined with weather and rainfall forecasts to reduce impacts of water extraction during dry periods and to avoid triggering of a “cease-to-take’ ruling by regulators (Smethurst et al 2015). Such systems can also assist communities to manage water quantity and quality during low-flow periods (Ellison et al. 2019).

YieldProfit®

YieldProfit® is a software package that assists farmers with running their farms (YieldProfit®, https://yieldprophet.com.au/yp/Home.aspx). YieldProfit® is an internet-based crop model that provides grain growers with information about their crops on a real-time basis. The outputs of the program can assist crop management and input decisions by producing crop simulations that combine the essential components for crop cultivation including characterising and testing of soils; historical and current local climate data; details on the crop(s) to be planted; and recommended fertiliser and irrigation applications during the growing season.

Changing of Crop types

One of the ways agriculture could adapt to climate change is to change the types of crops produced. One change could be through the production of feedstock for biotechnology. Biotechnology is booming with Australia ranked in the top five countries for biotechnology for three years running (Worldview, 2016, Nogrady, 2018), supported by a run of international sales and licensing deals by multinational pharmaceutical companies. In recent years the sector has benefited from substantial government funding and tax breaks for companies investing in R&D (State of Queensland, 2016). Biotechnology has the future potential to produce new pharmaceuticals and other drugs, plastics, food stuff along with many other items. Biotechnology will require significant quantities of basic supplies such as sugar as the feedstock for the yeasts and other microorganisms used to produce the new products. There could scope in some regions for farmers to transition from traditional crops to feedstocks that are more suitable to grow in the changing local climate. Alternatively, biotechnology has the potential to produce genetic variants of existing crops that can cope with the local changes to the climate, for example, increased heat tolerance or low water requirements, greater salt tolerance enabling the use of brackish groundwater as an irrigation source, or increased uptake of CO_2 which increases growth rates and crop yields etc.

Finally, there is the potential that some farms in areas could convert to carbon farming. The farms would gain funds by undertaking activities that sequester carbon, either directly into the soil or through long term tree cultivation.

NAWRA-Explorer

Recent research by CSIRO under the broad Sustainable Yields Program has shown how improved spatial mapping and hydrological modelling of entire catchments can provide new insights into the capacity of rivers, catchment and basins under different climatic conditions and hydrologic conditions. Such improved information can be shared between regulators and irrigators to best understand what are the more appropriate extraction volumes available at any particular time across an entire catchment.

While a number of large catchments and basins across Australia have now been studied to gain improved insights as part of the Sustainable Yields initiative, the most recent studied catchment as part of the Northern Australia Water Resource Assessment has enabled the production of a web-based product (NAWRA-Explorer) that provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water and agricultural development in three priority regions (https://nawra-explorer.csiro.au/). The NAWRA initiative also provides the **R-Shiny River Models** as an App that enables users to explore the reliability at which water can be pumped/diverted (i.e. water harvesting) or captured and released by large instream dams in different parts of each catchment, and how these extractions may impact river flows downstream. The R-Shiny River Model is accessible at https://www.csiro.au/en/Research/Major-initiatives/Northern-Australia/Current-work/NAWRA/Web-based-applications. These recent developments could be used other regions, for example, refining the Murray-Darling Basin sustainable yields information (or developed for any other NSW catchment or groundwater source) into a similar web-based package that could be used by anyone who downloads the App. The benefit to a regulator such as NRAR is it provides users with an improved understanding of the current conditions and limits of a river system across the entire catchment, not just in the local area. This has the potential to improve dialogues between government and farming communities and for irrigators to gain better understanding of the needs of water users across their entire region.

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Uncertainty #5: **Environmental Requirements**

Key Findings

1. Impacts to rivers and waterways are being caused by a combination of the naturally variable climate (with an increasingly strong influence from climate change) and extraction of water for human-based activities. Monitoring of compliance for water extractions will therefore remain vital to ensure there is a fair distribution of water between irrigators, rural communities and the environment.
2. The ecological condition of the rivers in the Murray-Darling Basin have been declining for some time with impacts on a range of flora and fauna in the basin, both in-stream and those reliant on river water (Table 3). This has been driven by overexploitation of water in the river system which has not only reduced water flows but increased salinity and acidity levels, as well as affecting soil structure that has resulted in the movement of large amounts of sediment and nutrients in to waterways.
3. Overfishing and removal of large volumes of floodplain timber resources has also compounded the ecological decline of the Murray-Darling riverine system.
4. Ecological studies have highlighted the importance of regular flooding for the lifecycle of many native flora and fauna. Where water has been reallocated back to ecological icon sites within the Murray-Darling Basin, significant improvements in the health of those sites have been recorded.
5. There are many rivers and groundwater systems that are often interconnected, both within the Murray-Darling Basin and elsewhere in NSW. A combination of continued human use and the influence of climate change will have a detrimental impact on these groundwater-surface water dependent ecosystems through reduced water flows into rivers and lakes, and rising sea levels increasing the salinity of groundwater.
6. It is easier to gain support for providing water for the environment during periods of drought and at times when there are low water levels in rivers. Recent studies have shown that it will be more difficult to do so when there is more water flowing in the rivers during wetter periods (McGowan 2017). A continual dialogue with local communities is needed even when water levels are not at extreme low levels to provide a level of bipartisanship and transparency around decisions made to provide equity between human-based needs and adequate provision for the environment. Such dialogues can assist will help garner support for balancing completing needs in times of low water availability.
7. Economic assessment of environmental values has shown that improving ecological systems can add millions of dollars in value to regional areas through increased ecosystems services. This information, if explained and discussed appropriately could assist in engendering good compliance behaviour within local communities.

The Australian community is increasingly expecting that Australia's natural environment will be safeguarded, and where there is evidence of detrimental impact, that the environment will be remediated. Lakes, rivers, aquifers and associated water waters are highly visible and treasured environmental assets. Groundwater systems, often just as overexploited and impacted, are less visible, however, the impacts to groundwater systems can be indirectly observed through the loss of water to groundwater-dependent ecosystems, or the impact of discharge of saline groundwater into river systems.

There is the trade-off for Australia's waterways in that they provide essential input into many economic assets for local communities and industry. The balancing required between the need to extract water for economic uses and maintaining water in the waterways for essential environmental processes is a difficult one which will become even more problematic in a future impacted by climate change. Water levels dropping below that which can support essential ecological requirements can cause highly visible detrimental impacts such as the 2018-2019 fish deaths in the Lower Darling River (Vertessy et al. 2019). An awareness is also needed that as well as important for ecological functions, a healthy river system with sufficient water that can support ecosystem services that is important for indigenous spiritual connections to country, land and waterways, tourism and recreational benefits (McGowan 2017, CSIRO 2012)

Most Australian environments are complex natural systems which have evolved to deal with the naturally variable climate, however, human intervention since European settlement has considerably changed the dynamics of many local environments (CSIRO 2011). There are many aquatic environments in NSW from coastal rivers and lakes through to the large, multi-faceted Murray-Darling Basin. All these systems have different inputs ranging from snow melt, through to localised catchments from local mountains and hills. Water flowing through these systems may provide ecological services for just local environments and communities or may be part of a much larger system flowing through a much broader landscape. All of these riverine and aquatic systems need to deal with the natural climate variability while supplying water to local communities, a balancing act that will only become more problematic as climate change begins to have an influence post-2030.

Like other regions of Australia, NSW has many different ecosystems that rely on water from a variety of inputs. Some of these are coastal environments towards the end of river systems which are becoming increasingly at risk of sea water intrusion due to less water flowing in the rivers, or more inland in the rangelands and central slopes which can rely on water that has flow 100's of kilometres through inland water systems. Due to the wide variety of aquatic systems in NSW with varying ecological needs and local communities reliant on water from these systems it is beyond the scope of this horizon scan to consider all impacted ecosystems, therefore, this Uncertainty will focus predominantly on the Murray-Darling system as an example due to the complexities and high visibility of this system and its problems. It could be expected that most other aquatic systems under the remit of NRAR would have similar issues, at least to some degree.

The Murray-Darling Basin is a complex system that with the introduction of irrigation has become a 'wicked' problem (Williams 2017). Water has been continually extracted from the Murray Darling river systems since irrigated farming commenced, however the amount of water extracted has increased considerably since the 1940s to the extent that now there are licences to extract more water from the Murray-Darling Basin than there is physically present in the Basin. This means that the available water in the rivers continues to be heavily used leaving only a relatively small amount of water to service the ecological and hydrological functions of the river and groundwater system upon which the rivers depend to remain healthy (Williams 2017).

The overexploitation of the river system has altered the flow rates of water in the rivers resulting in rising salinity and acidity, loss of soil structure, increased loads of nutrients and sediments into the rivers, and large-scale degradation of the broader rangelands environment (Williams 2017). The removal of so much water from the rivers has reversed groundwater flows into many parts of several rivers with highly saline groundwater discharging into rivers, impacting on the life cycle of many plants and animals (CSIRO 2012). The 2016 Australian State of the Environment Land report (Metcalfe and Bui 2017) indicated that soil conditions in much of the Murray-Darling Basin continues to remain in poor condition from increasing soil acidity, salinity and from erosion. This has had a corresponding impact on water quality within the different rivers of the Murray-Darling Basin with a study released in 2012 indicating that the majority of the rivers were in a poor to very poor condition with only one river considered to be in good condition in the study time period (Table 3). The condition of the rivers has failed to improve in subsequent studies (CSIRO 2012). This is not only detrimental to the local environments but also to the health and wellbeing of local communities and their long-term sustainability (Marsden Jacob Associates et al. 2010).

A study on the ecology of the Murray-Darling system and the benefits of returning water for ecological purposes (CSIRO 2012) noted that the health and condition of water-dependent ecosystems in the Basin have been declining from a long time caused by water resource development (irrigation) and overallocation. They also observed that the overharvesting of fisheries and floodplain timber resources have also compounded on the ecological decline of the Murray-Darling riverine system. Frequent flooding of the rivers in the Murray-Darling system has been found to be important for the health of the river and animals in the river. A reduction of flooding impacts on many animals including waterbird breeding, the lignum shrubland and river red gum forest and woodland vegetation communities (CSIRO 2012). Changes to in-channel flows can affect animals such as main channel generalist and specialist fish groups.

Table 3. Summary of regional ecological status and trends in the Murray-Darling Basin based on long-term published data sets and comparison with the Sustainable Rivers Audit Ecosystem Health Rating. (Copied from CSIRO 2012)

Basin Plan region*	Sustainable Rivers Audit ecosystem health rating	Fish	Birds	Vegetation	Wetland area
Border Rivers	**Moderate**		↔		
Campaspe	**Very poor**	↔			
Condamine–Balonne	**Moderate**			↔	
Goulburn–Broken	**Very poor**	↑↔	↘	↘	
Gwydir	**Poor**		↓	↔↘	↘
Lachlan	**Very poor**		↘	↘	
Lower Darling	**Poor**	↔ ↘↓	↔		
Macquarie–Castlereagh	**Very poor**		↔↘	↘	↘
Murray	**Poor**	↔↘	↔↘	↔↘	
Murrumbidgee	**Very poor**	↔↘↓	↘	↘	↘
Namoi	**Poor**			↔	
Ovens	**Poor**			↘	
Paroo	**Good**		↔↘	↘	
Whole-of-Basin	**Na**	↘	↘		

* No datasets were found for Barwon–Darling, Eastern Mount Lofty Ranges, Loddon, Moonie, Warrego and Wimmera–Avoca regions

Status: = No status data available; = Declining, Poor; = Heavily depleted, Very poor. The spatial scale of original studies varies and status may refer to a site or sites within the region or the whole of the region. See Appendix B for details of each study.

Trend: ↑ = Improved; ↔ = Fluctuating, stable; ↘ = Monotonic decrease; ↓ = Step change decrease. Multiple trend symbols in a cell indicate that a range of trends are reported in the studies for that region. See Appendix B for details.

Blank cells indicate that no published studies are available for that region.

na – not applicable

A reduction in water flows also impacts on fish movement through the river system, and the ability of fish species to escape from drying regions of the rivers during low flow periods (Creswell et al. 2017). Human intervention in the form of weirs and dams has further impeded fish migration causing them to be trapped above or below these weirs (CSIRO 2012). This influence has been highlighted by the recent fish kills in the Menindee Lakes. The investigation in the fish deaths determined that there was a higher risk of fish deaths during droughts in the lower Darling River than previously considered due to limitations in current river models and resulting planned water sharing. This was considered to be a particular issue over the longer term (Vertessy et al. 2019). The investigating committee expressed an expectation that these fish deaths will impact native fish populations in the Lower Darling River for many years. They observed that to minimise the potential for such an event to occur again, and to protect the native fish populations and other resident biota, the impact of an increasing frequency of low inflow sequences in the northern Basin will need to be dealt with. The panel concluded that irrigators ability to access water during and immediately after low flow periods has been enhanced due to changes to the Barwon–Darling water access arrangements. This has been further complicated by the River Models used to develop water sharing arrangements have been obserfved to overestimate streamflows during dry sequences, and thus result in an underestimation of the impacts of extractions during dry times (Vertessy et al., 2019).

While not as high profile, or perhaps as complex, there are many other rivers and aquatic system in NSW that require continual monitoring and regulation. Water is drawn from many rivers, lakes and groundwater systems for human needs, often at numerous locations distributed along these systems.

Due to their relative size, many of these smaller waterways and catchments may be even more sensitive to changes in rainfall or extraction levels.

Impacts on groundwater through over-extraction can be even less visible than for rivers and waterways. Over-extraction of groundwater can occur slowly over years or decades with limited visibility until bores run dry or groundwater-fed ecosystems such as wetlands, lakes or rivers become impacted. There are examples of groundwater dependent ecosystems that can be suffer water losses, even if these above ground systems do not directly have the water extracted from them (Barron et al. 2010). Climate change will further impact these groundwater-surface water aquatic environments through reduced water flows, increased evaporation and heat stress, rising sea levels causing saltwater intrusion in coastal environments and reduced water flow into rivers and lakes significantly impacting on the lifecycle and wellbeing of many animal and plant species (NSW Department of Industry 2018b). This combined with human inputs such as sewage discharge, contamination of urban stormwater and inadvertent pollution from sediments and nutrients flowing into waterways will continue to stress these systems.

To be effective, there needs to be sufficient water in rivers and waterways in times of low water availability. Studies at ecological icon sites in the Murray-Darling Basin have shown that sites with targeted environmental works to deliver environmental water over successive years are performing better against their ecological objectives than sites that are yet to be included in such interventions (Murray-Darling Basin 2018b). This can have an adverse impact of bringing the needs of the environment into direct competition with the needs of irrigators. An improved understanding of the water level limits and/or the time between significant inundations or flooding an ecosystem can cope with will become increasingly important for regulators such as NRAR. Being able to demonstrate the impacts from extractions when local ecosystem becomes untenable enables a defensible reason for ensuring that set extraction limits are maintained.

To reduce competing demands, the Federal and State governments are investing heavily in programs to improve water efficiencies on farms by promoting better irrigation practices, better management of private irrigation networks, modernisation of on-farm infrastructure, and ensuring that such improvements occur along the length of river basins (Australian Government Department of Agriculture and Water Resources, 2018). Faced with low flow rates in the northern Basin, an intergovernmental panel has recommended a range of interim measures to better manage environmental water in the Murray-Darling river system which includes amending shared water plans, protection of held environmental water, managed resumption of flows after cease-to-flow events, and supporting legislative changes (NSW Department of Industry, 2018b). A major function of the Murray-Darling Basin Plan is to ensure that there is a balance between the needs of irrigators and the environment. NRAR has an important role in managing this balance through the monitoring of compliance to extraction licenses and enforcing any non-compliance behaviours.

Similar to NRAR's role in supporting regulations overseeing water access to support the Murray-Darling Basin Plan, NRAR has responsibility for regulating all controlled in-stream activities and on waterfront land and riparian zones (NSW Department of Industry 2018c). Cresswell et al. (2017) have noted that it is important to consider complementary issues relating to human water use aside from water-flow based ecological requirements. Issues that involve ecologically-beneficial nonflow-based interventions, such as infrastructure works to provide fish passage and/or mitigate downstream effects of cold water releases from storages, in- stream snagging to provide fish habitat, restoration of riparian vegetation and removing barriers to floodplain connectivity. With an increasingly variable climate and impacts from climate change, these additional non-stream-flow considerations will take an even greater relevance for protecting susceptible ecosystems.

While the Murray-Darling Basin covers a large proportion of NSW, there are other rivers and waterways that will need increasing attention as climate change takes effect. The NSW Government has also commenced the implementation of programs set up to protect the environmental value of river systems across NSW (Table 4). The outcomes of these programs cover issues such as water sharing rules, licences and purchasing of water, infrastructure investment for delivering water for the environment, improving partnerships with landholders, and increased research and monitoring (NSW Department of Industry 2019).

There is an increasingly recognised economic value for maintaining a healthy riverine ecosystem. This is known as ecosystem services. Ecosystem services are the aspects of ecosystems that contribute to both natural and human wellbeing. Because ecosystem services can provide both direct and indirect benefits, they have a value that can be measured in monetary and non-monetary terms. Ecosystem services therefore provide the link between the environment and the economy. A healthy and functioning environment can have positive economic benefits to society through the enhanced supply of ecosystem services. This will continue to be an important consideration of any risk management approach used by NRAR as part of its compliance enforcement activities. A loss of water to the environment is not just some esoteric impact. While the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) has estimated that the costs of recovering 2800 GL/year of water for the environment to be an annual AU$542 million reduction in the gross value of irrigated agricultural production across the Basin, in the long term it has been also shown that there are a number of expected benefits of recovering this 2800 GL/year of water for the environment. It has been estimated that under the Sustainable Diversion limits, with water held back to protect the environmental system of the Murray-Darling Basin, the additional Basin-wide value of enhanced habitat ecosystem services – arising from floodplain vegetation, waterbird breeding, native fish and the Coorong, Lower Lakes, and Murray Mouth – will be worth between AU$3 billion and AU$8 billion compared to the baseline where no additional water is reallocated to the environment (CSIRO 2012).

The success of improving the environment of river systems usually requires a cooperative partnership between government and the communities in impacted regions. The nature of this cooperation will vary from region to region. Research in the Murray-Darling Basin has noted that farmers and communities of the Basin are not homogenous, and that policy prescriptions in one region may not suit other areas. Similarly, irrigators and communities in other areas across the breadth of NSW will respond to any changes to access to water depending on a range of experiences (both historical and current) and knowledge and beliefs (Marsden Jacob Associates et al. 2010). It cannot be automatically assumed that farmers and communities in rural regions will automatically respond to a step-change of access to water in purely rational and marginal ways, particularly in those times of climate variability when water is more available. McGowan (2017) recorded that there was stress amongst some farmers who found it hard to reconcile that their water extraction rights remained limited even though there was “substantial water flowing down the river”. This is a social impact/issue that NRAR as a regulator needs to manage. Social research into trust on water related issues has shown that developing a long term relationship and dialogue on long term planning and values will be of benefit in setting a mutually acceptable position (Nancarrow et al. 2007). This needs to be considered an important activity not just for the wellbeing of farmers and irrigators , but also for NRAR staff and other water officials.

Table 4. Examples of recent programs implemented by the Australian and NSW Governments to improve rivers and waterways in NSW

PROGRAM	REFERENCE
NSW RiverBank	NSW Office of Environment & Heritage (2019)
Pipeline NSW	NSW Office of Water (2013)
Rivers Environmental Restoration Program	NSW Office of Environment & Heritage (2019)
NSW Wetland Recovery Program	NSW Office of Environment & Heritage (2019)
Living Murray initiative	Murray-Darling Basin Authority (2019a)
Hawkesbury–Nepean River Recovery Program	NSW Department of Primary Industries (2013)
Environmental Works and Measures Feasibility Program	Australian Government, Department of Agriculture (2017)

Saving water for the environment is a necessary part of the long-term health of rivers and waterways, and thus the health, wellbeing and continuing economic viability of many rural industries and communities. There will continue to be trade-offs and a balance needed between the requirements of the environment and the needs of communities and industries (both rural and urban). Agencies such as NRAR who carry responsibility for ensuring compliance for regulations relating to access to water resources, in part to protect environmental systems, will need to develop continual regional consultation and ground-truthing as part of this regulatory purposes. All the studies undertaken through the Murray-Darling Basin Authority, State and Local government and the Federal Government have shown the importance of maintaining healthy rivers and waterways, not only for ecological purposes but for economic and community wellbeing. It will continue to be important to bring the community along with this "*journey*" to promote understanding for decisions made and to ensure the broadest support possible, particularly under a continually changing climate. It remains vital that the information and outputs from these studies are not only considered and enacted upon, but are incorporated into the roles and activities of agencies such as NRAR as an on-going, common-placed set of activities and functions.

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Uncertainty #6: **Data Management and Analysis**

Key Findings

1. The ability to manage and analyse Big Data from a series of different, disparate sources has the potential to provide better ways to manage important resources such as water, both for water users and regulators.

2. The Australian Bureau of Statistics and the Bureau of Meteorology are already developing methods and tools to analyse large data sets from a range of disparate sources and stakeholders. Both these agencies already collaborate with a range of partners in the development of these new methods and tools. Further broadening of these partnerships will inevitably bring benefits across all levels of government.

3. Combining the application of sensor technology providing real-time data, information from smart meters and data from a range of other sources including satellite images, social and financial data from the ABS, as well as climate projections from BoM will enable NRAR to produce more accurate and transparent regulatory decisions in a timely manner.

4. The use of innovations such blockchain technology can assist NRAR in ensuring compliance with water extraction limits over a range of timeframes through the ability to track a range of transactions involving water extraction, amounts of commodities produced and sold, and any water market interactions (Figure 15).

5. The ability to analyse large data sets and any associated distributed ledgers can also help monitor for, and reduce opportunities for fraudulent activities relating to water extraction, use and the water market.

The increasing data management and analysis capabilities that are becoming available to governments and businesses will have the potential to create major changes in the way data is stored, analysed, used and valued. The ability to analyse big volumes of data from a range of potentially disparate sources (Big Data) holds hold significant potential to provide new avenues for monitoring and providing insights into interconnected subjects, that previous methods such as economic forecast tools, built upon theories of supply and demand, have failed to achieve a result (Hajkowicz, S. 2015). Examples of large data sets already being analysed by groups of data users include statistical data between the Australian Bureau of Statistics and the Department of Agriculture (Australian Bureau of Statistic 2016, 2019), analysis and modelling of climate change by CSIRO and the Bureau of Meteorology (CSIRO and Bureau of Meteorology 2015), analysis of spatial data from satellite imaging and GIS mapping, monitoring statistical files on commodity production, social and community structures, and in managing government regulations.

Machine learning, and artificial intelligence is already being used to work through data sets and on ways communities communicate (think Facebook and Google) and hold the promise to enable governments and businesses to make much more use of data than at present. Combined with real-time sensors and other data collection processes, this can speed up the processing of information and provide improved ways to do business and manage regulatory systems.

For governments, the E-government services concept will become increasingly more important as community members increase the expectation on quick, convenient access to government services via electronic means while at the same time governments department strive to reduce costs without impacting on the quality of services. In addition, data management and analysis also can provide new and innovative ways to set regulations such as water extraction licenses under a more flexible process which can also improve monitoring and enforcement processes.

The control of water use has moved from mere issuing of licenses based on set points of water availability (and expecting end users to follow their part of these agreements and only use amounts allocated to them) to a more dynamic regulatory approach which can change the amount of water allocated for extraction, based on current needs of both users and the environment and be reflective of local conditions in different regions (i.e., varying extraction licenses during drought periods and times of plentiful water). To do so requires ready access to secure, high-quality data across the full breadth of catchments that can provide information that can be used to make accurate decisions in smaller regions of a catchment or basin. The National Climate Resilience and Adaption Strategy (Commonwealth of Australia 2015) has noted that entities such as the Bureau of Meteorology are already collecting high-quality data as part of their operation. The BOM provides information on the Australian water market as well as information on climate change, climate variability and on rainfall, groundwater, and streamflow. This information is frequently used by

BOM and many other government units and private businesses for planning and management decisions for both the urban and rural water sectors in Australia.

Advances in technology, data gathering services and data analysis will provide new ways to handle large volumes of data (commonly known as 'Big Data'). Big data can be characterised as extremely large data sets that, when analysed computationally can reveal patterns, trends, and associations that may otherwise be not visible (Hajkowicz et al. 2012, Hajkowicz, et al. 2016). In the instance of water systems, Big data sets could be a combination of historical and real-time water flows across a catchment/basin, water quantities and quality in specific locations, monitored water extraction and use, observed and predicted short- and long-term weather, and even modelled climate change potential. Farmers and authorities will have the potential to examine these large data sets from varied, disparate sources and glean vital facts and learnings on potential crop performance and production, optimum water and nutrient requirements, transport options and even social and community impacts based on crop and climate cycles. If analysed appropriately, this combination of data can greatly improve decision processes for timely modifications extraction limits etc and subsequent monitoring and regulation of the compliance to these short-term or long-term limits.

Analysis of Big data can be daunting based on the sheer volume of data. Advances in computational capability, advances in artificial intelligence and machine learning are already making significant changes to the way data is analysed and used (Hajkowicz et al. 2012). When used appropriately, such increased computational power will be able to provide new ways for entities such as NRAR to effectively regulate and control water extraction from waterways and aquifers. This will enable effective regulatory monitoring and appropriate enforcement resolutions to be undertaken in partnership with other government agencies and end users due to the ability to have an open and transparent decision-making process.

"A **blockchain** is both a database recording transactions between parties, and also a computational platform to execute small programs (called 'smart contracts') as transactions."

(Staples et al. 2017)

Some government agencies responsible for handling large volumes of data from a range of partners and stakeholders are already working on ways to better handle, sort and analyse these complex data sets. The Australian Bureau of Statistics for example is working on ways to handle and analyse big data to provide faster more timely output of sophisticated data sets. New methods under development through this initiative are already demonstrating that new insights can be obtained from improved analysis and visualisation of networks in Big Data (Chien and Mayer 2015).

Another major issue is the ablity to integrate data from a range of sources that use different data language etc. Agencies such as the Australian Bureau of Statistics and the Bureau of Meteorology have developed and are continuing to develop new ways to integrate and analyse different forms of data from a range of partners and stakeholders (Australian Bureau of Statistics 2019, Bureau of Meteorology 2013).

As government agencies such as the ABS and BoM continue to develop better ways to handle and analyse large, disparate data sources, there would be a benefit for these methodologies to become available for use across other federal and state government agencies such as NRAR that have need be able to handle large big data sets. This can be expedited if more agencies unite to work on data handling and analysis. BoM and ABS already partner with other agencies to analyse data important to each agency involved (Bureau of Meteorology 2013, Australian Bureau of Statistics 2019), therefore actions to broaden these partnerships will inevitably bring benefits across all governments. While detailed, publicly available information from the Bureau of Meteorology in relation to data sharing and analysis plans is limited, the Australian Bureau of Statistics provides more details on how it is engaging in a large-multi-agency program known as MADIP (Australian Bureau of Statistics 2019).

Data analysed through MADIP is retained within the ABS and partners for security purposes, however, examples are provided on tools that are being developed that provide new ways to explore large data sets to provide:

- insights into the design and evaluation of government policies;
- better measures of productivity analysis by deriving new aggregate measures;
- new information from existing data; and
- analysing data provided from multi-agency businesses to gain better insights into activities, inputs and outputs in branch offices by filtering out the unintentional head office bias reporting. (Australian Bureau of Statistics 2019)

The handling of very large data sets will also require new ways to store and distribute data sets of ever increasing size. The current trend is for the ever increasing bigger data sets to be stored in virtual locations such as cloud computing and storage. It has been predicted that the amount of data stored in the cloud will increase from 33 Zettabytes (ZB) in 2018 to 175 ZB by 2025 (Reinsel et al. 2018). Technical advances like cloud computing and storage also already started to enable increased flexible work arrangements amongst geographically diverse groups of workers by increasing their ability to collaborate and share files, data and information. Part of these new ways to work with other agencies and end users through the use of systems such as cloud storage and computing will be through the use of distributed ledgers and blockchain. Distributed ledger technology is a system that records transactions and all the subsequent details across multiple, often independent, locations at the same time. No one entity needs to own a specific distributed ledger, however, transactions by any individual or organisation that occurs under a specific ledger, or have links into a ledger are recorded in perpetuity. As a result, these ledgers can speed up the rate of transactions, all the while improving on security of data and transactional information. In addition, blockchains hold the promise to maintain a high level of accessibility, traceability and transparency of all transactions within that distributed ledger (Poenitzsch 2018, Staples et al. 2017). Examples of blockchain transactions already being employed include supporting services for payments, escrow, notarisation, voting, registration, and process coordination. Such activities are imperative to the operation of government and industry. An example of how this could be used in an agricultural economy is given in Figure 14.

1 Zettabyte is the equivalent of 1 trillion Gigabytes

From an initial list of candidate use cases, we selected three using the criteria listed previously. The selected use cases are:

1. SUPPLY CHAIN – in an agricultural supply chain, recording events from various participants in the neutral ground provided by a blockchain, in order to improve supply chain visibility and efficiency, and to track provenance.

2. REGISTRY – using blockchain to host government registries of open government data, for improved access to facilitate interoperation with registries of commercial data.

3. PAYMENTS – approaches for using blockchain to support improvements to efficiencies of international remittance payments.

Figure 14. Uses of Blockchains in Agriculture. (Staples et al. 2017)

An example of how blockchains could be of value to a government entity such as NRAR could be around quota management. For example, government-granted licenses, allocations, and provision of rights to physical resources could be awarded and tracked through tokens established on a blockchain. An example of such a blockchain model is provided in Figure 15. Another benefit to NRAR is that independent secondary markets could be linked to a blockchain to enable the further tracking of the value or result of the initial transactions. For example, where policy allowed, blockchains covering licenses for the extraction and use of water could be linked to blockchains covering the sale of farm produce, thus linking the use of water to the value and sale of commodities produced from that water. The linking of these different blockchains creates an ongoing immutable audit log of these rights and their use and a demonstration of the subsequently linked value of the produce. Not only would this provide greater linkages, transparent understanding of decisions made and the subsequent outcomes, but also provide valuable data for future planning and decisions on the regulation of water extraction under approved allocation licenses etc.

A concluding cautionary note that needs to be considered is that all the advances in digital technology have already created new forms of cybercrime. Criminal elements are increasingly using digital means as new ways of criminal activity on a scale and frequency never seen before (Cisco 2018). As discussed above in the **Water Technologies** Uncertainty, there are increasing potential opportunities for fraudulent activities relating to water extraction, use and the water market. This will create a need for increased cybersecurity within government agencies such as NRAR and will require close partnerships and interactions with irrigators and or water-related businesses to prevent unauthorised access and manipulation of stored data (Ponemon Institute. 2017). While NRAR will require increased IT capabilities in new IT technology such as blockchains etc. there is also a high likelihood that there will be an increase in cybersecurity businesses which will be able to provide a range of services such as building and maintaining firewalls, working with distributed ledgers, and protecting against illegal access to data systems. (Hajkowicz et al. 2018).

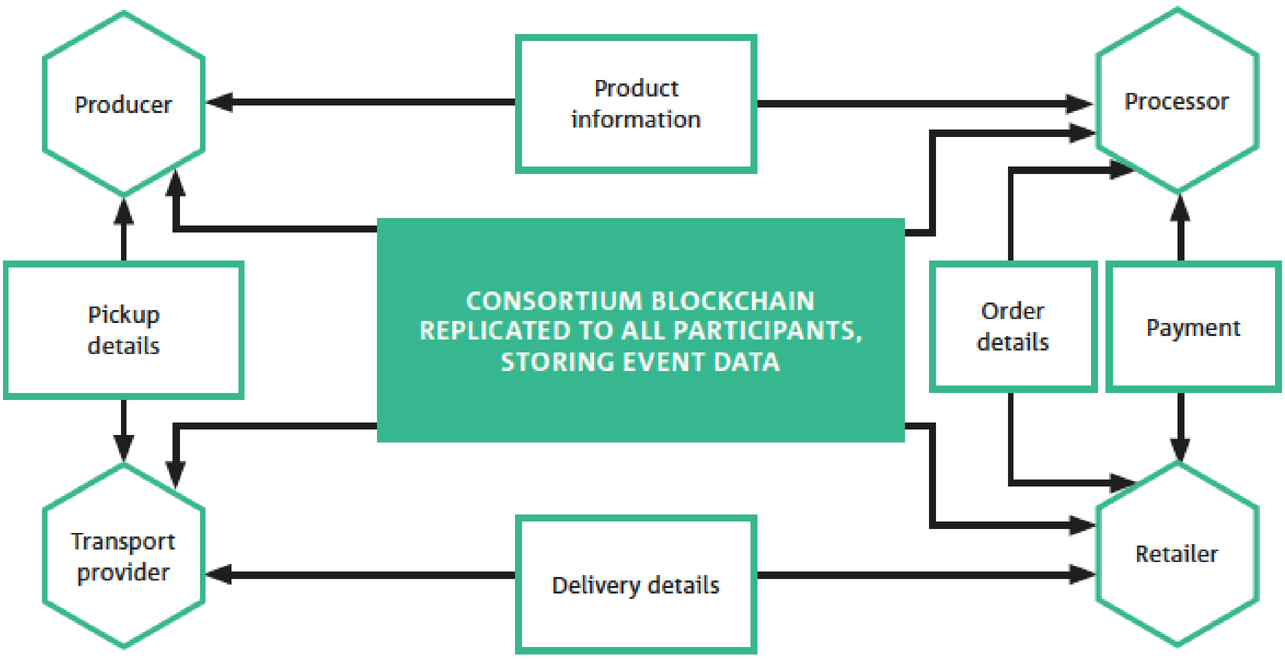

Figure 15. Example model of supply using blockchain for event data and point-to-point integration (Staples et al. 2017)

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