MURRAY-DARLING BASIN ESSAY

Essay #8 in a series of nine by Australia's leading water experts

Challenges and adaptation opportunities for the Murray-Darling Basin in response to climate change: Industry development & adjustment

Anne-Maree Boland with Claire Flanagan-Smith, Carl Larsen, Rebecca Schwarzman and Tim Cummins

Above: Centre-oivot irrigator, near Mulwala New South Wales, JohnCarnemolla, iStock.

EXECUTIVE SUMMARY

Boland et al. address the emerging challenges and opportunities for the agricultural industry in the MDB considering four plausible futures in 50 years: base case, drying and contracting agriculture, adaptive and market-driven agriculture, water abundance and agriculture powerhouse. The cases are evaluated through critical variables like water, climate, commodity mix, production systems, and market conditions.

The authors conclude that the preferred future is one where industry works with society and the environment, relying on advances in technology and sustainable management practices, and embedding principles of a circular economy (eliminate waste and pollution, circulate products and materials, and regenerate nature). Hence, they identify critical adaptation factors for a future ready agriculture as water resource sharing, producing more from less, securing domestic supply, thriving in export capabilities, using innovative and advanced technologies, capitalising on a skilled workforce, and responding to the Basin's societal and cultural values.

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Challenges and adaptation opportunities for the Murray-Darling Basin in response to climate change:

Industry development & adjustment

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Summary

Primary production in the Murray-Darling Basin (MDB or Basin) in 50 years' time will be substantially impacted by a changing climate. This essay explores the emerging challenges and opportunities for industry considering:

- The likely factors (drivers and barriers) influencing the future of the MDB
- A series of plausible futures for a 50-year time frame
- Opportunities (options) to protect or enhance the values of the Basin.

The MDB supports an economy currently worth around $230 billion per year including agriculture, tourism and recreation, and mining. Agricultural production has contributed over $20 billion per year in gross value since 2010 with irrigated agriculture responsible for a significant portion of this value (around 30%) from 3% of the land area (MDBA 2020b). The prosperity of irrigated agriculture relies on the sustainable management of water resources and provision of a reliable supply for consumption.

A 50-year future for the agriculture industry in the MDB must concede a significant decline in water availability (due to climate change and continued policy reforms), more frequent and severe extreme weather events and increasing temperatures impacting feasibility of certain production systems. Sharing of water under a changing climate will continue to challenge industry with meeting environmental needs essential to ensuring a healthy and thriving river system resilient to more extreme and frequent shocks.

Our 50-year vision for agriculture in the MDB is for a highly profitable industry producing more from less through sustainable practices and technology advances. This preferred future is one where market-driven agriculture adapts (Future 3) to the impacts of climate change and water scarcity. This future is desirable as it will ensure the sustainability of the Basin values, maintain production levels and protect the environment, while producing high-quality, safe, healthy, and environmentally friendly food that meets consumer expectations and supports a circular economy.

To reach this preferred future, the industry will need to adopt innovative technology and sustainable management practices supported by a favourable policy environment. Interventions will include a mix of implementation of technology and management practices and changes to policy settings. At the core of this response is the protection of the environmental and social values of the MDB – while supporting and encouraging an industry known globally for its innovation, efficiency and market responsiveness. Industry has demonstrated an ability to adapt to changing conditions and we are confident this capacity will continue resulting in a thriving agriculture sector.

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1. Introduction

Primary production in the Murray-Darling Basin (MDB or Basin) in 50 years' time will be substantially impacted by a changing climate. Exploring the emerging challenges and opportunities for primary production under these conditions will ensure that policy settings, technology and management practices can support industry to successfully adapt – maintaining productivity and retaining its 'social license'.

To consider the potential challenges and opportunities of climate change on primary production in the MDB we have explored:

- Current industry supported by the MDB
- The likely factors (drivers and barriers) influencing the future of the MDB
- A series of plausible futures for a 50-year time frame incorporating climate change projections and uncertainty
- Opportunities (options) to protect or enhance the values of the Basin through transformative technology, management and policy.

Our vision for a 50-year future is one that acknowledges the considerable impact of climate change and variability on the agriculture industry in the MDB with a significant decline in water availability (due to climate change and continued policy reforms to ensure sufficient water for the environment), more frequent and severe extreme weather events and increasing temperatures effecting feasibility of certain production systems. However, we are confident that industry is well equipped to undertake adaptive and transformative change to meet the demands of this future.

Adoption of technology and sustainable management practices and policy settings that support industry will ensure that the needs of society and environment are optimised. Agriculture will be market driven, sustained by smart people and sustainable production systems and focused on valuing precious resources.

Key concepts in this paper: futures thinking and complex systems

This essay is underpinned by a number of key concepts including futures thinking and acknowledgement that we are dealing with a highly complex system.

The capacity of MDB industry to thrive is influenced by a multifaceted set of factors including availability of natural resources, access to infrastructure and services, skills and education of regional workforces, industry diversity and financial resources accessible to businesses and individuals (Productivity Commission 2017). These factors are interdependent with many unpredictable relationships, interactions and feedback loops between the people, organisations, environments, infrastructure, policies and laws at play. These connections at times appear to be competing and/or contradictory.

> *"We can't impose our will on a system. We can listen to what the system tells us and discover how its properties and our values can work together to bring forth something much better than could ever be produced by our will alone."* (Meadows 2018)

In such a complex system like the MDB, many futures are possible, some are plausible and even fewer are the future we want to see realised (Hancock et al. 1994). In this essay, we describe several possible futures and select a preferred future we believe the MDB system should navigate towards.

To describe the 50-year future for the MDB we have used the CSIRO Global megatrends (Naughtin et al. 2022) as a framework to explore potential impacts of climate change. We have also utilised the current state of the MDB as described in detail in the publication by Hart et al. (2021) including challenges over the next 30 years, particularly due to climate change and possible policy and management responses.

2. Murray-Darling Basin industry

The MDB as the largest river system in Australia, provides essential resources (biophysical and social) to support communities and a thriving economy based largely on primary production and tourism. Water resources are a key ingredient of the prosperity of the MDB contributing to irrigated agriculture production. The MDB consists of the Northern and Southern Basins (Figure 1).

The MDB Economy

The MDB supports a large economy currently worth around $230 billion in Gross Regional Product per year (Aither 2022). Many water sensitive industries contribute to the economic value of the region including agriculture, tourism and recreation, and mining.

Agriculture is the major economic contributor to the MDB with more than $20 billion per year in gross value since 2010 (MDBA 2020b). Agriculture dominates land use in the MDB, with over 82 million ha or 80% of the total land area used primarily for agriculture (Hart et al. 2021, ABS 2022a). Grazing is the principal agricultural land use at around 80%, with the remaining area used for cropping and horticulture (ABS 2022a). In 2020-21 the gross value of production of agriculture in the MDB was around $30 billion per annum or more than 40% of the total value of agricultural production in Australia.

Tourism, including water- and environment-related tourism, is also a significant industry contributing more than $7 billion in gross value added in 2017-18 and 2018-19 (Aither 2022). Over 31,000 tourism businesses operated in the MDB in 2016 (Hart et al. 2021).

While water sensitive industries are important economically in the MDB, the range of sectors providing employment is diverse. The largest employers in 2016 were construction including mining and transport (14%), retail and wholesale trade (12%) and health and social assistance (13%) (Hart et al. 2021).

The future demands on water and water sharing arrangements are likely to shift as water sensitive industries develop. Improved infrastructure will assist the growth of agriculture and export reliant industries such as mining. Energy transformation and decarbonisation and increased interest in tourism may also encourage growth in regional areas. The relative composition of water sensitive industries is uncertain, however policy will need to support equitable and sustainable sharing of water.

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Figure 1. Map of the Murray-Darling Basin. The northern Basin is delineated in pink and the southern Basin in green.

Irrigated agriculture contributes to the national economy

The irrigated agriculture industry in the MDB contributes significantly to Australia's economy and the local communities. Irrigated agriculture is responsible for around 30% of the gross value of agriculture production (MDBA 2020b) despite representing only 3% of the land used for agriculture (Hart et al, 2021).

In the southern MDB there are large areas of irrigated pastures, cereals, and rice as well as high value horticulture crops including permanent plantings such as fruit and nut trees and grapevines. In contrast, cotton and grain are the major crops in the northern MDB (MDBA 2020).

The development of irrigation infrastructure in southern MDB in the 1950s-1980s prompted the replacement of low-intensity agriculture, mostly grazing, with high-intensity and higher value crops (horticulture and pasture for dairy and grain cropping) (Hart et al. 2021). Irrigation communities expanded with industry development, government support and access to low-cost water supplies.

The number of businesses irrigating in the MDB is around 8,300 (ABS 2022b). This number has continued to decline over the past 30 years, consistent with trends in agriculture across Australia as smaller farm businesses consolidate into larger commercial holdings.

Irrigated agriculture in the MDB remains important in terms of its contribution to the Australian economy at a national scale and to local communities, offering employment and supporting local economic activity including associated businesses and services. In 2020-21, the MDB contributed $8.4 billion of the gross value of irrigated agriculture making up around 45% of the national irrigated agriculture value (ABS 2022c).

The gross value of irrigated agricultural production has remained above $7 billion for the past decade despite fluctuating water availability. Agricultural output has increased from a smaller land area, with fewer businesses compared with the past 40 years. Greater disparity also now exists between the economic output of larger and smaller agricultural enterprises with more than 80% of value generated by just 30% of the largest farms in the MDB (Hart et al. 2021).

Managing water for agriculture use

The prosperity of the irrigated agriculture industry relies on the sustainable management of water resources and provision of a reliable supply for consumption. The management of water resources in the MDB has become increasingly important with over consumption leading to a stressed system. Water sharing agreements within a sustainable consumptive volume has become the primary focus.

Management of the MDB has involved four State governments, the Australian Capital Territory (ACT) and the Commonwealth (Federal) governments working together for over 100 years on issues of water resource development, water sharing between states, river management, and key aspects of catchment and land management.

Recent challenges have included:

- Over allocation of the consumptive pool resulting from high rates of water extracted for irrigation
- Environmental impacts arising from decline in water availability and poor water quality
- Social and economic impacts with changing land systems and communities
- Declining flows exacerbated by a warming and drying climate.

Implementation of policy to address these challenges and working towards the sharing of water within a sustainable consumptive pool has been the focus of recent times. The irrigated agriculture industry has adapted to increasing production with less available water.

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Basin communities and their links to agriculture

Around 2.4 million people live in the MDB with just under 60% of the population residing in cities or regional centres of more than 10,000 people, including Canberra (around 500,000) Toowoomba (around 134,000), Bendigo and Albury-Wodonga (each 100,000). At least 2% of the population reside in very remote areas (ABS 2022d).

Over 40 Aboriginal Nations are represented in the MDB by an Aboriginal and Torres Strait Islander population of more than 120,000 people. Water is central to the cultural, social and spiritual identity of Australia's First Nations people, as well as to their livelihoods. 'Cultural flows' are water entitlements owned and managed by First Nations to improve the spiritual, cultural, environmental, social and economic health and well-being of Traditional Owners and Country. Water is an important part of self-determination.

Some parts of the MDB are home to culturally and linguistically diverse populations and around 10% of the total population speak a language other than English at home (including Indigenous languages) (ABS 2022d). These culturally and linguistically diverse communities have intergenerational links to agriculture as both business owners and labourers throughout the MDB.

Direct employment in agriculture or agricultural services accounts for up to 8% of those employed in the MDB. This includes farmers and farm managers, labourers, skilled workers, machinery operators, and scientists (ABS 2022d).

The demand for employment for tourism, mining and service industries will continue to grow providing competition for agriculture industries. Agriculture will require more skilled labour as farming systems continue to become more sophisticated.

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3. Influencing factors at play in the MDB

The MDB system is influenced by a complex suite of factors. To consider the future impact of climate change on industries in the MDB, we must understand the impact that water (resources, infrastructure and policy reforms), climate, and global trends have had on the development of the MDB and its likely future.

WATER

The availability and use of water in the MDB is a critical factor influencing agricultural development. Over time, water infrastructure and policy reforms, together with environmental factors such as climate change, have changed access to water resources, who uses the water, and the way it is managed to balance competing demands. Challenges and adaptation opportunities for the MDB have been influenced by:

- Infrastructure development and policy reforms
- Consumptive pool of water resources, agricultural water use, and water quality issues.

Water limited agricultural growth until infrastructure was built

Variability in water availability has played a significant role in the development of surface water resources for agriculture in the MDB. In the early 1900's, shortly after the Federation drought, state governments entered into an agreement to share water resources along the Murray River. The agreement included joint investment in the development of major infrastructure (dams, weirs, and locks) to ensure that the river would remain navigable and to maintain access to water resources under low flow conditions. Between the 1950s and 1980s, the MDB experienced very wet conditions which were accompanied by a rapid expansion in government owned infrastructure (including dams, weirs and channels), this time primarily for irrigation along with flood mitigation.

Irrigation facilitated rapid expansion of agriculture

These developments set the stage for a rapid expansion in irrigated agriculture and resulted in flows of major river systems in the southern MDB, particularly the Murray, Murrumbidgee, and Goulburn, being highly regulated by large storages and diversions to irrigation districts. Irrigated agriculture was initiated later in the northern MDB, in the 1960's and 1970's (Hart et al. 2021), mainly driven by private investment in infrastructure development. Major irrigation areas now occur along the Murray River (NSW, Victoria and South Australia), Murrumbidgee and Goulburn Rivers. This includes irrigation districts centred around infrastructure typically built originally by governments, and now managed as private corporations or cooperatives while many river diverters access entitlements using private infrastructure directly from waterways. Small but important irrigation districts also include the Coleambally and Lachlan in the southern MDB and Namoi, and Gwydir irrigation areas in the northern MDB. There are also several very large properties with significant private water collection and storage infrastructure in the northern MDB.

In addition to surface water, groundwater resources support irrigated agriculture and stock and domestic use across the MDB. Private infrastructure (bores) is typically used to access groundwater and yields can be more or less sustainable depending on local hydrogeological conditions and rates of use.

Water reforms addressed over-allocation

With the development of infrastructure and irrigated agriculture, water consumption from the MDB rapidly increased leading to a system that was over-allocated. The past 30 years has seen a number of urgent reforms to the planning and management of water in the MDB to reduce the proportion of water that is allocated to consumptive uses – primarily agriculture. Significant reforms impacting on the current availability of water for irrigated agriculture have included the following (Table 1).

Table 1. Major reforms affecting the MDB and impacting on its consumptive pool and availability for irrigated agriculture

Reform	Description
Water Reform Framework (1994)	Council of Australian Governments (COAG) endorsed the Water Reform Framework which underpins many aspects of our system for managing water resources today. Reforms included: ▪ Separating water access rights from land title ▪ Allowing trading of water rights ▪ Water pricing for full cost recovery, and ▪ Provisions for water for the environment.
Murray-Darling Basin Cap (1995)	An upper limit of surface water diversions in the MDB. Responding to a decline in river health and establishing 'a line in the sand' to ensure conditions did not deteriorate.
Intergovernmental Agreement on the National Water Initiative (2004)	States agree to a National Water Initiative to re-energise the water reform agenda of 1994. The initiative clearly defined key aspects of the water management framework including "entitlement" (perpetual access to a share of consumptive pool) and "allocation" (volume or proportion of an entitlement made available each year). The agreement also recognised the need for overallocated water systems to be returned to sustainable levels of use through water planning and recovery of water for the environment.
Water Act (2007)	A significant phase of water reform prompted by the Millennium drought that had devastating impacts on communities, irrigators, and the environment. Desire to reset the balance between consumptive and environmental water in the MDB with the establishment of new Sustainable Diversion Limits (SDLs) for Basin catchments and the Basin overall.
Basin Plan (2012)	Legislated to ensure that water resources of the MDB are managed in an integrated and sustainable way to achieve 'a healthy working Murray–Darling Basin that supports strong and vibrant communities, resilient industries, including food and fibre production, and a healthy environment' (the Vision). Key elements to implement the Basin Plan were (i) purchase of water entitlements and (ii) subsidies for irrigation efficiency. In addition, the Basin Plan aims to establish long-term average SDLs that reflect an environmentally sustainable level of water use and introduce water trading rules to facilitate water reaching its highest value use. SDLs came into effect from 2019 for each of the 29 surface water areas and 80 groundwater areas. The Basin Plan includes a SDL accounting framework and to provide flexibility, it includes a mechanism to adjust SDLs.

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Current availability of surface water resources

With the implementation of the Basin Plan, there has been significant change to the consumptive surface water allocation across the MDB. The current situation with regards to water that is available for agricultural irrigation, the volume of water that has been recovered through purchases and irrigation efficiency programs and the current environmental water entitlements is described in Table 2. Since the commencement of the Murray Darling Basin Plan, the consumptive pool has declined by 2,137 GL per year.

Adaptive management enables governments and communities to adjust their approach with regular 10 yearly reviews of the Basin Plan required to consider emerging climate change patterns, new information, tools and techniques. These reviews could result in changing water limits or other water management arrangements with the first review in 2026.

Table 2. Consumptive pool of surface water resources in the Murray-Darling Basin and recovery of environmental entitlements

Item	Value	Description
Consumptive pool prior to Basin Plan	13,957 GL per year (MBDA 2022a)[2]	Total Baseline Diversion Limit (BDL) – or the amount (long-term average estimate) of water being extracted annually at the time of Basin Plan development under the Murray-Darling Basin Cap
Current consumptive pool	11,820 GL per year (MBDA 2022b)[3]	Total Sustainable Diversion Limit (SDL) – or the amount (long-term average estimate) of water resources available for annual extraction as of 2022.
Surface water recovery – purchases	1,231 GL per year (DECCW 2022a)	Total volume of water recovered towards 'bridging the gap' between BDLs and SDL through the purchase of consumptive entitlements
Surface water recovery – irrigation efficiency	693 per year (DECCW 2022a)	Total volume of water recovered towards 'bridging the gap' between BDLs and SDL through irrigation efficiency subsidies (both on and off-farm). Note there is some disagreement about the figure due to uncertainties as to whether the return flows from these infrastructure projects are increasing or decreasing flows to groundwater and rivers.
Environmental water entitlements	2,877 GL per year (DECCW 2022a)	Commonwealth Environmental Water Holdings in 2021–2022

Which agriculture industries use the water?

The MDB accounts for more than 60% of the total water used for irrigated agriculture in Australia, including more than 70% of water used from irrigation district infrastructure such as channels and pipes and more than 70% of water extracted from rivers, creeks, and wetlands in Australia.

The amount of MDB water resources used for irrigation, and the proportion of water resources used by different crop types varies greatly according to seasonal and market conditions. The water used for irrigation in 2020-21 in the MDB is summarised in Table 3 as total volumes and a percentage of water use for irrigated agriculture in Australia.

[2] Note: Estimate as of July 2022. BDLs reflect estimates due to difficulties measuring diversions. Adjustments continue to be made in each sub-catchment as more information becomes available, for example through the development of water resource plans.

[3] Note: Estimate as of July 2022. SDL estimates are updated annually to accommodate revised BDL figures and progress on recovery and the SDL adjustment mechanism.

Table 3. Water used for irrigation in 2020–21 (ABS, 2022a)

Item	MDB 2020-21	% of total use/applied
Total water used for irrigation	5,082 GL	
Water use by source		
Irrigation districts (channels or pipes)	2,481 GL	49%
On-farm dams or tanks	268 GL	5%
Rivers, creeks, lakes	1,582 GL	31%
Groundwater	703 GL	14%
Recycled or re-use	39 GL	1%
Town or reticulated mains	9 GL	0.2%
Water applied[4] by commodity		
Pastures	1,103 GL	23%
Vegetables	88 GL	2%
Fruit trees	800 GL	17%
Grapevines	418 GL	9%
Nurseries	12 GL	0.2%
Rice	530 GL	11%
Cereals	585 GL	12%
Cotton	1,223 GL	25%
Other	86 GL	2%

Water availability, trade and reliability varies across the Basin

Water availability and the reliability of that water being supplied varies across the MDB. The southern MDB is a highly connected system with a mature trading market and an allocation system, that allows water products with different levels of reliability to be 'moved' across the Basin and used according to availability. For example, high reliability water in the southern MDB supports significant areas of perennial horticulture which require certainty around water supply each year. Lower reliability water is often used more opportunistically in the southern MDB to grow annual crops such as rice and cereals when water is available. This pattern of use is interrupted in dry years when lower reliability water becomes largely unavailable, leading to large transfers of remaining water allocations to higher value perennial horticulture, as was observed during the Millennium drought.

The northern MDB is less connected with the movement of water between basins constrained. There is a less mature trading market and the security of water is significantly lower with greater fluctuations in the yearly allocation of water. Given this reduced water security, the production of crops is more opportunistic on an annual basis – this suits the production of annual crops such as cotton, rice and cereals.

To manage the uncertainty of irrigation water supply businesses have implemented risk management strategies including maintaining a portfolio of held and leased entitlements across

[4] Note: Discrepancies exist between total water used (i.e. diverted) and applied. Total water applied in 2020-21 was reported as 4,844 GL.

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jurisdictions, trading water through the water allocation market and having access to both surface and groundwater allocations.

These strategies allow irrigators to manage production through variable seasons.

Water quality varies across the Basin

Water quality varies across the MDB and is impacted by external environmental conditions. Fluctuations in water flows (i.e. floods and droughts) has major impacts on parameters such as:

- Salinity
- Acid sulfate soils
- Blackwater events
- Thermal stratification
- Blue-green algae

The primary water quality issue for irrigated agriculture is salinity with excessive concentrations causing a reduction of production and potentially damaging plant health.

CLIMATE

Agricultural production in the MDB has long been influenced by both natural geographic climatic variations and human induced climate change, leading to industry adaptation and innovation. The important factors are:

- Climatic variations across the MDB and how they impact commodities grown and their production systems
- Impact of human induced climate change on agriculture.

Geographic climate variations influence commodity mix

The historical and current climate of different locations across the MDB has governed the agricultural commodity mix. This has been driven by rainfall, temperature and runoff determining water availability for irrigation in combination with other agronomic suitability factors such as soil types and topography.

As a result, more perennial horticulture, such as citrus, table and wine grapes, nuts, stone and pome fruit as well as pasture for dairy is grown in the southern MDB, compared to a higher proportion of cropping, cotton and cereals, and livestock in the northern MDB. The predominance of crops regionally is demonstrated analysing the current climate and commodity mix in selected key locations across the MDB (Table 4). Temperature is particularly important for some horticultural crops, with citrus requiring adequate heat units or growing degree days, or pome fruit needing sufficient chill units to promote optimal budburst and flowering.

Extreme historic climate drivers such as droughts and floods have heavily influenced the expansion and subsequent contraction of specific agriculture industries across the MDB, in combination with other critical factors such as commodity prices, market access and pest and disease pressure. Most notable was the recent Millennium Drought, causing significant agricultural, social and economic disruption and adjustment. There were differing impacts in the southern MDB which has higher and more regular rainfall, than the northern MDB, with more opportunistic cropping.

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Table 4. Current climate (1991-2020) and commodity mix of key MDB locations (BoM 2022)

Key location	Current climate (ave.)	Commodity mix
Southern MDB		
Mildura, Victoria	Rainfall (annual): 264 mm Temperature (annual): 24.8°C Evapotranspiration (annual): 1,642 mm	Dominated by irrigated perennial horticulture including citrus, table grapes, dried fruit and nuts (almonds), with some annual horticulture (vegetables). Large areas of dryland cropping (wheat, barley and oats) with some sheep.
Shepparton, Victoria	Rainfall (annual): 465 mm Temperature (annual): 22.0°C Evapotranspiration (annual): 1,434 mm	Large areas of irrigated pasture for dairy, perennial horticulture (stone and pome fruit) and fodder cropping (maize, lucerne).
Griffith, New South Wales	Rainfall (annual): 395 mm Temperature (annual): 24.2°C Evapotranspiration (annual): 1,613 mm	Dominated by livestock, cereal crop and other broadacre crops, wine grapes, citrus, vegetables and nuts.
Northern MDB		
Bourke, New South Wales	Rainfall (annual): 336 mm Temperature (annual): 28.0°C Evapotranspiration (annual): 1,893 mm	Includes cotton, citrus and other fruit, livestock (cattle) and irrigated wheat,
Moree, New South Wales	Rainfall (annual): 577 mm Temperature (annual): 27.4°C Evapotranspiration (annual): 1,828 mm	Dominated by cotton and cereal crops with livestock (sheep and cattle), oil seeds, olives and nuts (pecans).
St George, Queensland	Rainfall (annual): 476 mm Temperature (annual): 28.2°C Evapotranspiration (annual): 1,893 mm	Includes cotton, wheat, livestock (sheep and cattle), and some grapes.

Production systems have adapted as technology advancements are made

Agriculture has and continues to adapt to changes in climate across the MDB due to its reliance on biophysical climatic factors and the natural resource base for production. Irrigated agriculture is particularly exposed and sensitive to reduced water availability in the MDB system.

The Millennium Drought provides a number of insights into how irrigated agriculture adapted to the lowest inflows on record, which differed across industries, and how these industries may respond in the future (Kirby et al. 2014). Overall, there was an increase in water use efficiency with more agricultural output produced per unit of water between 1996-2009. While there was a decline in water for diversion of 67%, this was only accompanied by a reduction in adjusted gross value of irrigated production across the MDB of 20%. On-farm irrigation efficiency measures were also coupled with significant water delivery infrastructure investment through modernisation.

In the southern MDB, the dairy industry was able to adjust production systems by ceasing or reducing on-farm pasture irrigation, purchasing more feed (hay and grain), and/or using 'cut and carry' systems whereby fresh grass is cut daily and fed to housed cows. This was combined with selling water on the market. Higher value horticulture in the southern MDB maintained productivity by purchasing water from lower value annual crops and pastures, which had more flexibility in their production systems. Inter-basin trading occurred from Murrumbidgee primarily a rice growing region, to the South Australian and Victorian Murray which are primarily horticultural and viticultural irrigation regions.

In the northern MDB, lower irrigation requirement crops such as irrigated cereals increased, while higher irrigation requirement crops like cotton significantly decreased. Large price rises in cereals and meat also contributed to buffering the extent of the worst effects of the drought.

Productivity gains within sectors, substitution of inputs, and water trading among sectors and regions will continue for perennial and annual cropping, with this adaptation potentially offsetting the impacts of a reduction in water availability (Kirby et al. 2012).

There has also been transformative change within some sectors as a result of recent and predicted future climate changes. Examples include wine grape businesses in the southern MDB establishing vineyards in Tasmania and changing varieties produced in the MDB. This has been driven by continuing earlier and more rapid ripening and more compact vintages over the past 20 years.

The structural adjustment and adaptations made by agriculture in response to climate change will continue to have implications for the MDB environment and communities that are part of the complex system.

Human induced climate changes and their impact on agriculture

Based on the historical climate and industry adaptation, it is important to consider the predicted changes in climate over the next 50 years and the impact this will likely have on agriculture. Climate change will cause an increase in average temperature, reduced average rainfall and water availability for irrigation, as well as increase in frequency and severity of extreme events (e.g. heat waves, drought, rainfall intensity and flood).

The MDB has warmed by around 1°C since 1910 and will continue to warm (by 0.6–1.5°C by 2030 relative to 1995 and by 0.9–2.5°C by 2050 without mitigation), with more hot days and fewer cold days (Hart et al. 2021). Rainfall is projected to decrease, particularly in the southern MDB in winter and spring, with more time in drought and decreased soil moisture (BoM 2020). The median estimated decrease in mean annual runoff is 14% in the southern MDB (10–90 percentile range of -38% to +8%) by 2046–75 under the medium warming scenario. In the northern MDB the median projection is a decline in mean annual runoff of 10% (10–90 percentile range of -38% to +21%). Importantly, the median estimated decline in runoff is similar to the volume of water sought to be returned to the environment under the Basin Plan (Hart et al. 2021).

There are significant uncertainties as to the impacts of climate change on run-off and water availability in the MDB. However, there is an expectation that there will be significantly less water available for consumption in the southern MDB and likely a smaller reduction in the northern MDB. The water allocation system will need to adjust to a highly variable climate.

The relationship between plants, soils, climates, microclimates, and the human inputs necessary to generate economic outputs will continue to evolve in the MDB, accelerated by climate change. Potential future climate of key locations across the Basin region may generally increase the suitability of annual cropping and pastures in the southern Basin, with continued increase in intensity of production systems particularly for higher value perennial horticulture crops. These production systems will continue to use infrastructure (e.g. shade, hail netting) and other technological developments (e.g. protected cropping systems with precise monitoring and management of water, nutrients and temperature) and varietal advancements to adapt to reduced water availability.

For example, factors that will influence type, extent and location of horticulture in the southern MDB include:

- Optimum temperatures and sunlight during the growing season: Optimum temperature range for growth for specific cultivars – for example the optimum range for citrus is between 13^0 and 36^0C.
- Less rainfall during the harvest period: Minimal rainfall during harvest is preferred to ensure harvest continuance and reduced profitability from pest and disease damage.
- Better trafficability after rain and other soil suitability issues: Well drained soils reduce waterlogging to achieve commercial yields and enable operational access to the orchard following high rainfall.
- Water availability, trade and reliability: A portfolio of held and leased entitlements will ensure that risk can be managed. Secure water and ability to trade is essential for perennial horticulture.

In the northern MDB, there will continue to be opportunistic irrigated cropping like cotton in response to more variable water availability and higher average temperatures, with an increase in suitability for livestock (sheep and cattle) and cereal and oilseed crops. Perennial horticulture will be less suitable due to the higher risk of variable water availability and more frequent extreme weather events. The climate analogues show a general shift north to north-west from their current location, with the future climate of Mildura, Victoria similar to current day Leonora, Western Australia and the future climate of Moree, New South Wales similar to current day Blackall, Queensland in the year 2090 (Table 5).

Table 5. Future climate (2056-2085) and commodity mix of key MDB locations (BoM 2022)[5]

Key location	Future climate (ave.)	Similar to current day (CSIRO 2020)	Commodity mix
Southern MDB			
Mildura, Victoria	Rainfall (annual): 267 mm (→) Temperature (annual): 27.4°C (↑) Evapotranspiration (annual): 1,794 mm (↑)	Leonora, Western Australia	Potential increase in dryland cropping (wheat, barley, oats) and livestock (sheep), with continuation of perennial horticulture citrus and table grapes. Reduced suitability of some nuts (almonds) and vegetables.
Shepparton, Victoria	Rainfall (annual): 461 mm (→) Temperature (annual): 24.8°C (↑) Evapotranspiration (annual): 1,576 mm (↑)	Cobar, New South Wales	Potential increase in fodder and dryland cropping (wheat, barley, oats) and livestock (sheep), with warmer climate wine grapes. Reduced suitability of stone and pome fruit.
Griffith, New South Wales	Rainfall (annual): 419 mm (↑) Temperature (annual): 27.0°C (↑) Evapotranspiration (annual): 1,717 mm (↑)	Bourke, New South Wales	Potential increase in livestock (cattle) and dryland wheat, with some citrus. Reduced suitability of vegetables and nuts.
Northern MDB			
Bourke, New South Wales	Rainfall (annual): 342 mm (→) Temperature (annual): 31.0°C (↑) Evapotranspiration (annual): 2,048 mm (↑)	Longreach, Queensland	Potential increase in dryland cereal crops and livestock (sheep and cattle). Reduced suitability of irrigated cotton and citrus.
Moree, New South Wales	Rainfall (annual): 578 mm (→) Temperature (annual): 30.3°C (↑) Evapotranspiration (annual): 1,947 mm (↑)	Blackall, Queensland	Potential increase in cereal crops with livestock (sheep and cattle), oil seeds, olives. Reduced suitability of irrigated cotton and some nuts (pecans).
St George, Queensland	Rainfall (annual): 489 mm (↑) Temperature (annual): 31.3°C (↑) Evapotranspiration (annual): 2,030 mm (↑)	Winton, Queensland	Potential increase in wheat and livestock (sheep and cattle). Reduced suitability of irrigated cotton and grapes.

Legend: → = remains relatively similar to current climate; ↑ = increase (negative impact on agriculture); ↑ = increase (positive impact on agriculture); ↓ = decrease (negative impact on agriculture)

5 Note: Under a High Emissions – Scenario RCP8.5

The changing climate will continue to present numerous challenges, testing the resilience of the agriculture industry and its ability to persist, adapt and/or transform. Structural transition will be facilitated by the water market and trade, with reduced water availability for irrigation from the consumptive pool increasing prices and shifting water to higher value uses. This is a key adaptive capacity mechanism that allows agriculture to manage the implications from climate variability and change. For example, a three percent reduction in average rainfall has been modelled to result in a 17% increase in temporary market prices in the southern MDB (Gupta & Hughes 2018). Added to this is a potential challenge of increased salinity and reduced water quality due to declining in-flows with the remaining water potentially less fit-for-purpose.

Industries and businesses will need to continue to evaluate the use, quality, security and price of water relative to other input costs and commodity prices, as this will ultimately govern the profitability and sustainability of irrigated agriculture in the MDB (MDBA 2020).

Dryland agriculture will also be impacted by climate change through, for example, reduced pasture productivity rates, reduced forage quality, livestock heat stress, and increased risk of soil degradation (MDBA 2020).

REGIONAL TRENDS

Significant changes have occurred in regional Australia over the past decade expedited by the impacts of the coronavirus pandemic. We are likely to see these regional shifts continue in the next 50 years with regional centres having a big role to play in the future of living in Australia.

The ability to work remotely has encouraged the growth of regional centres. Flexible working arrangements and the desire to balance work and lifestyle has seen many move from coastal cities to the regions. This shift is likely to continue with the expectation that strong regional economic growth centres with world-class liveability, seamlessly connected physically, digitally and economically to cities and other regional centres will emerge (Lazarow et al. 2021). Critical to this regional growth will be the development of small and medium-sized enterprises (SMEs) and high value-added advanced manufacturing capacity, accompanied by modern and agile agricultural systems.

Improved infrastructure including housing, digital connectivity and transport (e.g. the Inland Rail) will support the growth of regional centres in the MDB and ensure the provision of skilled workforce. Increased water security will also ensure prosperity for irrigated agriculture.

GLOBAL TRENDS

What megatrends will impact agriculture in the MDB?

The key influences on the global economy and society (or megatrends) have been considered by CSIRO (Naughtin et al. 2022). Megatrends are trajectories of change that typically unfold over years or decades and have the potential for substantial and transformative impact. Seven megatrends were described in the CSIRO 2022 update highlighting the significant changes that have occurred since the first release (Hajkowicz et al. 2012) exposing new risks and opportunities.

The relevance of these megatrends for agriculture in the MDB and how they may influence future development have been considered in Table 6.

Agriculture adaptation in the face of these trends

The agriculture sector has experienced significant change over the past 30-50 years including:

- Agricultural output continuing to increase (e.g. a target of $100 billion in farm gate output by 2030 due largely to unprecedented demand (NFF, 2030)
- Farm numbers and land used in agricultural production falling with an increase in average farm size
- A major disparity between farming enterprises with the largest 20% of farms producing 80% of the output
- Growth of larger inland population centres and the decline of smaller outlying towns.

In a thriving and growing economy, we expect the trends of larger farms, growth of larger cities and increasing agricultural production in the MDB to continue. The description of megatrends shaping our world reinforces the exciting opportunities for agile and well-resourced agricultural industries. In particular, a more sophisticated and nuanced agriculture industry will be well positioned to respond to these emerging issues in 50 years.

Table 6. Relevance of CSIRO megatrends for the agriculture industry in the MDB

Megatrend	Relevance for the Murray-darling basin
Adapting to a changing climate	• Decreasing run-off will lead to declining water quantity, quality and availability • Extreme and unprecedented weather events increasing in their frequency and scale will impact production in both short-term (e.g. frosts, hail storms) and long-term (e.g. droughts) • Climate variability may require economic policy intervention in the form of subsidies and grants to protect industry and communities • Changing climate will require organisations and communities to adapt and identify new ways of operating • Communities will need to prepare to live in a hotter world with higher evapotranspiration
Leaner, cleaner and greener	• Resource constraints will drive cutting-edge innovations that aim to do more with less, achieve carbon neutrality, reduce biodiversity loss and address the global waste challenge • Changing consumer expectations will increase demand for food produced sustainably – clean, green and resource efficiency • Escalating pressures will be placed on finite food, water, mineral and energy resources • Global population growth and more people transitioning from lower to higher income brackets will increase global demand for high value food
The escalating health imperative	• Healthcare expenditure will continue to increase • Opportunities provided by preventative and precision health in supporting better health outcomes will increase interest • Changing diet including a focus on healthy options and differing protein sources will increase demand for high value food
Geopolitical shifts	• Emerging geopolitical shifts relating to science, technology, trade, supply chains and defence strategy will influence position in global markets

	• Ensuring self-sufficiency and secure supply chains will ensure diversity in domestic food production and establishment of robust export markets • Fluctuating global trends will cause increasing impacts on Australian communities
Diving into digital	• Adoption of digital and data technologies will provide opportunities for organisations and businesses • New technologies for primary industries and water resource managers will increase efficiencies and productivity • Increased ease in global communications and responsiveness will contribute to improved production systems
Increasingly autonomous	• Scientific breakthroughs in artificial intelligence (AI) and global investments in technology-driven research and development (R&D) will improve efficiencies • AI and related science, research and technology capabilities will boost agricultural productivity • Increased automation will result in decreased reliance on workforce in primary industries
Unlocking the human dimension	• Heightened influence of human perspectives and experiences on future community, business, technology and policy decisions will increase collective decision-making • Consumers demand for increased transparency from organisations, governments and scientists to maintain their trust will result in more sustainable production systems • Changing consumer expectations will result in ethical and trusted food production systems

4. Industry development 50 years from now….

FUTURES THINKING

To plan and manage our future water resources in the MDB, we must understand what the future might look like under a changing climate (Horne 2022). We know there is considerable uncertainty and that the future may unfold in a multitude of ways. While the changes that will lead to the future are largely out of our control, it is possible to improve our response to change by considering the types of changes that may occur. This approach allows us to build our resilience to change – our capacity to persist, adapt or transform as needed.

One lens to explore the future is through what is known as the "cone of futures" (Figure 2) whereby a range of futures are described:

- Possible futures are the full range of futures that changes could lead to
- Plausible and probable futures are the futures that we think are likely
- Preferable futures are the futures that we wish to steer towards.

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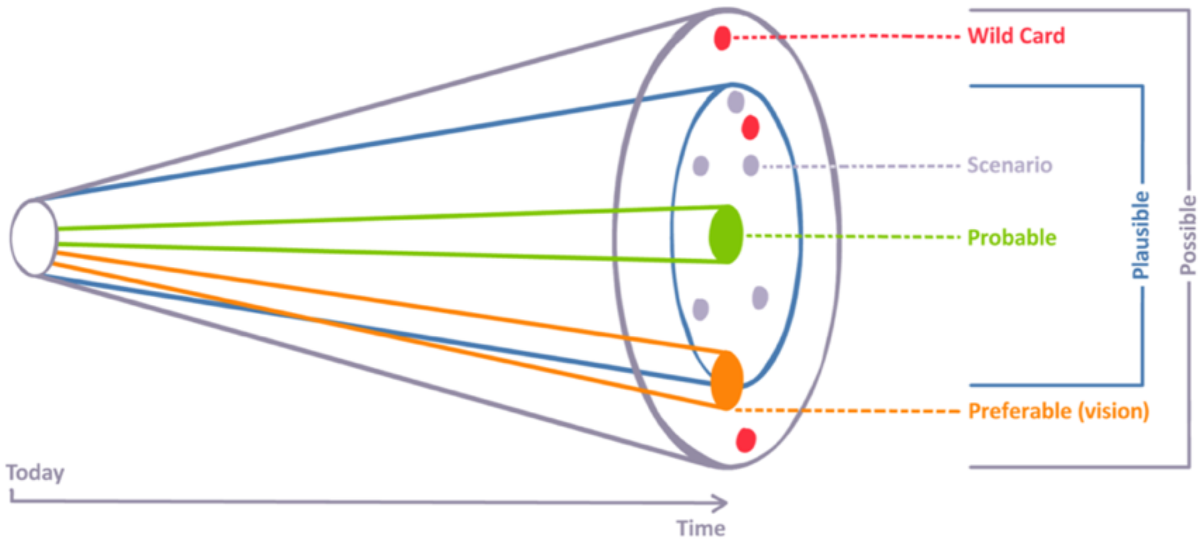

Figure 2: The cone of possibilities: possible, plausible and preferable futures

A series of plausible futures for a 50-year time frame have been developed to:

- Encourage different ways of thinking about the future
- Inspire the development of problem-solving skills and
- Focus on solutions.

PLAUSIBLE FUTURES

Four Plausible Futures for industry in 50 years in the MDB are described below and in Table 7 with the critical variables of:

i. **Water** – availability (including conveyance considerations) and quality
ii. **Climate** – averages and extremes
iii. **Commodity mix** – annual and perennial crops
iv. **Production systems** – intensive versus extensive
v. **Markets** – consumer preferences and export/domestic.

Future 1: Base Case

The Base Case considers a consumptive pool which is relatively stable with over-entitlements having been successfully dealt with through the MDB Plan. The impacts of declining water availability due to a changing climate (at an intermediate level (RCP4.5)) is to some extent built into the allocations. For agriculture, whilst the consumptive pool has been reduced the allocations are more sustainable being delivered most years. Water quality continues to improve due to better management of flows. Under this future the industry adapts to a changing climate through the breeding of new varieties and movement of production to different areas. While the agriculture industry can adapt to averages it is ill-equipped to respond to extreme events. The commodity mix remains relatively consistent with horticulture in the southern MDB and cropping and mixed enterprises increasing in the northern MDB. There is limited adoption of new technology and management practices with a focus on incremental change and stagnation in productivity and value of output per ML of water. Production systems are similar to the current practices and industry responds to market signals both domestically and internationally.

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Future 2: Drying and contracting agriculture

Future 2 provides a scenario where the consumptive pool is 30% less than the current due to a changing climate (at a high level (RCP8.5). Impact of reduced rainfall and run-off and increased evapotranspiration are experienced in both southern and northern production regions and also resulting in negative effects of salinity. The drying conditions will also result in severe and more frequent droughts causing a significant reduction in perennial horticulture and an increase in dryland and mixed annual enterprises in the northern MDB. Adaptation to conditions of reduced water resources and increasing salinity will see the adoption of technology and management practices to moderate levels. This will mean that production levels in the MDB will decline but not proportionate to the reduced volumes of water with marginal improvement in the value of output produced per ML of water. Production systems will adapt incrementally. There will be a focus on the domestic market and exports will decline.

Future 3: Adaptive and market driven agriculture

Future 3 explores an option in which the consumptive pool declines by 10–30% (in line with intermediate current climate models (RCP4.5)) with a consistent decrease in the southern MDB and a more variable change in the northern MDB. Unlike the Base Case, this scenario results in a greater reduction in water allocations to agriculture with SDLs declining to benefit the environment. However, this reduction in water availability is accompanied by a pro-active response from the agriculture industry increasing its resilience with a focus on improved practices and technology. Transformative change will ensure that production systems can meet the challenges of producing more with less and pre-empt the impacts of climate change.

Horticulture will expand in the southern MDB with a smaller footprint and greater reliance on intensive systems. Annual cropping will expand in the northern MDB but will be opportunistic depending on weather conditions and water allocations with the use of precision agriculture. There will be an increase in the value of product per ML of water. Regional centres will provide a highly skilled workforce. Under these conditions industry will demonstrate a high degree of resilience and adaptability by being on the front foot. Industry will be responsive to market drivers striving for efficient and profitable production for the domestic market and production efficiency to increase export competitiveness. Production will focus on clean, green and healthy products demonstrating environmental credentials including efficient use of resources.

Future 3 is the scenario that we consider most preferable. A reduction in the consumptive pool is most likely under the intermediate climate change models. The ongoing protection of environmental values of the MDB is paramount resulting in 10-30% decline in water available for agriculture. However, we believe that the agriculture industry can respond to this challenge through technology, management and policy modifications.

Future 4: Water abundance and agriculture powerhouse

Future 4 reflects a scenario where the consumptive pool increases periodically particularly in the northern MDB. This scenario predicts a changing climate (RCP2.6) that results in increased run off in the northern basin MDB and fluctuating allocations. Under this future, industry would be well positioned to adapt to increasing water allocations on an annual basis. Horticulture production would continue to use the more secure water in the southern MDB whilst growth in annual production would be experienced in the northern MDB – this would be highly opportunistic based on seasonal conditions. It is likely that production would increase in the northern MDB although the unstable nature of this will challenge the provision of a skilled work force in the region. An increase in total production volumes will be accompanied by a greater focus on self-sufficiency and also high value export markets. There will be a marginal improvement in the value of output produced per ML of water.

Table 7. Plausible futures for agriculture industry in 50 years

Variable	Future 1: Base case	Future 2: Drying and contracting agriculture	Future 3: Adaptive and market driven agriculture	Future 4: Water abundance and agriculture powerhouse
(i) Water				
Availability – consumptive pool	**Allocation:** Continues as is Consumptive pool relatively stable	**Allocation**: > 30% decline on average Consumptive pool shrinks rapidly due to climate and policy decisions	**Allocation:** 10-30% decline on average Consumptive pool declines – consistently in southern MDB and more variable in northern MDB	**Allocation:** Increases periodically Consumptive pool increases periodically particularly in northern MDB
Water quality	Water quality (salinity) improves	Salinity levels restrict production at certain times	Water quality (salinity) is variable with technology supporting improved river management	Water quality (salinity) improves due to an abundance of water
(ii) Climate				
Averages	Continued decline in annual rainfall, particularly in southern MDB in winter and spring, with increased temperatures and evapotranspiration (RCP4.5)	Significant reduction in annual rainfall and run-off, combined with increased temperature driving evapotranspiration and higher plant water requirements (RCP8.5)	Decline in annual rainfall, particularly in southern MDB in winter and spring, while increased temperature and evapotranspiration are less pronounced (RCP4.5)	Decline in annual rainfall, with periodic heavy falls and increased run-off and storage in the northern MDB, while increased temperature and evapotranspiration are less pronounced (RCP2.6)
Extremes	Industry adapts to averages, but not resilient to extremes	Millennium drought conditions occurring one in every 4-5 years	Industry resilient to extremes through the implementation of practices and technology	Industry responds to regular increases in the availability of water in northern MDB

(iii) Commodity mix				
Agriculture commodities	Commodity mix remains relatively similar with horticulture (almonds, winegrapes, citrus, dried fruit, table grapes) and dairy in southern MDB and dryland cropping (cotton and grain) and mixed enterprises in northern MDB	Decrease in area of horticulture and minimal pasture irrigation in southern MDB. Large increase in dryland cropping and mixed annual industry in northern MDB	Significant expansion of horticulture in southern MDB with an increase in intensive production systems. Minimal pasture irrigation in southern MDB with intensive livestock production relying on cut and carry. Growth in annual cropping which is opportunistic in northern MDB	Maintenance of horticulture as predominant commodity for highly secure water in the southern MDB with maintenance of the current footprint. Growth in irrigated annual cropping in the northern MDB which is highly opportunistic
(iv) Production systems				
Production system advances	Similar production systems to current Limited innovation and incremental adoption of technology and practices Stagnating output and value from irrigation water applied ($/ML)	Moderate level of technology and automation advancement results in moderate increases in productivity in southern MDB and increases in dryland annual cropping in northern MDB Adoption of technology and management practices are through necessity and a required adaptation response to reduced water resources and increasing salinity Moderate output and value from irrigation water applied ($/ML)	High level of technology and automation advancement Intensification of agriculture particularly in the horticulture sector with protected cropping in the southern MDB Implementation of precision agriculture in the northern MDB for annual crops allows industry to respond effectively and opportunistically to water supply increases Increased automation requires reduced reliance on labour Thriving inland regional centres provide the required skilled workforce to implement	Moderate level of technology and automation advancement Abundance of water results in production in southern MDB increasing and considerable expansion of irrigated annual production systems in northern MDB A highly flexible workforce is required challenging some production systems Moderate output and value from irrigation water applied ($/ML)

			sophisticated production systems Adoption of technology and management practices is transformational due to a focus on innovation and pre-empting impacts of climate change Industry demonstrates a high degree of resilience and adaptability by being on the front foot High output and value from irrigation water applied ($/ML)	
(v) Markets				
Market demand	Remains similar with domestic and export production varying across commodities	Increased importance of domestic market and greater focus on self-sufficiency Reduced exports as total production declines	Efficient and profitable production for the domestic market Strong commodity prices and labour efficiency increase export competitiveness Increased focus on clean, green and healthy products demonstrating environmental credentials including efficient use of resources Increased demand for plant-based products	Increased importance of domestic market and greater focus on self-sufficiency Total production increases (irrigation and dryland) Increase in high value export markets

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5. Designing a future for the MDB

WHAT NEEDS TO CHANGE?

A 50-year future for the agriculture industry in the MDB must concede a significant decline in water availability (due to climate change and continued policy reforms), more frequent and severe extreme weather events and increasing temperatures impacting feasibility of certain production systems. Sharing of water under a changing climate will continue to challenge industry with meeting environmental needs essential to ensuring a healthy and thriving river system resilient to more extreme and frequent shocks.

Industry will have a known consumptive pool for use – with a high level of certainty in the southern MDB and greater variability in the northern MDB. Industry will actively use the water market to ensure that perennial production is maintained during periods of low water allocation with more opportunistic annual production, particularly in the northern MDB.

Innovation is core to Australian agriculture and production systems will continue their reliance on adoption of the most current and efficient management practices and technology. Increased levels of automation replacing labour will also ensure more profitable farming systems. A skilled workforce drawn from regional centres is required for managing intensive and sophisticated production systems.

The demand for Australian produce will increase globally with a reputation for high quality, safe and environmentally friendly food focused on health benefits. We will continue to focus on domestic production with less reliance on imports. Being highly efficient and innovative, agriculture businesses in the MDB will respond to changing market demands in response to an increasing domestic population and consumer expectations.

Critical adaptation factors for agriculture in 50 years are described below and in Figure 3.

- **Water resource sharing** – ensuring the equitable sharing of water in the MDB for communities, environment, cultural and recreational purposes. Adapting to a more secure supply in the south and opportunistic production in the north and working with the environment.
- **Produce more from less** – aiming to reduce consumption and produce more with less resources. In some instances this will lead to more intensive production with a smaller footprint.
- **Secure domestic supply** – securing the production of essential agriculture commodities to alleviate geo-political challenges and supply-chain breakdowns.
- **Thriving export** – exporting high value products to an increasingly wealthy global consumer focused on health benefits and bulk commodities produced efficiently and profitably.
- **Innovation and advanced technology** – using technology and communications to improve efficiency and mitigate challenges presented by climate change/variability. This includes improved plant and animal genetics.
- **Skilled workforce** – capitalising on the highly skilled workforce in regional centres where they are attracted due to excellent services and community capital.
- **Responding to societal, cultural values** – appealing to consumer expectations associated with changing societal and cultural values. A desire for agriculture production to be ethical, safe and environmentally responsible meeting Sustainable Development Goals (SDGs) (United Nations 2015), environmental, social and governance (ESG) and Agricultural Sustainability (AFI 2022) and progressing the principles of circularity (Ellen Macarthur 2022).

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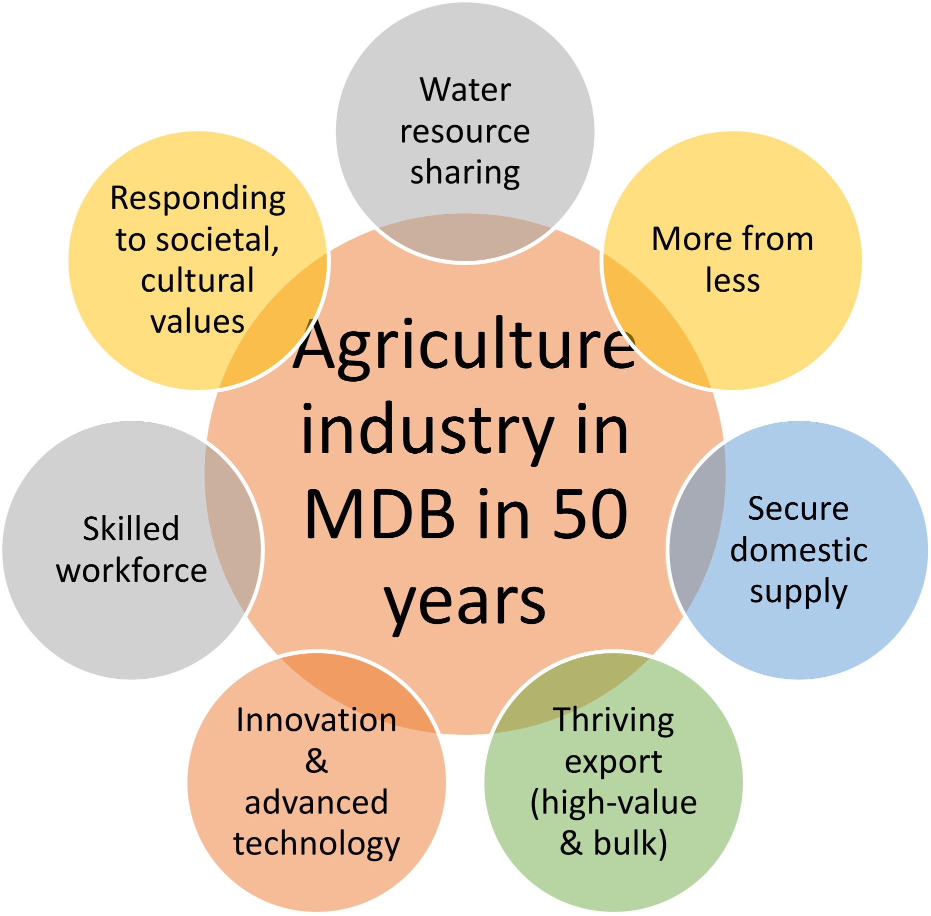

Figure 3. Adaptation factors in the face of global trends

A PREFERRED FUTURE FOR AGRICULTURE

Our 50-year vision for agriculture in the MDB is for a highly profitable industry producing more from less through sustainable practices and technology advances. This preferred future is one where market-driven agriculture adapts (Future 3) to the impacts of climate change and water scarcity. This future is desirable as it will ensure the sustainability of the Basin values, maintain production levels and protect the environment, while producing high-quality, safe, healthy, and environmentally friendly food that meets consumer expectations and supports a circular economy.

The preferred future requires the implementation of technology enabling water to be shared equitability, resources used efficiently and agriculture using a smaller footprint to produce the same amount. Highly automated and intensive production systems producing for the domestic and export markets will facilitate this change. Automation will have replaced reliance on a casual labour force. Sophisticated production systems will be managed by a skilled workforce, providing economic benefits to the region. Smart people will manage farming systems more suited to a drier and more variable climate (including floods and storms). Technology will assist in better decision-making to ensure the best use of finite resources. Food and fibre production will be safe, clean, green and ethical responding to the expectations of well-informed consumers and societal values.

Our vision emphasises a thriving industry in charge of its own destiny with light touch government involvement.

INTERVENTIONS TO ACHIEVE THIS FUTURE

To reach this preferred future, the industry will need to adopt innovative technology and sustainable management practices supported by a favourable policy environment.

Proposed changes will incorporate both a 'resilience' approach where we aim to protect industry from environmental trends and an 'adaptive' approach where industry changes with the environment (Hart et al., 2021). Opportunities to protect industry are summarised in Table 8 and include a mix of implementation of technology and management practices and changes to policy settings.

Table 8. Potential interventions to achieve our preferred future

	Technology	Management	Policy
1. Water resource sharing	▪ Infrastructure management to optimise beneficial use ▪ Live information to assist equitable, transparent and adaptive water sharing	▪ Active water market which ensures water reaches most appropriate use	▪ More water for the environment and cultural water through Sustainable Diversion Limits ▪ Continuation and enforcement of Murray-Darling Basin Plan ▪ Improvements to Plan based on monitoring and evaluation
2. Produce more from less	▪ Maximising resource efficiency through the precision agriculture and current technological advances ▪ Intensive production systems that are resource efficient and have a smaller footprint (e.g. protected cropping)	▪ Change to the crop types grown including more drought tolerant or water efficient varieties ▪ Spatial shift in where crops are grown with a reduction in area of permanent plantings and an increase in annual crops allowing for greater interannual flexibility in water use	▪ Incentives provided for efficiency in resource use and recovery ▪ Incentives provided for decarbonisation of production systems
3. Secure domestic supply	▪ Efficient production systems that provide secure domestic supply of essential food and fibre	▪ Efficient production systems that provide secure domestic supply of essential food and fibre	▪ Incentives to ensure the supply of domestic market of essential food and fibre
4. Thriving export (high-value and bulk)	▪ Efficient production systems supplying international markets – commodity and niche products	▪ Efficient production systems supplying international markets – commodity and niche products	▪ Support for development of international markets and trade ▪ Promotion of high value production – clean, green, and safe

5. Innovation and advanced technology	▪ Production systems reliant on advanced technology and automation	▪ Production systems reliant on good management decisions	▪ Incentives and support for research and development and an innovative industry
6. Skilled workforce	▪ Automation replacing casual labour force	▪ Educated and expert labour force focused on decision-making skills ▪ Thriving and resilient regional centres	▪ Investment in regional centres in MDB ▪ Investment in skills and training
7. Responding to societal, cultural values	▪ Technology to ensure production of clean, green and safe food	▪ Management decisions to ensure production of clean, green and safe food ▪ Production systems that respond to societal values and consumer expectations	▪ Industry investment in responding to market expectations and promoting sustainable practices (e.g ESG) ▪ Financial markets investing in ESG businesses

Interventions will require significant investment in research and development, to create and implement cutting-edge solutions that address the challenges posed by climate change and water scarcity. The government will need to play a role in promoting sustainable practices by creating policies and regulations that encourage the adoption of these technologies. Additionally, the industry will need to collaborate with researchers, farmers, and other stakeholders to share knowledge and implement best practices.

Water sharing rules will need to be well-defined to promote water efficiency. Market signals and incentives will drive industry towards sustainability and ESG principles. Sustainable production systems will also be supported financial institutions providing 'green financing'.

There may be incentives to supply the domestic market when needed to ensure continuity of supply. Support and promotion of exports and our associated credence values (safe, clean, green and ethical) will be provided. Investment in regional centres and skills and training will ensure ongoing provision of a skilled workforce. This will include the requirement for management that is familiar with technology and sophisticated production systems.

Production systems that minimise the risk of climate variability will be viewed favourably in an environment where insurance premiums have increased significantly. With increased intensity however comes increased concentration of resources and the potential for greater pollution. Improved understanding of resource recovery and enhanced logistics infrastructure in inland Australia will ensure these production systems move towards circularity.

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6. A bright future – if we're up to it

Primary production in the MDB provides significant return for Australian GDP and is a major feature of the landscape. It is clear that industry will need to change through adaptation and transformation in response to a suite of influencing factors that will shape the MDB in 50 years.

A high degree of uncertainty leads to many plausible futures – a few of which we have explored. We have concluded that our preferred future is one where industry works with society and the environment relying on advances in technology and sustainable management practices and embedding principles of a circular economy (eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature). Society will have higher expectations on how their food and fibre is produced and our industry will be uniquely placed to respond.

At the core of this response is the protection of the environmental and social values of the MDB – while supporting and encouraging an industry known globally for its innovation, efficiency and market responsiveness (high-quality, safe, healthy and environmentally friendly). Industry has demonstrated an ability to adapt to changing conditions and we are confident this capacity will continue resulting in a thriving agriculture sector.

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