GOVERNMENT OF WESTERN AUSTRALIA

GASCOYNE DEVELOPMENT COMMISSION
Creating the climate for growth

Gascoyne Development Commission

THE GASCOYNE DROUGHT PLAN 20 25

Regional Drought Resilience Plan for the Gascoyne region in Western Australia's North West

The Regional Drought Resilience Planning Program is jointly funded through the Australian Government's Future Drought Fund and the WA Department of Primary Industries and Regional Development.

Australian Government
Department of Agriculture, Fisheries and Forestry

Future Drought Fund

Department of Primary Industries and Regional Development
GOVERNMENT OF WESTERN AUSTRALIA

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This Regional Drought Resilience Plan was developed by the Gascoyne Development Commission drawing on stakeholder engagement, regional data, and the guidelines of the Future Drought Fund's Regional Drought Resilience Planning Program.

Contents

About the Gascoyne Drought Plan

The Gascoyne Region Drought Resilience Plan (the Gascoyne Drought Plan) provides a strategic foundation for the communities of the Gascoyne to define, prioritise and align drought and climate resilience efforts across the Gascoyne.

The Gascoyne Drought Plan is designed to be used by local communities, industries, all levels of government, not-for-profits and the private sector to:

- Guide action on drought and climate change preparedness
- Prioritise resources towards actions that will have the greatest impact
- Attract investment in drought and climate resilience projects and to inform funding submissions.
- Support and strengthen collaboration
- Provide a foundation for monitoring and adaptive management

The Gascoyne Drought Plan is intended to be a living document. It was developed during 2024 and 2025, reflecting the needs and priorities of the Gascoyne's diverse and rich communities at a point in time. Community needs and priorities are constantly changing – like the natural environment that supports us.

This plan is intended to be regularly updated. Continuous monitoring, evaluation and knowledge sharing across the region will help ensure this plan accurately reflects the needs and priorities of the Gascoyne's communities in the face of a changing climate.

The audience of the Gascoyne Drought Resilience Plan is broad and includes Gascoyne's residents and communities; local, state and Australian governments; visitors; research and scientific communities, the businesses and supply chains that support regional and remote communities of the Gascoyne.

An important purpose of this plan is to outline the characteristics of the Gascoyne region – its uniqueness, experiences, ideas and priorities, to audiences outside of the Gascoyne.

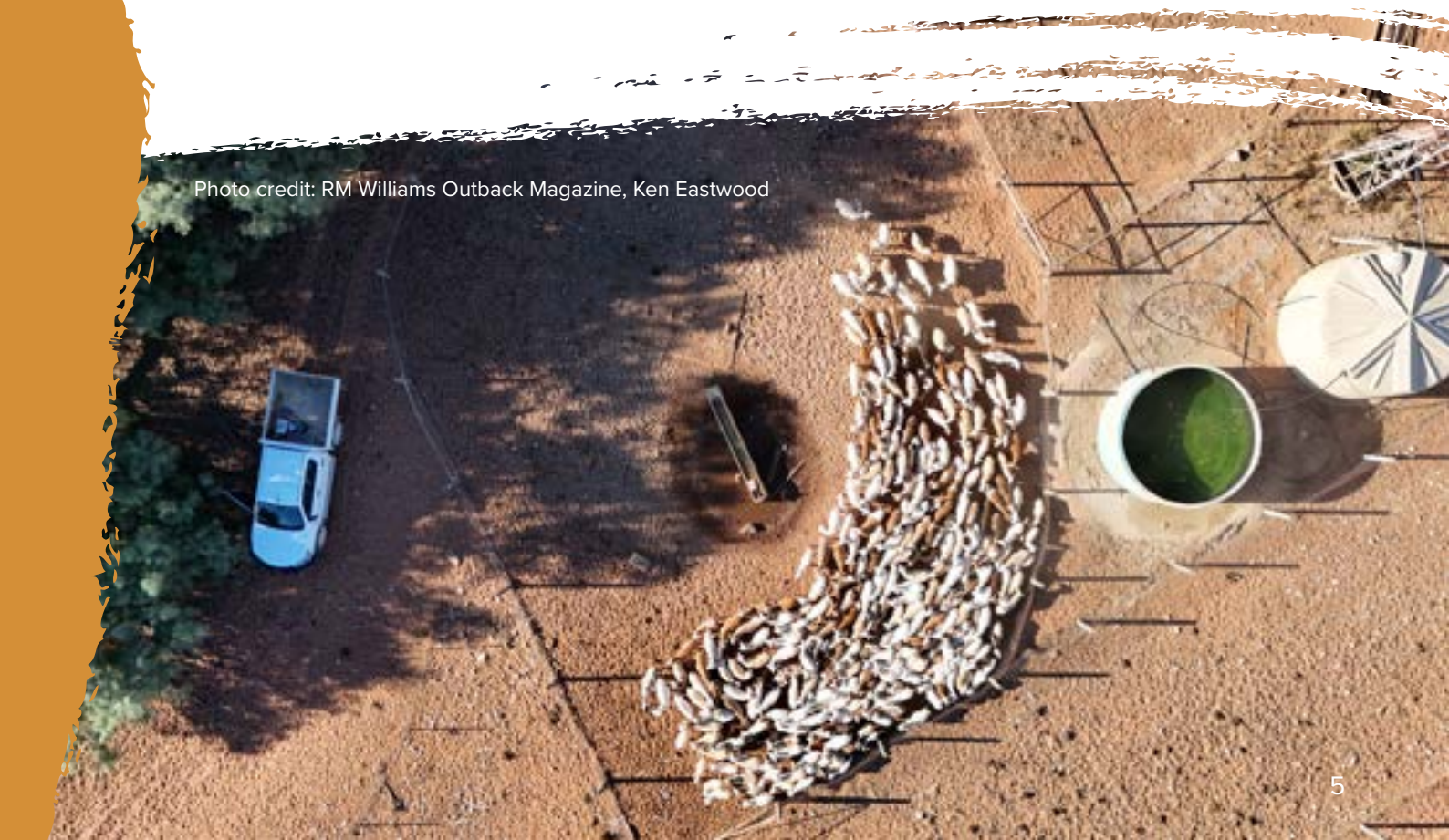


Photo credit: RM Williams Outback Magazine, Ken Eastwood

Introduction

This Gascoyne Drought Plan is a community-led action plan developed by the Gascoyne Development Commission in partnership with and on behalf of the communities of the Gascoyne region in WA.

The Gascoyne region covers 135,277 km^2 and supports nearly 10,000 people across coastal and inland communities. This Plan brings together industry, Traditional Owners, stakeholders and communities to outline strategies that enhance drought and climate change preparedness and supports sustainable land and water management.

This collaborative approach aims to build stronger, more resilient communities and industries across the Gascoyne.

The Gascoyne

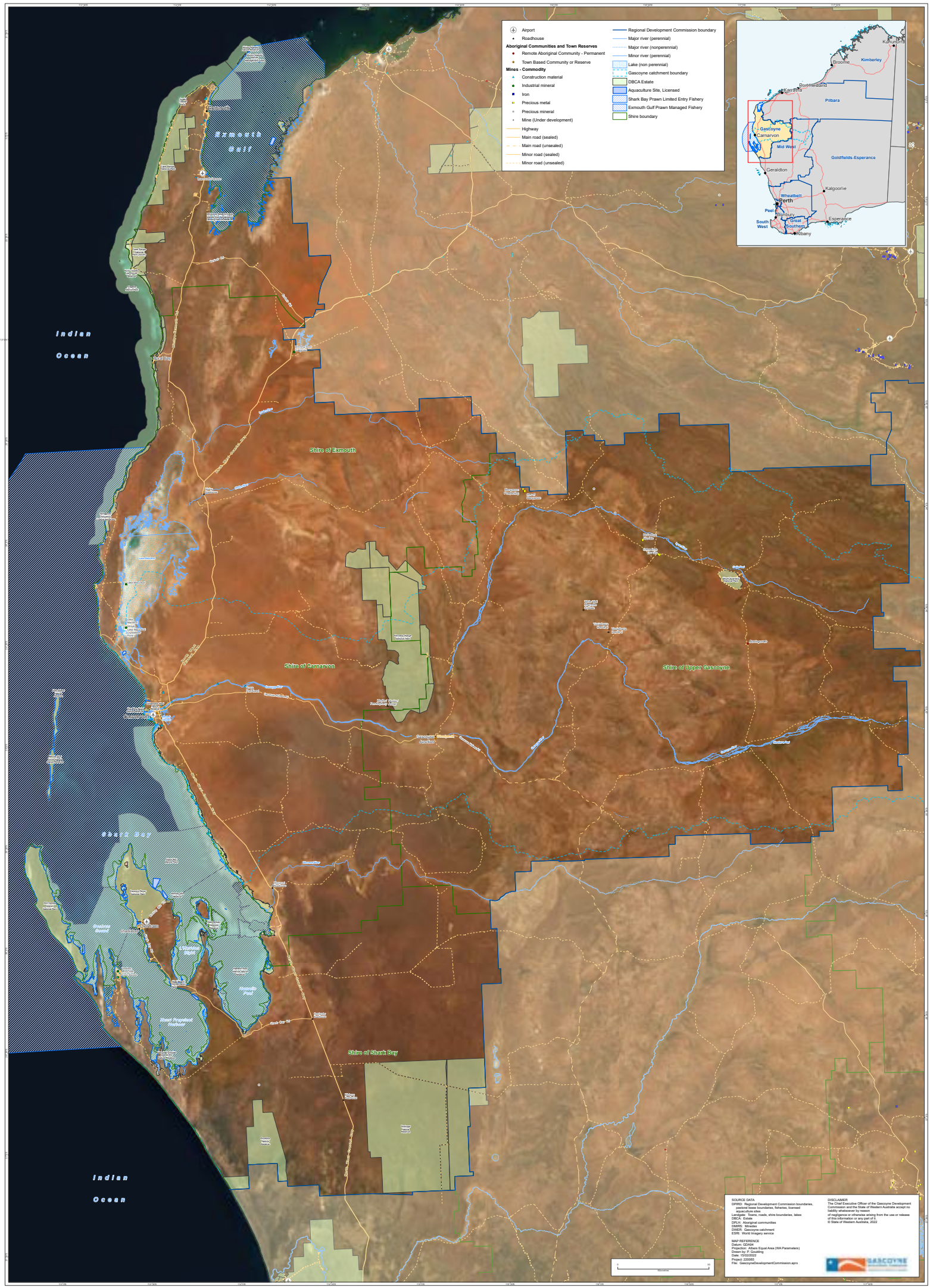
The Gascoyne region is one of the nine regions of Western Australia. It is located in the northwest of Western Australia, and consists of the local government areas of Carnarvon, Exmouth, Shark Bay and Upper Gascoyne.

The Gascoyne is renowned for iconic natural assets including two of Western Australia's four World Heritage areas: the Ningaloo World Heritage area and the Shark Bay World Heritage area.

The Gascoyne's economy is driven by tourism, mining and resources and primary industries including pastoralism horticulture and fisheries. Renewable energy, rare earths and critical minerals are growing opportunites.

The Gascoyne's communities, like its natural environments, are diverse. First Nations people and cultures have nurtured the Gascoyne's landscapes for many thousands of years. Major population centres include Exmouth and Carnarvon, with other small towns and communities at Coral Bay, Burringurrah, Gascoyne Junction and Denham. Across the region, there are also small communities of people working across the Gascoyne's pastoral landscapes.

Map of the Gascoyne



ECONOMIC SNAPSHOT

GOVERNMENT OF WESTERN AUSTRALIA

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Regional Overview

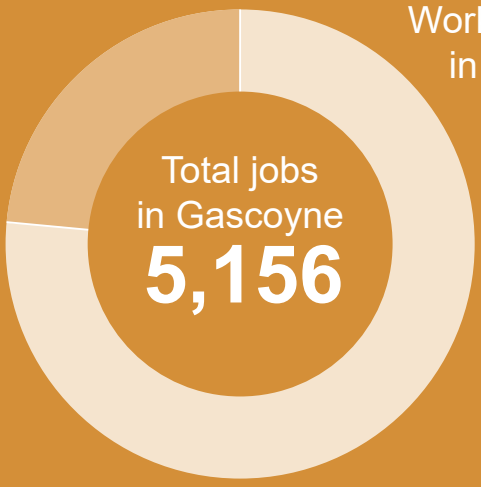
Gross Regional Product[1] **$1.35 Billion**

Unemployment[2] **3.9%**

Businesses[3] **1,010**

Total Jobs[7] **5,156**

Employment[7]



Works and lives in Gascoyne[7] **80%**

Lives elsewhere, works in Gascoyne[7] **20%**

Population[4] **10,324**

Aboriginal and Torres Strait Islander[5] **12%**

Average Age[4] **39**

Highest WA Average Daily **Solar Exposure**

75% of Land is Covered by Pastoral Leases[6]

Home Ownership[8] (owned outright) **932**

School Enrolments[9] **1,525**

1. REMPLAN (2024 R1) - Economic Overview Gascoyne Region, 2. Jobs & Skills Australia - Small Area Labour Market Estimates - LGA (June 2024), 3. ABS Business Counts – LGA (June 2024), 4. REMPLAN (2023 ERP), 5. (2021) Census - ABS Quickstat Aboriginal & Torres Strait Islander Statistcal Area Profile - Gascoyne (SA3), 6. Pastoral Lands Board 2022, 7. REMPLAN (2023 R2) - Economic Overview Gascoyne Region, 8. (2021) Census - ABS Quickstat Statistcal Area Profile - Gascoyne (SA3), 9. Australian Curriculum Assessment & Reporting Authority (2024).

ECONOMIC SNAPSHOT

GOVERNMENT OF WESTERN AUSTRALIA

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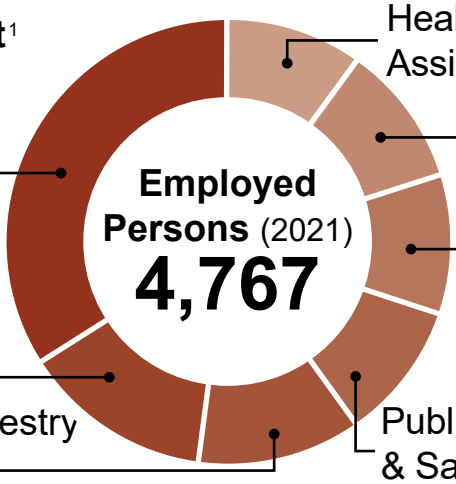
Major Industries

Value of Economic Output (millions $)[1]

Resources	573
Agriculture, Forestry and Fishing	287
Construction	267
Tourism	247
Public Administration and Safety	170
Transport Postal and Warehousing	158
Electricity, Gas, Water and Waste Services	146
Ownership of Dwellings	94
Health Care and Social Assistance	74
Other	377

Employment[1]



- Health Care & Social Assistance 8%
- Construction 8%
- Retail Trade 8%
- Public Administration & Safety 9%
- Agriculture Forestry & Fishing 12%
- Tourism 21%
- Other Industries 34%

WA's Largest Prawn Fishery[2] - **Shark Bay**

Main Mined Commodity[3] - **Salt**

Tourism[4]

Total Visitors (2023)
307,000

Total Visitor Nights (2023 / millions)
2.42

Total Visitor Spend (2023 / millions)
$476

In 2024, the Gascoyne region's tourism output contributed $247 million to the Western Australian economy, supporting over 1,000 full-time jobs.[1]

1. REMPLAN (2024 R1) - Output (with separate toursim sector), 2. DPIRD - Prawn Resource of Shark Bay Harvest Strategy 2022-27, 3. Department of Mines, Industry Regulation & Safety - Western Australia Mineral and Petroleum Statistics Digest 2022-23, 4. Tourism WA - Gascoyne Region Visitor Factsheet 2023.

ECONOMIC SNAPSHOT

GOVERNMENT OF WESTERN AUSTRALIA

GASCOYNE DEVELOPMENT COMMISSION
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Local Profiles

Carnarvon

Population [1]
5,528

Gross Regional Product (millions) [2]
$777

Unemployment [3]
5.9%

Exmouth

Population [1]
3,466

Gross Regional Product (millions) [2]
$436

Unemployment [3]
1.7%

Shark Bay

Population [1]
1,129

Gross Regional Product (millions) [2]
$123

Unemployment [3]
1.7%

Upper Gascoyne

Population [1]
201

Gross Regional Product (millions) [2]
$17

Unemployment [3]
1.9%

1. REMPLAN 2023 ERP, 2. Remplan (2024 R1) - Economy Profile, 3. Small Area Labour Market (Sept 2024)

Understanding drought

The term drought, while widely understood to be the conditions arising from a shortage of water, can mean different things in different communities and places.

In Australia, to identify drought, most states have moved beyond 'drought declarations', due to the inherent complexity of drought and the recognised need to take a risk management approach. Historically, drought was declared in many parts of Australia based on the meteorological drought definition, mostly when decile rain deficiency is observed, i.e., a lack of rainfall generally only seen once every ten years. States and territories declared regions to be in drought to enable support mechanisms to be enacted, but this system has progressively changed with more nuanced methods and frameworks to recognise phases of drought.

Currently, states across Australia focus on a system that gives a policy relevant interpretation of the manifestation of the physical phenomenon. In this sense, the importance of how drought is defined lies in how to meaningfully capture the potential or actual change in other natural, built physical and socioeconomic systems (Poruschi et al, 2023).

Motsumi et al (2023) state: "droughts are often defined and understood as a product, not as a process. As a result, the approach to understanding droughts has been to quantify, predict, and forecast drought-related variables, while less attention is paid to understanding drought and the feedback between society and nature."

The Gascoyne Drought Plan adopts the definition of drought developed by the Department of Primary Industries and Regional Development (DPIRD) Technical Working Group for other WA regions. It reflects meteorological and agricultural drought within the context of broader community impacts.

Like drought plans for other parts of regional Australia, the Gascoyne Drought Plan explores the impacts of three different types of resilience to drought:

- Economic resilience: the ability to sustain and diversify economic activity during and after drought.
- Social resilience: the capacity of individuals and communities to cope with and adapt to stressors, particularly in remote and vulnerable populations.
- Environmental resilience: the capacity of natural systems to maintain.

What is drought resilience?

Drought resilience is defined by Australian Government (2024) as the ability to adapt, reorganise or transform in response to changing temperature, increasing variability and scarcity of rainfall and or changed seasonality of rainfall, for improved economic, environmental and social resilience essential functions and recover from drought-related impacts.

"A prolonged period of abnormally dry conditions that impacts negatively on water availability and agricultural production in a region and, consequently, impacts negatively on the economy and environment of the region and the health and well-being of its residents"

(Mastrantonis, 2022)

Drought planning process

The Regional Drought Resilience Planning program

The Future Drought Fund (FDF) was established by the Australian Government in 2019, with an initial investment of $3.9 billion. The earnings from this are reinvested. The Fund is expected to grow to $5 billion by 2028-2029 (Australian Government, 2024). The Fund was established with the aim to build climate resilience for the broader benefit of the Australian agriculture sector, landscapes and communities (Australian Government, 2024) and ensure that investments continue to address the evolving challenges from drought conditions across Australia.

Each year, $100 million is made available for FDF grants and programs.

A key initiative of the Future Drought Fund is the Regional Drought Resilience Planning (RDRP) program, which fosters collaboration between federal, state and territory governments to develop comprehensive drought plans for regions.

Regional rural and remote communities are keenly aware that local solutions are needed for local problems. Drought, and climate change, affect environments, local communities and local and regional economies in different ways.

The RDRP program aims to empower regional communities to proactively plan and respond to drought risks, by building capability and resilience through partnerships and identifying actions to prepare for future droughts and climate variability.

In Western Australia, the Department of Primary Industries and Regional Development (DPIRD) oversees the administration of the RDRP Program extension 2022-2025, supported operationally in the Gascoyne Region by the Gascoyne Development Commission.

The WA State Government, through DPIRD, and the Australian Government jointly funded the delivery of the Regional Drought Resilience Planning program in the Gascoyne region to support the development of this plan.

Principles

The Gascoyne Drought Plan was developed in accordance with the Australian Government's (2024) principles for regional drought plans:

- are community-owned and led involving local governments, regional organisations, the agricultural sector and local Drought Resilience Adoption and Innovation Hubs,
- identify actions to prepare for future droughts based on evidence,
- build on existing planning,
- draw out regional needs and priorities to inform future investment.

The goals are to:

- build economic, environmental and social resilience to future droughts,
- be in a stronger position to adapt to climate change,
- form stronger connections and networks within and between regions,
- apply best practice data and information to make better decisions.

How the Gascoyne Drought Plan was developed

The development of the plan used four steps: 1. Review of regional plans and strategies that have previously been developed with actions contributing to regional resilience; 2. Key stakeholder identification and targeted engagement; 3. Regional analysis of drought impact and vulnerability on social, economic and environmental aspects in the region; 4. Development of a drought resilience action framework. The result of these steps is combined in a comprehensive drought resilience plan for the Gascoyne region.

Regional plans and strategies

Development of drought resilience in the Gascoyne region must be seen in the broader scope of regional development. It is important to build upon the existing regional plans and strategies rather than develop a drought resilience plan in isolation. The same applies to state-wide and regional plans and strategies related to climate change adaptations.

Water management plans, climate change adaptation plans, Caring for Country plans, and economic and agricultural development strategies were sources used to guide the development of the Gascoyne Drought Plan, where available.

Stakeholder identification and engagement strategy

The stakeholder identification and engagement strategy defines the approach taken to develop the Gascoyne Regional Drought Resilience Plan. As a community-based plan, stakeholder engagement was two-way, to involve stakeholders across sectors and from across the various communities of the Gascoyne, so that diverse stakeholder concerns and aspirations were properly understood and reflected in the plan and to:

- increase drought preparedness awareness,
- understand drought for different stakeholders,
- understand vulnerabilities for different locations and stakeholders,
- work together to develop actions to build and strengthen drought resilience,
- strengthen ownership of the Plan by the communities of the region.

Sectors of importance in the Gascoyne region are horticulture, pastoralism, tourism, fishing and aquaculture and mining (including salt).

Geographically, the Gascoyne region spans four local government areas: the Shires of Carnarvon, Exmouth, Upper Gascoyne and Shark Bay.

Governance

The Gascoyne Drought Plan was developed by the Gascoyne Development Commission working closely with key stakeholders across the region. Figure 1 shows the process from regional stakeholder engagement, guidance and facilitation of the plan, and the assessment, approval and acknowledgement process.

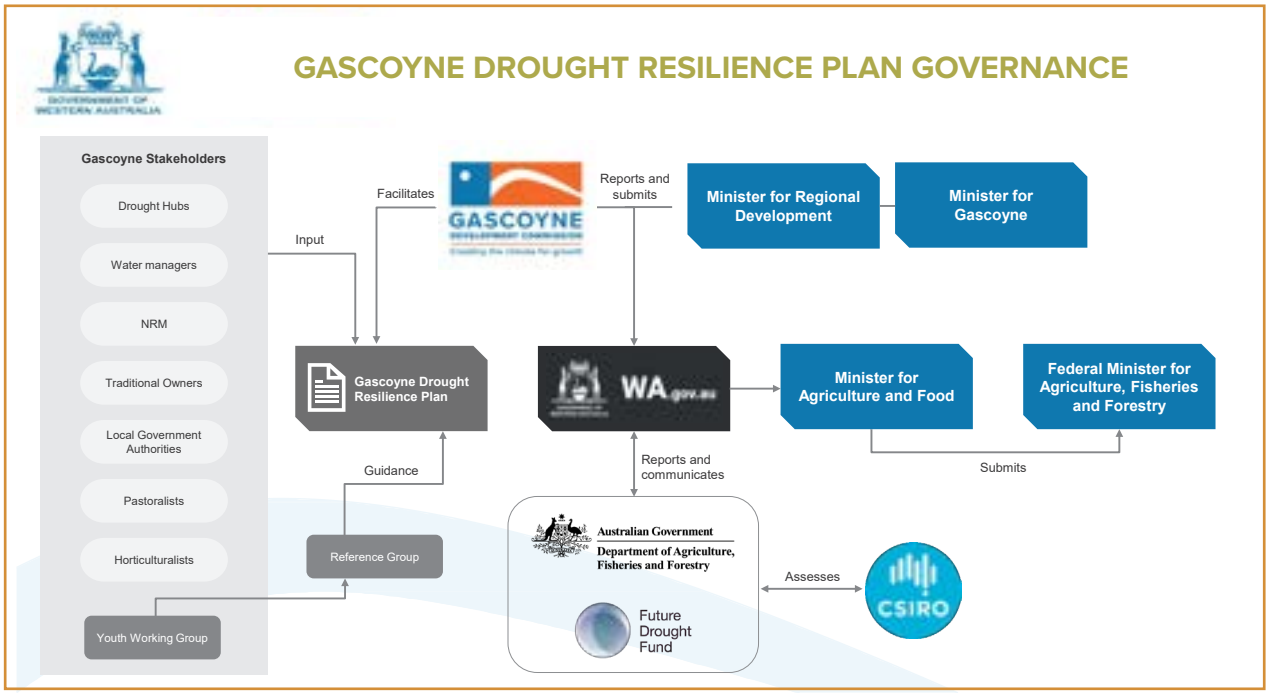


Figure 1: Gascoyne Drought Resilience Plan development and approval process.

Over the course of the Plan's development, more than 200 individuals have participated in engagement through individual and group discussions. A regional reference group provided guidance to the development and developed a regional vision for the Plan. The reference group was comprised of regional stakeholder representatives, as well as the South West and Northern drought hubs.

Drought Impact, Vulnerability Analysis and Scenarios

The Gascoyne Drought Resilience Plan contains a section on previous drought impact and a regional analysis of different impacts on different geographical regions and economic sectors. This includes a summary of stakeholder feedback on experiences and adaptations to drought, as well as a scenario analysis for economic sectors in the Gascoyne region. A simplified regional economic model, based on Duncan and Leong (2014) was initially used to as a basis to assess climate events on economic sectors. A set of potential drought impact indicators by Poruschi et al (2023) was evaluated for application in the Gascoyne region.

It is noted that drought vulnerability covers a broad area, and that vulnerability may differ by industry sector, social group, or type of environment. During engagement, questions were included on self-assessment of vulnerability by stakeholders.

Drought Resilience Actions

The actions contained in this plan are activities arising from regional engagement, extracted from existing plans and strategies, and are identified as required to build and strengthen resilience to drought.

The actions are organised in themes. The function of the themes is to support the narrative of the thematic framework to state and federal recipients, as well as to ensure that the broad areas of interest in the Gascoyne are included.

It is important to note that some themes have overlap with other FDF pillars. The RDRP for the Gascoyne aims to include activities funded through other FDF streams, to ensure that these are captured as part of the priorities that the region identifies for a broad regional drought resilience, while recognising that additional funding streams may cover those activities.

Photo credit: Tourism WA

Upper Gascoyne
Photo credit: Sean Scott Photography

The Gascoyne Region

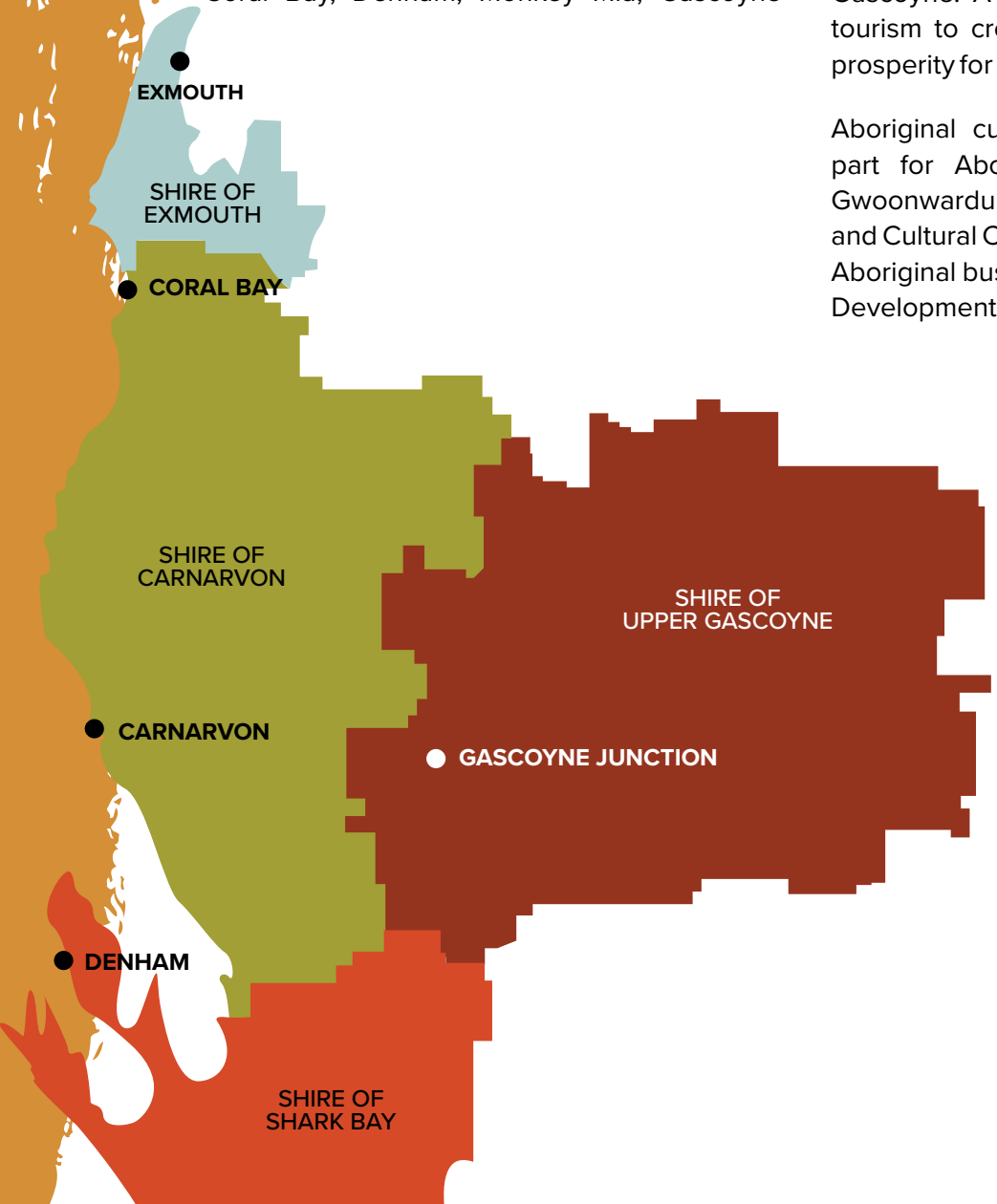
Socio-economic profile

The Gascoyne region, covering an area of 135,277 km^2, is known to have the lowest population density of any region in Australia. However, the region is a very important contributor to the Western Australian economy. It is an established region with an economy founded on quality horticulture, pastoral and fishery production, resources and tourism (Gascoyne Development Commission, 2015).

The Gascoyne region encompasses the Shires of Carnarvon, Exmouth, Upper Gascoyne and Shark Bay. Carnarvon, the Gascoyne's largest town, is located 1000km north of Perth. Other communities in the Gascoyne include Exmouth, Coral Bay, Denham, Monkey Mia, Gascoyne Junction and Burringurrah. The census conducted in 2021 counted 9,537 people in the region, 12% of which identified themselves as Aboriginal or Torres Strait Islander status (Australian Bureau of Statistics, 2024).

There are several Aboriginal language groups of the Gascoyne. The Yinggarda, Baiyungu, Thalanyji, Malgana, Thadgari and Wajarri people have occupied the region for thousands of years and are custodians of its rich heritage, as well as very significant contributors to its current economic and social environment (Gascoyne Development Commission, 2015). There are several Aboriginal tourism businesses in the Gascoyne. A significant opportunity exists for tourism to create jobs and support economic prosperity for the Gascoyne's Aboriginal people.

Aboriginal cultural tourism forms an integral part for Aboriginal economic development. Gwoonwardu Mia Gascoyne Aboriginal Heritage and Cultural Centre in Carnarvon functions as an Aboriginal business and tourism hub (Gascoyne Development Commission, 2024d).



Location (Census 2021)	Population
Carnarvon	5,528
Exmouth	3,466
Denham	1,129
Gascoyne Junction	201

Table 1: Urban and settlement population in the Gascoyne region as per REMPLAN 2024 ERP.

The main industries of employment identified in the census are accommodation (6.6%), hospital (4.4%), Local Government Administration (LGA) (3.6%), supermarket and grocery store (3.5%) and non-metallic mineral mining and quarrying (3.2%) (Australian Bureau of Statistics, 2024).

Remplan (2024a) data show 14.2% of jobs in the accommodation and food sector, 12.5% in the agriculture, forestry and fishing sector, 9.1% in retail, 8.5% in public administration and safety, 8.3% in construction and 8.2% in health care and social assistance.

Tourism combined in the Gascoyne provides approximately 20% of the total jobs in the region (Remplan, 2024a). Salt is a major export product for the Gascoyne. This industry is located at Useless Loop in the Shire of Shark Bay and at Lake MacLeod near Cape Cuvier, north of Carnarvon. When operating at their collective full capacity, these two operations account for nearly half of the state's total salt production. Both major salt operations maintain private port facilities for direct transport of product, which is largely exported to Asian countries for food and chemical production (Gascoyne Development Commission, 2015).

Economic output of the region in **2024 was estimated at $2.34 billion.** The largest contributor to annual economic output in Gascoyne is mining, including salt, which represents 23.9% of total output. Agriculture, forestry and fishing contributes 12.2%, construction 11.2%, transport, postal and warehousing 7.6%, rental, hiring and real estate services 7.5%, public administration and safety 7.1%, electricity, gas, water and waste services 6.1%, and accommodation and food services 5.1% (Remplan, 2024a).

Horticulture is the most propulsive sector for the Carnarvon economy, ranking in the regional top five sectors for export, value-add and employment. Sheep and beef cattle is the top propulsive sector in the Upper Gascoyne, ranking high in the export, value-add, employment and backward linkages. In Exmouth, transport and construction are listed, while construction and mining listed as the main propulsive sectors in Shark Bay (Remplan, 2024b).

The major agricultural commodity in the Gascoyne is beef cattle, with an economic output of $50.33 million. Other contributors are tomatoes ($33 million), capsicums ($13.4 million), table grapes ($13.1 million), bananas ($10.7 million), melons ($9.3 million), eggplants ($6.5 million) and mangoes ($4.5 million). The total value of the horticultural sector is estimated at $113 million (Gascoyne Development Commission, 2024e).

The horticultural production of the Carnarvon local government area is the 5th highest in Western Australia, in terms of economic output (Radhakrishnan et al, 2022).

Landscape, terrestrial environment and land use

The Gascoyne region is characterised by its iconic arid inland and coastal landscapes. The Kennedy Ranges and Mount Augustus are highlights of the inland environment, both are protected in the Western Australian conservation estate (Remplan, 2024a).

Mount Augustus

Located in the Mount Augustus National Park, the prominent landmark is a monocline twice the size of Uluru and the largest monocline in the world. Standing over 1106 m above sea level, the central ridge of the monocline is over 8km long. Created over 1.75 billion years ago as part of an ancient river system that flowed through the area, Mount Augustus is a popular tourist destination with climbs and trails on the monocline and around the park.

The inland Gascoyne is characterised by low and gently undulating landscape with open drainage. Vegetation is mainly acacia shrublands and saltbush/bluebush shrublands, with dense shrub-steppe vegetation, dominated by hummock grassland, or spinifex north of Carnarvon (Gascoyne Development Commission, 2015).

Pastoral leases cover 75% of the land area in the Gascoyne (Figure 2). The introduction of sheep to the Gascoyne in 1876 marked the beginning of an industry that would drive the development of the region well into the twentieth century. Sheep production was initially so successful that the Gascoyne became one of the State's largest wool producing regions.

There are 61 active pastoral properties in the Gascoyne that derive income from livestock (see Appendix A). The average size of these pastoral properties is approximately 150,000 hectares. Livestock are raised largely on natural pasture and are watered through a variety of sources including artesian bores, permanent water holes and dams.

Declining vegetation condition and cover along with topsoil loss are risks for landscape productivity. Wholistic land management is a key focus for land managers in the Gascoyne. This includes landscape rehydration, herd management and total grazing pressure management.

Landscape rehydration involves land management practices that retain rainfall on the lands, slowing runoff, increasing water infiltration into the soil, increasing soil moisture content, resulting in increasing vegetation cover and density. Improved vegetation cover in turn slows sheet flow, improves infiltration and increases soil moisture retention, driving a positive feedback loop that reduces erosion and reinstates natural hydrological patterns that help maintain landscape productivity and function (Gascoyne Development Commission, 2024c).

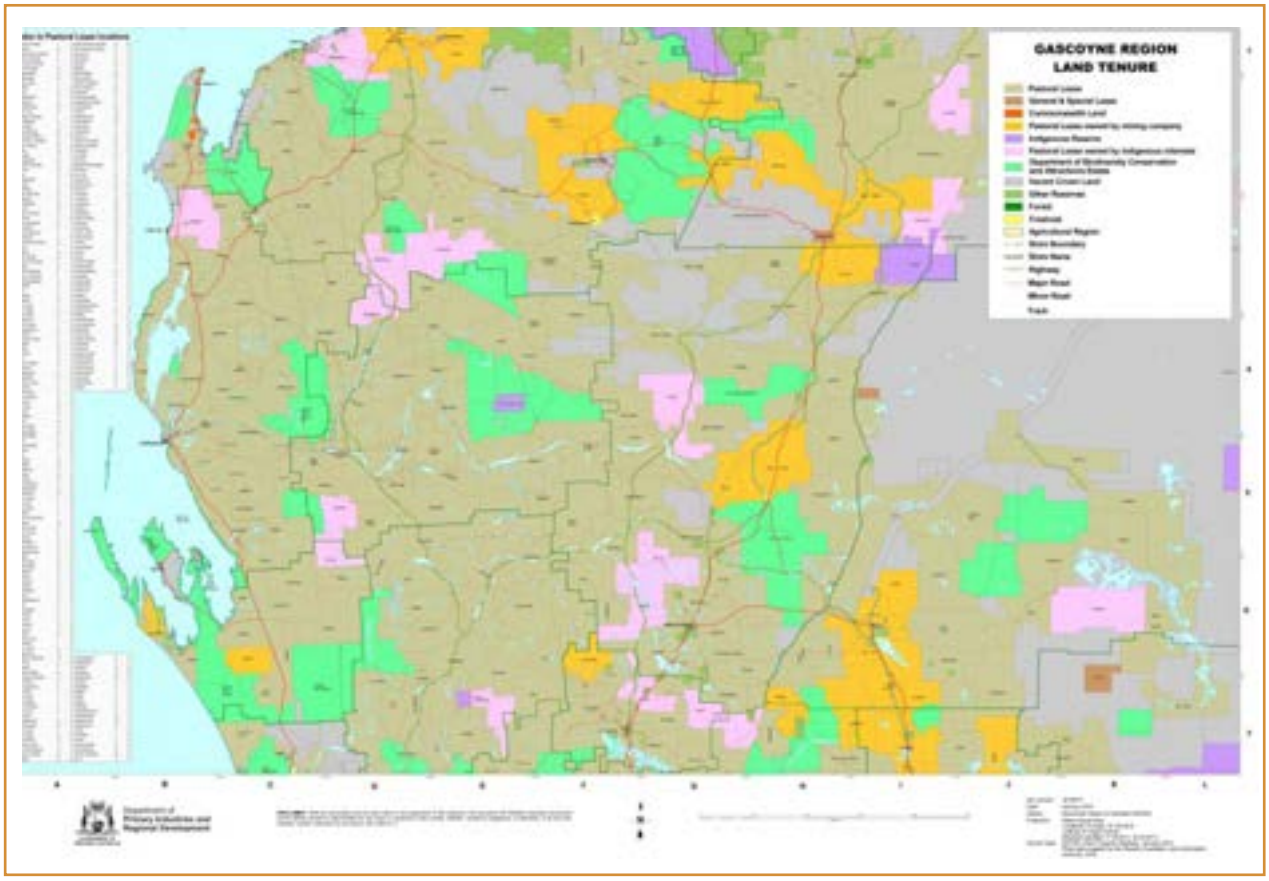


Figure 2: Land tenure, including pastoral stations, in the Gascoyne Region

In addition to the inland protected areas of the Kennedy Ranges and Mt Augustus national parks, the Gascoyne is also renowned for iconic coastal land and seascapes. Several are included in the conservation estate:

- Francois Peron National Park
- Cape Range National Park
- Exmouth Gulf Marine Park
- Jarralya National Park
- Nyinggulara National park
- Ningaloo Marine Park
- Gascoyne Marine Park, in Commonwealth waters
- Shark Bay Marine Park

Covering less than 1% of the total land area, intensive horticulture is located on the North and South bank of the Gascoyne River near Carnarvon valued at over $110 million. There are 180 plantations, with the majority of plantation sizes ranging between 2-40 hectares. In 2021, 300 ha of horticultural land was released in stage two of the Gascoyne Food Bowl initiative (Gascoyne Development Commission, 2024b).

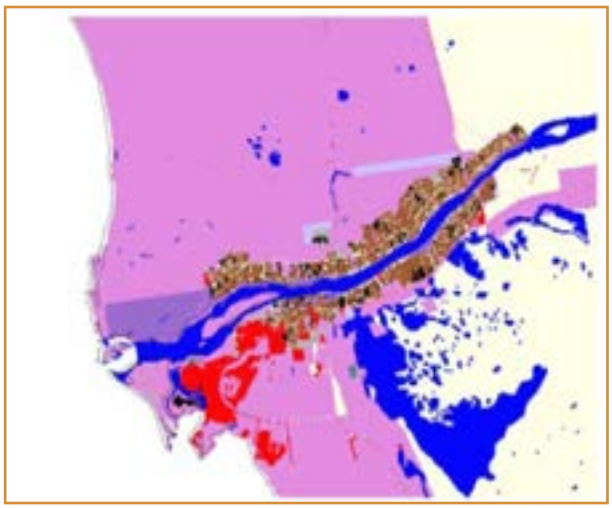


Figure 3: Land use classes showing intensive horticulture east of Carnarvon, WA

The industry benefits from productive soil types, sub-tropical climate, seasonal advantage, minimal pests and diseases, a secure water supply and industry-driven development. Around 1500 hectares of land is currently under cultivation producing a wide variety of fruit and vegetables. Major crops include bananas, table grapes, tomatoes, capsicums, melons and mangoes.

Innovations such as shade cropping, fertigation techniques, water use efficiency systems and investment in research, development and irrigation infrastructure and flood mitigation have increased the volume and value of product in the Carnarvon Horticulture District (Gascoyne Development Commission, 2024b).

Marine and freshwater environments

The Gascoyne region is characterised by vast coastlines, rich marine environments and freshwater ecosystems supported surface and surficial groundwater.

The Shark Bay World Heritage Area is one of the few areas around the globe that meets all four natural criteria for the World Heritage listing; natural beauty, biological diversity, natural processes and earth's history. Monkey Mia, in the eastern gulf of Shark Bay, was one of the first places in the world where wild dolphin interaction became possible. The Ningaloo Reef is one of the world's largest fringing coral reefs and is home to thousands of species of marine life and megafauna including migrating whale sharks, manta rays, turtles and humpback whales.

The Gascoyne Coast Bioregion is a distinct ecological zone from the Zuytdorp Cliffs, north of Kalbarri, to the Ashburton River, south of Onslow. The waters of the Gascoyne Coast Bioregion provide a marine environment that presents a transition between the fully tropical waters of the North West Shelf of the North Coast Bioregion and the temperate waters of the West Coast Bioregion. Offshore ocean temperatures range from about 22-28°C, while the inner areas of Shark Bay regularly fall to 15°C in winter.

Because of the many natural marine incubators such as coral reef, sand flats and seagrass beds, the Gascoyne Coast Bioregion features important breeding grounds, fish nurseries and feeding habitats. These conditions contribute to both successful commercial fisheries and a popular recreational fishery. The major fish stocks are generally tropical in nature, with

the exceptions of the temperate species, pink snapper, whiting and tailor, which are at the northern end of their range in Shark Bay.

The Gascoyne Coast Bioregion has been identified as one of 18 world 'hotspots' in terms of tropical reef endemism and the second most diverse marine environment in the world in terms of tropical reef species (Gascoyne Development Commission, 2024a, 2024d).

Groundwater dependant ecosystems are natural systems that rely on groundwater for their survival and ecological function. Groundwater dependant ecosystems often provide ecological functions that bring benefits to human communities, like water filtration, or protection from erosion during flood events.

About 20,483 km^2 (18.3%) of the Carnarvon Basin geological formation, which underlies the Gascoyne region, is covered by over 550 discrete terrestrial groundwater-dependent ecosystems (GDEs). These are all vegetation communities of various types, including sandy plains supporting acacia shrublands and low-lying evaporite pans with low shrublands of samphire and saltbush.

Various small springs are associated with groundwater-dependent wetlands, especially near major rivers such as the Gascoyne.

About 1979 km^2 (1.8%) of the Carnarvon Basin is classed as aquatic GDE. There are over 440 discrete GDEs mapped in the region. Most of these are stretches of the lower Gascoyne River and associated streams within the Gascoyne River catchment. There are also over 50 wetlands classed as GDEs, also mostly in the catchment of the Gascoyne River.

The Directory of Important Wetlands (DIWA) lists the following wetlands in the Gascoyne Region: Bundera Sinkhole; Cape Range Subterranean Waterways; Exmouth Gulf East; Hamelin Pool; Lake MacLeod; Learmonth Air Weapons Range - Saline Coastal Flats and Shark Bay East (Geoscience Australia, 2023).

Water resources

The Gascoyne region is covered by three major hydrological surface water catchments: Lyndon-Minilya River basin in the north, Gascoyne River basin in the centre, and the Wooramel River basin in the south (Figure 4).

Figure 4: Hydrological basin boundaries within the Gascoyne region

At 865 kilometres in length the Gascoyne River is the longest river in Western Australia and flows into the Indian Ocean at Carnarvon. It is joined by 36 tributaries and the 561 kilometre long Lyons River near Gascoyne Junction which together provide a catchment area of 68,326 square kilometres. The Gascoyne River (and other rivers in the Gascoyne region) is known locally as an upside-down river, because its surface expression flow occurs for only approximately 120 days of the year, while flowing below the surface of the dry river bed for the remainder of the year. The river's surficial aquifer, lying just below the surface, acts as a huge water storage system, and provides for important productive uses – including supporting the Carnarvon horticultural district. Water use for horticultural irrigation is managed through water licences, and provided through private bores. Scheme water is also available to growers which is supplied from areas upstream of Carnarvon. Approximately 12 GL of water is abstracted per year.

The Gascoyne River also features several permanent pools that are valued for stock watering and supporting native ecosystems in the inland pastoral areas (Gascoyne Development Commission, 2015).

The region's horticulturists use technology to produce large quantities of product efficiently. Carnarvon produces about $6 to $7 million of crop per GL compared to the national average of $1 to $2 million per GL (Gascoyne Development Commission, 2024b).

Domestic water use in towns across the Gascoyne Region is supported by groundwater resources. The Birdrong aquifer supports domestic water uses in the towns of Denham, Useless Loop and Coral Bay, with Denham's scheme water treated via reverse osmosis prior to use. The town of Carnarvon is supplied by groundwater from the unconfined to semi-confined aquifers of the lower reaches of the Gascoyne River. Groundwater from unconfined aquifers is extracted for town water supplies for Exmouth, Carnarvon and Gascoyne Junction (Geoscience Australia, 2023). Burringurrah Remote Aboriginal Community's scheme water is provided through access to confined groundwater resources, but was deemed unfit for human consumption on account of high concentrations of nitrates and uranium. Bottled water is currently supplied as a temporary solution whilst a permanent solution is investigated.

Climate

There are four major rain producing mechanisms in the Gascoyne region:

- Tropical lows and cyclones are the main source of heavy rainfall in the warmer months from November to March. From 1910 to 2000, 27 cyclones delivered significant rainfall to the region, approximately one every three and a half years.
- North-west Australian cloud bands form off the north-west coast of Australia and extend south-eastwards across the continent. They typically produce rainfall in the cooler months from April to October and can combine with cold fronts to produce significant rainfall. For example this occurred in 1980, when the region received the annual average rainfall in May and June.
- Cold fronts mainly occur during the cooler months and sweep across Western Australia from west to east. Most fronts pass to the south of Carnarvon and rainfall declines as the front moves inland.
- Troughs and lows with easterly winds can generate significant rainfall in exceptional cases producing either thunderstorms from throughs in warmer months or mid-level lows in cooler months. Thunderstorms generally affect inland areas and may result in small flows in upper catchment of the Gascoyne river, whereas mid-level lows generally affect the coastal areas.

While rainfall in the Gascoyne is generated in several ways, the last 25 years has included several years of challenging climate conditions, including low rainfall years, extreme events (including heavy rainfall and destructive winds) (Government of Western Australia Department of Water, 2011b).

Photo credit: Tourism WA

Gascoyne River Outlet
Photo credit: Andrew Robinson

Drought and other climate impacts in the Gascoyne

Different types of drought in the Gascoyne

Drought is defined in many ways. The way that drought is defined impacts on how the problems arising from drought are understood, and the actions or responses that are required (Motsumi et al, 2023). Four types of drought, most applicable to the Gascoyne, are described below.

Meteorological drought

Meteorological drought is when rainfall is less or more infrequent than expected. This is the most common definition of drought. The resulting lack of rainfall then impacts rain-dependent vegetation (whether natural or cultivated).

Meteorological drought in the Gascoyne impacts grazing dependent farming systems, including pastoral systems.

Hydrological drought

Hydrological drought refers to a lack of surface water or groundwater. Hydrological drought can arise from lack of rainfall, where an aquifer or surface water storage (like a lake or dam) is recharged or replenished by rainfall. Water storage (and recharge) is important for economic social and environmental value, including for domestic, stock watering and irrigated agriculture.

The Carnarvon horticultural district depends upon the shallow, alluvial groundwater of the Gascoyne River's lower reaches, and the seasonal surface water flows that recharge that system. River sand aquifer recharge can be extracted by spear-bores by individual farms, while the alluvial aquifer can be accessed by deeper bores, managed by Water Corporation, DPIRD and Gascoyne Water Cooperative.

Water from aquifers often has higher salinity levels than rainwater. When aquifers are not frequently recharged while extraction continues, salinity levels of extracted water can increase. Depending on the type of crops grown, the salinity levels could increase to levels that are detrimental to the crop, resulting in the aquifer sourced water becoming unusable for irrigation. This is also a form of hydrological drought: when water availability is limited by quality.

Vegetative drought

Often resulting from a lack of well distributed rainfall and a limited soil moisture buffer (and water holding capacity), vegetative drought refers to the lack of available vegetation for grazing. Good amounts and timing of rainfall, corresponding with the optimal temperatures and daylight periods, and soil water holding capacity, are all needed for vegetation growth. In the absence of one or all of these conditions, vegetative drought may occur. A vegetative drought can have far reaching impacts in grazing farming systems including pastoral stations in the Gascoyne.

Institutional drought

Institutional drought is drought created by water policy, water rights or governance measures. Such measures are usually established with the purpose of allocating scarce water resources among competing uses, or across competing users, where the total demand for water exceeds the sustainable yield of the water resource and to prevent over extraction.

Institutional drought occurs when actual (or allowed) water extraction is less than the user's water needs. Water licences are a widely used tool to manage scarce water resources. Groundwater resources surrounding the town of Exmouth are managed via water licences. Similarly, alluvial aquifer extraction in the Carnarvon horticultural district is also managed via water licences.

In addition, access to water can be limited, or affected by, other legal and government policy obligations. In Western Australia, water is often

linked to important environmental and cultural heritage values. Such values are protected through legislation and policy, including the Aboriginal Heritage Act 1972 (Government of Western Australia Department of Planning, Lands and Heritage, 2024a). Several tools exist to help land managers identify and protect cultural heritage values, including the Aboriginal Cultural Heritage Inquiry System (Government of Western Australia Department of Planning, Lands and Heritage, 2024b).

Measuring drought

Meteorological drought indicators

For meteorological drought, the first indicator is rainfall. Although that sounds logical, rainfall can be measured over different time intervals, most commonly reported as hourly, daily, monthly or annually.

For seasonal crops like wheat, the total rainfall over the growing season, including pre-season rain stored as soil moisture, could be used as an indicator of meteorological drought. For natural grasses, shrubs and other grazing vegetation on pastoral stations, a one-year running cumulative rainfall can be used to indicate drought periods. The limitation of this measure is that it does not account for rainfall distribution over the accumulated period. For example, if one single major weather event (such as a cyclone-induced precipitation event) contributed the entire rainfall event to the annual metric, the area might be reported as having an "average rainfall year", while much or nearly all of that year might otherwise have been dry, or experiencing drought. A statistical value of "standard deviation" for the rainfall value may provide a more a more complete picture.

While rainfall is measured at meteorological stations, the distribution of the stations in a region with low population, or population concentrated in the coastal areas, may misrepresent the actual climate conditions (or variability of conditions) across an area.

One way to overcome this is to use spatially distributed data, calibrated on point source data, but adjusted to additional knowledge of landscape and associated climatic conditions. Figure 5 shows the annual rainfall, spatially averaged over the Gascoyne Murchison region (based on data from Bastin, 2024).

A report by Bastin (2014), with an updated dataset up to 2024 (Bastin, 2024) shows a time-series of one-year rolling cumulative rainfall data, based on spatially distributed rainfall grids, for the Gascoyne-Murchison region (Figure 6). Blue squares represent high flow events. The brown line at value 50 indicates no-flow periods in the Gascoyne River at Nine Mile Bridge near Carnarvon.

It is important to note that while this data (Figure 5; 6) gives an indication of meteorological drought in the Gascoyne, it has limitations. This data gives a spatial average from a data set that includes data points in both the Gascoyne and the adjacent Muchison Region – a separate and unique region that is outside the scope of this plan. There is an opportunity for further work to better understand meteorological drought in the Gascoyne.

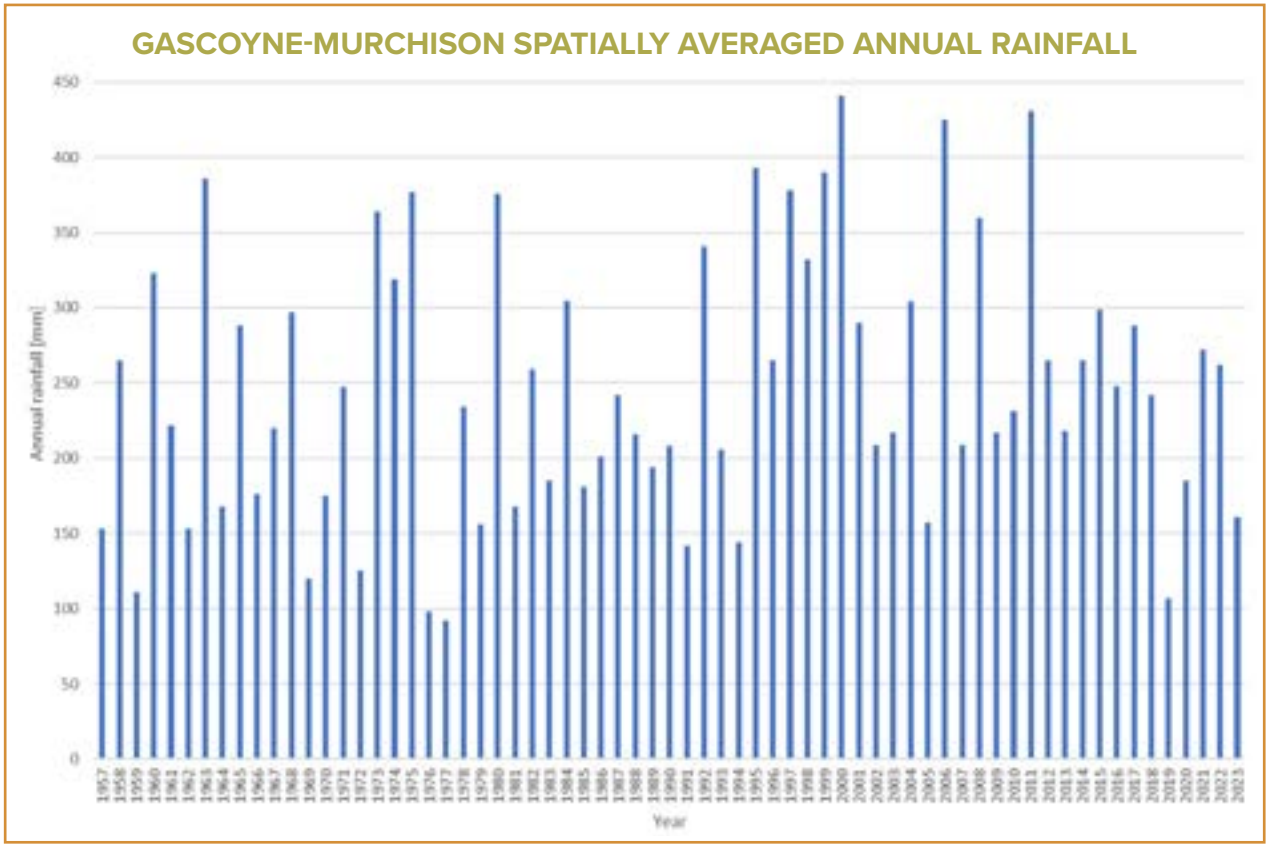


Figure 5: Gascoyne-Murchison spatially averaged annual rainfall

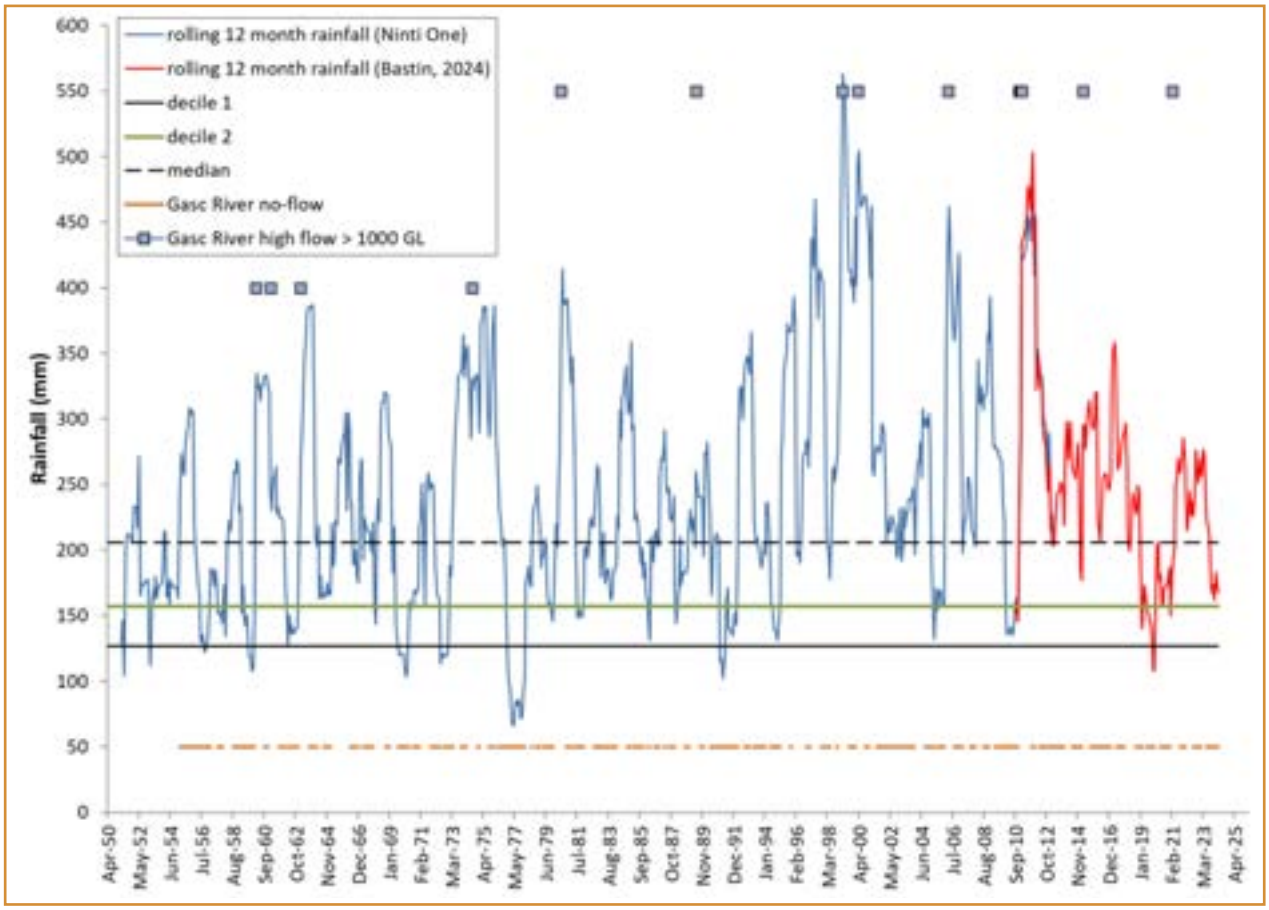


Figure 6: Twelve month rolling cumulative rainfall for Gascoyne-Murchison region (Bastin 2014; 2024), combined with no-flow periods in the Gascoyne River (line at value 50) and flow events of more than 1000 GL in a month (blue squares)

Hydrological drought indicators

Flow records of the lower Gascoyne River (Government of Western Australia Department of Water, 2024) are an indication of hydrological drought. While direct runoff is not directly used as a water source, the flow of the river recharges shallow alluvial aquifers, as well as the river sands used for direct pumping.

Annual descriptions of river flow variations are available from horticultural production summaries (DPIRD, 2022).

It is important to note that the Gascoyne River (and other rivers in the region) can and often does flow without 'local' rainfall, instead responding to rainfall that occurs in upper parts of the catchment. For example, the Lyons River has not flowed from local rainfall since 2022. There was also a gap of almost 2 years between flows, until December 2024 when the river flowed following rainfall in the upper catchment.

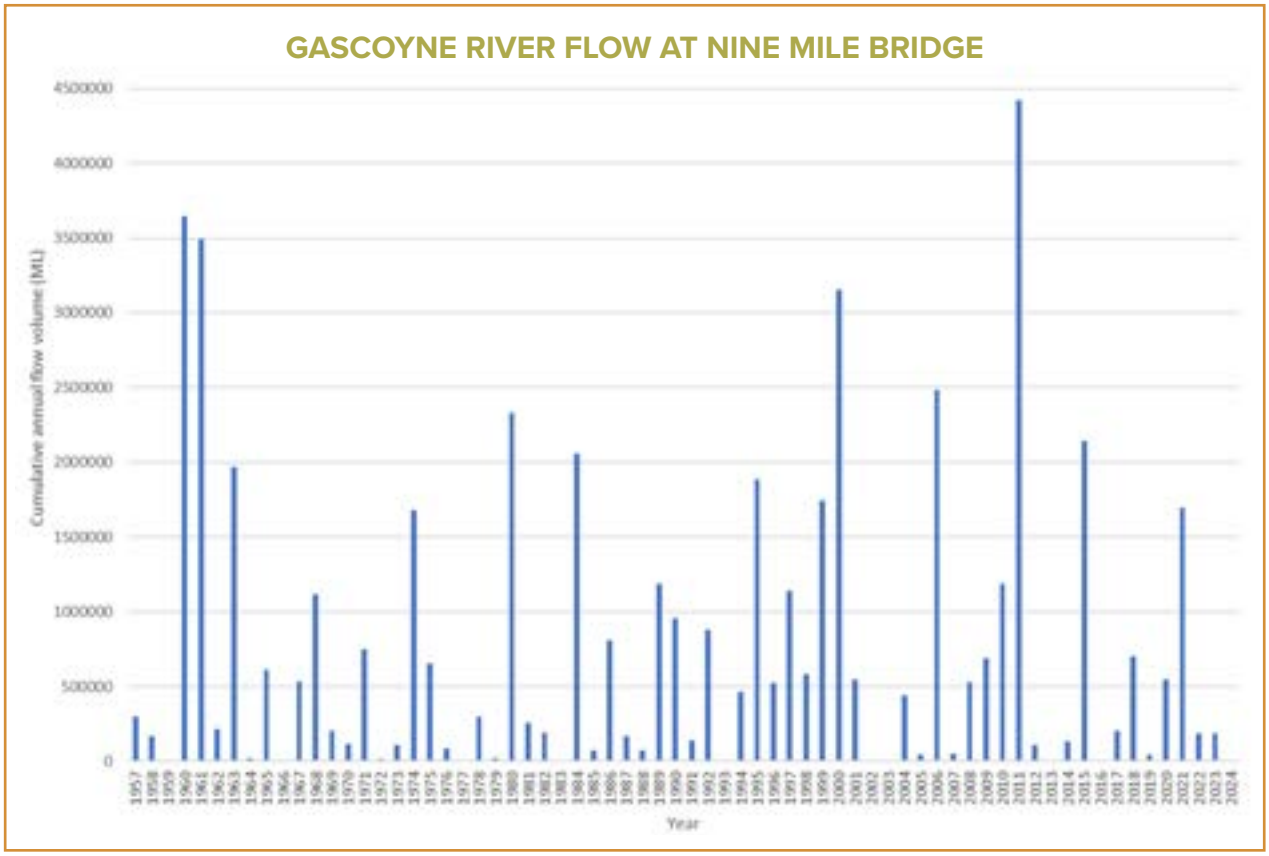


Figure 7: Gascoyne River total annual discharge at Nine Mile Bridge

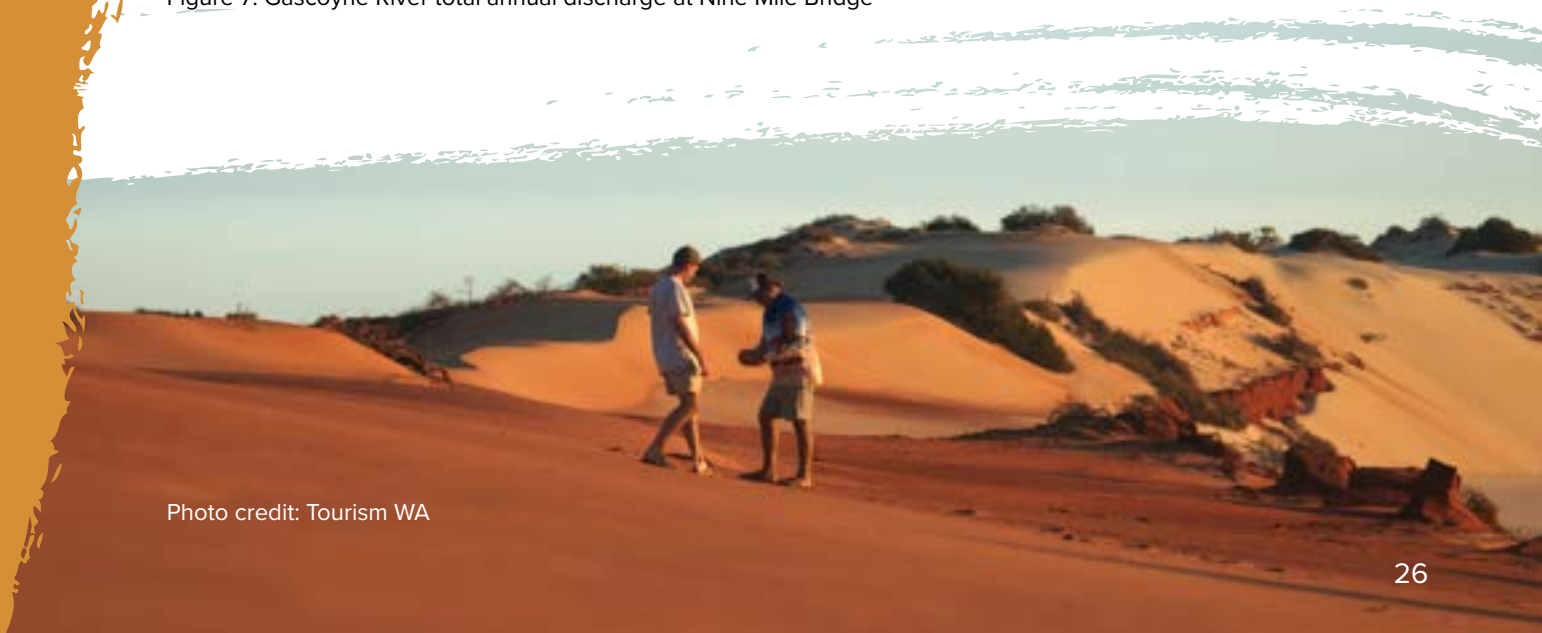


Photo credit: Tourism WA

Year	Description
2010	The Gascoyne River did not flow all year until 18 December 2010 when a monsoonal low crossed the coast and sat over Carnarvon for 6 days producing 255 mm of rain (BOM Carnarvon). This monsoonal low caused the river to flow with the headwaters reaching the Nine Mile Bridge on 18 December. The river peaked on 20 December at 7.74 metres
2011	The flooding event that occurred in late 2010 early 2011 was larger and of longer duration than any previously recorded. From December 2010 to February 2011 five peaks above 6 m were recorded at the Nine Mile Bridge, Carnarvon. The Gascoyne River continued to flow from these events until the 28 August 2011.
2012	The Gascoyne River flowed from 30 January to 21 March 2012 and the highest peak was 1.9 m recorded at the Nine Mile Bridge gauging station, Carnarvon in February 2012. No further flows were recorded for the remainder of the year.
2013	The upper Gascoyne River had two small flow events in May and June 2013. The closest these got to Carnarvon was 10 km upstream of the Nine Mile Bridge.
2014	The Gascoyne River recorded three small river flows in early 2014. The highest flow was 2.8 m recorded at Nine Mile Bridge gauging station on 3 February.
2015	The Gascoyne River flowed from 5 March until 13 August 2015 with a peak of 5.8 m on the 1 April. The river has not flowed since.
2016	No river flow reached Carnarvon in 2016.
2017	The Gascoyne River flowed from 5 February until 21 March 2017 with a peak of 2.8m on the 18 February. This was followed by two small river flows from 8 April to 23 April with a minor peak of 0.34 m and an even smaller peak of 0.04 m for the period 3 May to 5 May. The river did not flow for the remainder of 2017.
2018	The Gascoyne River had a flow that peaked at the Nine Mile Bridge on 17 January at 4.5 m and was followed by a secondary peak of 4.4 m on 13 February, ceasing to flow on 4 April. The third river flow for 2018 arrived at Nine Mile Bridge on 7 June peaking at 4.3 m.
2019	The Gascoyne River had one flow in 2019 that peaked at the Nine Mile Bridge on the 18 April at 2.2 m and stopped flowing in mid-May.
2020	The Gascoyne River peaked at Nine Mile Bridge on 17 February at 4.5 m with a further 3.4 m river peaking on 15 March and ceasing to flow on 22 April 2020.

Table 2: Annual descriptions of Gascoyne River conditions to 2020 (DPIRD, 2022)

Note: Historic flow data is more readily available for the Gascoyne River. There is a gap in available historical data describing flows of the Wooramel and Lyndon-Minilya catchments.

Time period	Period of no-flow (months)
May 1910 to January 1914	43
May 1937 to January 1940	31
February 1955 to February 1957	23
March 1976 to February 1978	22
July 1982 to March 1984	20
September 1992 to February 1994	18
May 2001 to January 2004	32
April 2009 to November 2010	20
March 2012 to December 2013	22
August 2015 to January 2017	18
May 2023 to June 2024	14

Table 3: Continuous months of no-flow for Gascoyne River at Nine Mile Bridge for periods exceeding 12 months.

Groundwater extraction data are not publicly available, but annual descriptions of water availability, both in quality, quantity and restrictions are available through annual horticultural production reports for Carnarvon (DPIRD, 2022).

Photo credit: Tourism WA

Year	Description
2012	The total draw from Subarea A in 2012 was 3.39 GL, comprising 0.4 GL unrestricted pumping and 2.99 GL restricted pumping. Draw from Subarea B-L for irrigation scheme water was 7.0 GL including 0.2 GL relief water drawn from October to December 2012.
2013	2 GL of relief water was issued under licence to the Water Corporation for the Gascoyne Water Cooperative to distribute for a one-year period to the end of September 2013. A further 1.5 GLs of relief water was made available in October 2012 for the next 12 months or until the river flowed again.
2014	Private bores in subarea A recharged sufficiently to allow irrigators to abstract 5.2 GL from subarea A which is about average year for this source. Approximately 4.0 GL was abstracted from the southern borefield which was below its normal allocation and 2.4 GL was from the northern borefield, which is its highest ever production, but still below its allocated amount. During 2014 all irrigation water supplies provided approximately 12.0 GL which is about average for the district. There was, however, limited trading of scheme water and some properties in subarea A had high salt levels, which resulted in some properties having a limited water budget for the year.
2015	Abstraction for horticulture during 2015 was below average due to a combination of limited supplies in January and February, the impacts of Tropical Cyclone Olwyn, overcast weather during winter and a mild start to summer. Annual abstraction from Subarea A was 4.6 GL, whilst the GWC scheme delivered 4.3 GL from B-L southern borefield and 1.5 GL from the northern borefield. Overall GWC members used 68 per cent of their shares for the year.
2016	In 2016 the total irrigation use was 11.6 GL, which is 0.8 GL above the 5 year average. Of this, 3.8 GL was abstracted from Subarea A, which was slightly below average. In comparison Subarea B-L produced 7.8 GL which was above average. Demand for irrigation water was high to the end of 2016 because of warm weather patterns, late harvests for mangoes and grapes and the availability of additional Low Aquifer Storage (LAS) water. Demand was able to be met by the irrigation scheme, except during a number of short outages.
2017	Abstraction for horticulture during 2017 was above average, primarily due to the greater level of plantings. Annual abstraction from Subarea A was 5.6 GL, while the Gascoyne Water Cooperative (GWC) scheme delivered 4.8 GL from B-L southern borefield and 2.8 GL from the northern borefield. Overall GWC members used 90 per cent of their shares for the year.
2018	Estimated total water abstraction was 13.2 GL in 2018. Annual abstraction from Subarea A was 6 GL while the Gascoyne Water Cooperative (GWC) scheme delivered 4.2 GL from B-L southern borefield and 3.1 GL from the northern borefield
2019	Total groundwater abstraction for 2019 was 12.69 GL.
2020	Total groundwater abstraction for 2020 was 13.39 GL.

Table 4: Descriptions of groundwater extraction volumes (DPIRD, 2022)

Vegetative drought indicators

Green drought, or vegetative drought, can be quantified for large areas through remote sensing data. A standard measure is the Normalised Differential Vegetation Index (NDVI). However, for grazing this was found to underestimate available feed, since dry grasses and shrubs can still contribute nutrition to grazing sheep and cattle. Vegetation cover is another measurement that can be used to monitor the availability or lack of grazing potential.

Pastoral Remote Sensing (PRS) reports are published by the Department of Primary Industries and Regional Development and provide information that can be used by land managers to infer vegetative drought conditions. Figure 9 shows monthly data in three different years, allowing comparison of estimated total vegetation cover between high years (e.g. 2021), low years (e.g. 2020) and the current year (2024).

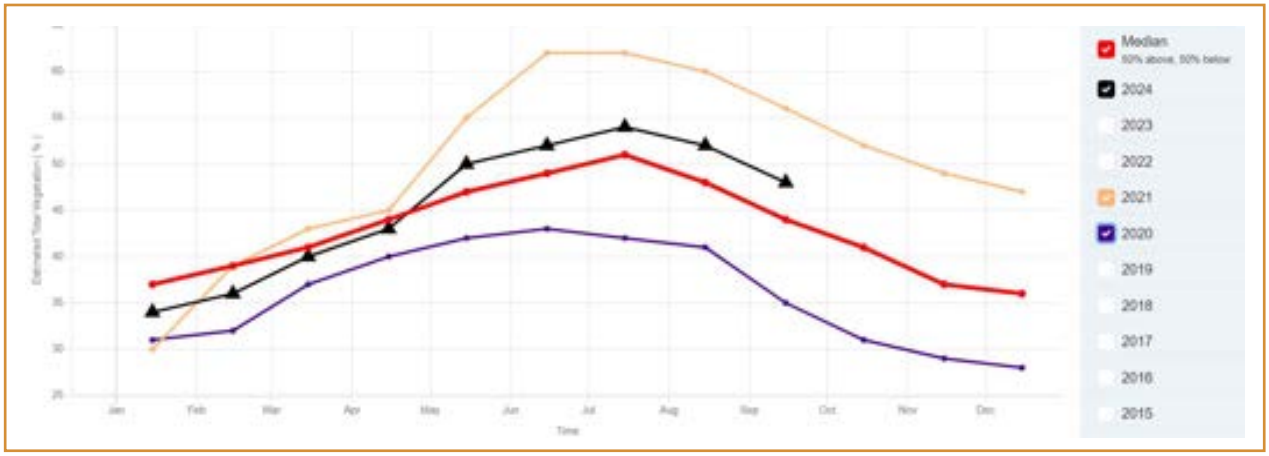


Figure 8: Example of a year with low total vegetation (2020), high total vegetation (2021) and the current status of total vegetation (2024) on an anonymous station.

Government of Queensland maintains a dataset named AussieGRASS. This combines simulated variables and climate data for all regions in Australia. Data for four local government areas in the Gascoyne region were extracted representing total standing dry matter on a monthly time step. Figure 9 shows the seasonal variation between summer and winter periods, as well as the variations between years.

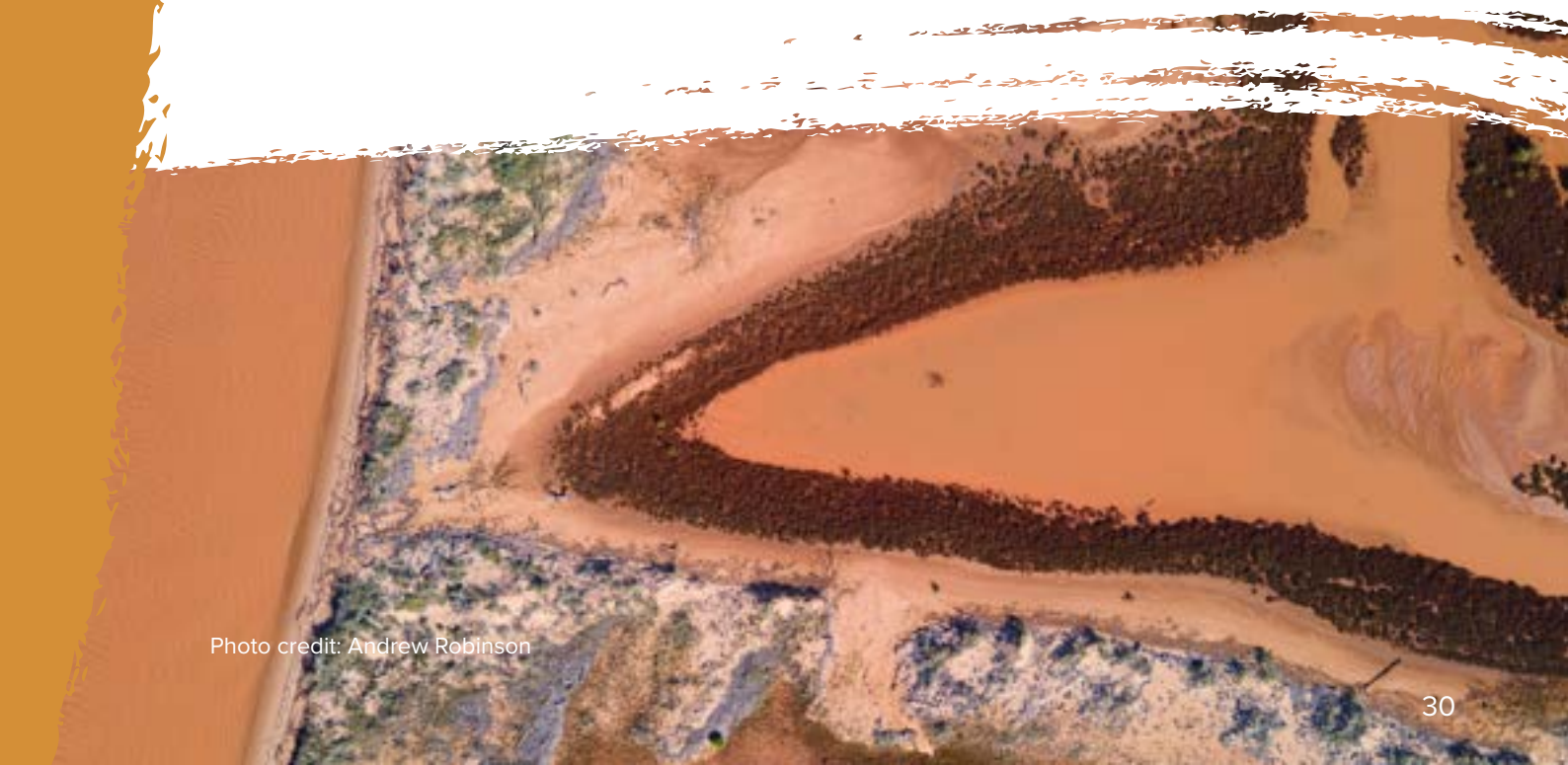


Photo credit: Andrew Robinson

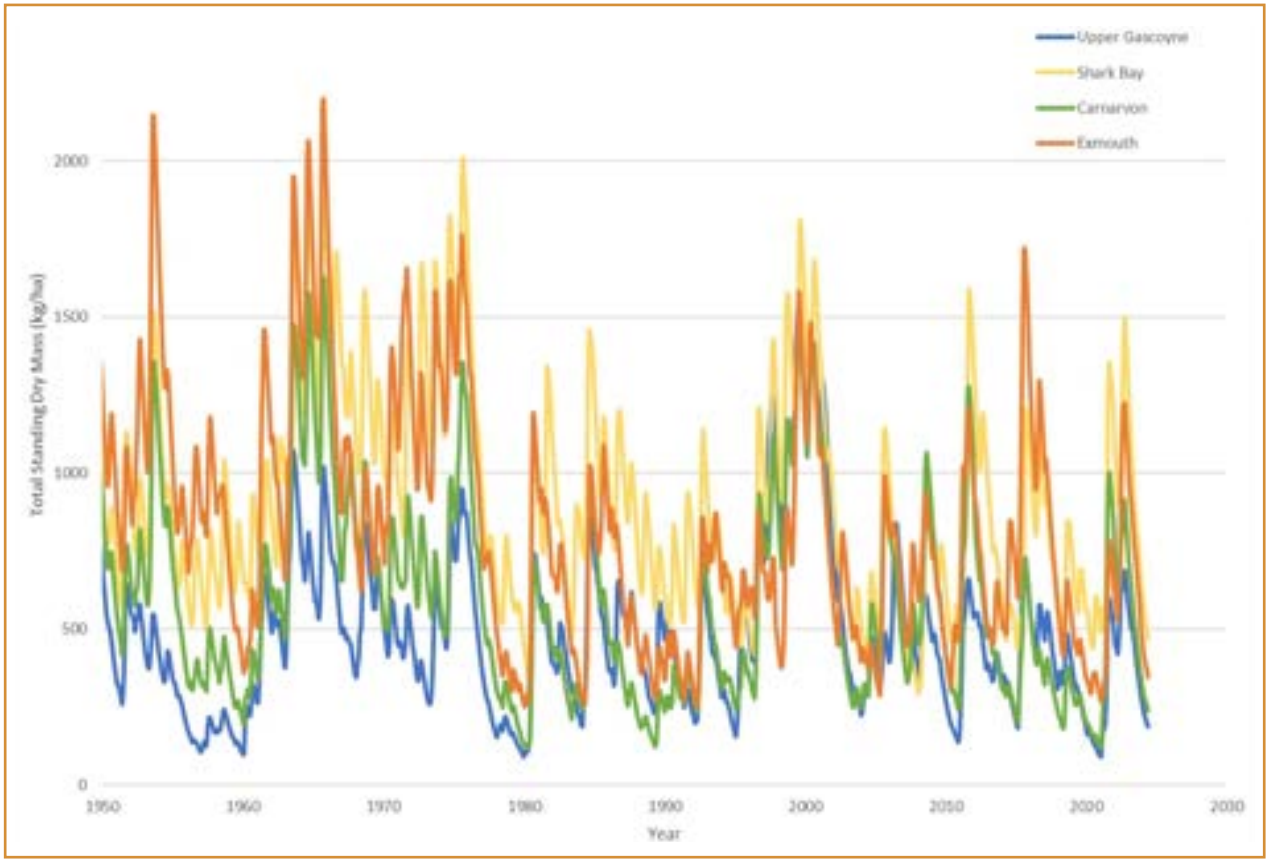


Figure 9: Total Standing Dry Matter (TSDM) averaged using local government areas in the Gascoyne region in kg per ha.

Institutional drought: water allocation and licencing

Water allocation planning and licences are among several tools used to manage water resources by limiting groundwater extraction in the Gascoyne. Groundwater allocation plans exist for the groundwater resource surrounding the town of Exmouth (see Exmouth Groundwater Subarea Allocation Plan 1999 by the former Water and Rivers Commission and the Exmouth Groundwater Subareas Allocation Limits Review report released in 2025 by the Department of Water and Environmental Regulation). The Carnarvon Artesian Basin Water Management Plan was released by the Department of Water in 2007 to ensure that groundwater resources of the Carnarvon Artesian Basin are managed effectively, noting increasing demand from new development proposals, existing pastoral users and the limited recharge potential of the aquifer.

In the Carnarvon horticultural district, the Lower Gascoyne water allocation plan sets out measures to manage local water resources. The plan has several objectives:

- maximise the volume of water for abstraction, while minimising the risk to groundwater quality, individual licensee supply reliability, and to in situ values,
- ensure continued provision of good quality water from Subarea B-L for the town of Carnarvon's drinking water needs,
- support the increasing agricultural potential of the region by allocating additional water in Subarea B-L, through water service providers,
- redistribute water abstraction from areas of poor water quality to areas of high water quality to avoid permanent salinity damage and maximise the productive use of the resource.

A maximum annual volume of 21.7 GL is available to users:

- 6.1 GL from alluvial subarea A, available for general licenses,
- According to the Lower Gascoyne Water Allocation Plan (2011), the maximum annual groundwater allocation volume is set at 21.7 GL:
  - ◊ Lower Gascoyne alluvial aquifer (Subarea A): 6.1 GL/year
  - ◊ Lower Gascoyne alluvial aquifer (Subareas B–L): 15.5 GL/year
  - ◊ Surficial aquifer: 0.1 GL/year (set as a nominal limit for small-scale local use)
- 0.1 GL from Yandoo surficial. The total volume is allocated for general licences.

Subarea A has relatively high water use, is privately abstracted and is over-allocated, whereas subarea B–L has relatively low water use, is distributed through an irrigation supply network and water is available (Figure 10). The water allocation plan highlights that "while licensed entitlements in subarea A still exceed the allocation limit, more water is available from subarea B-L. Transfer of water, localised options to increase take and efficient use of water will enable further development without risking water quality impacts."

Water users require a water licence to lawfully abstract groundwater and surface water under section 5C of the Rights in Water and Irrigation Act 1914 in this area (Government of Western Australia Department of Water, 2011a). Water licenses are published through a geographically-based information system (Government of Western Australia Department of Water and Environmental Regulation, 2024).

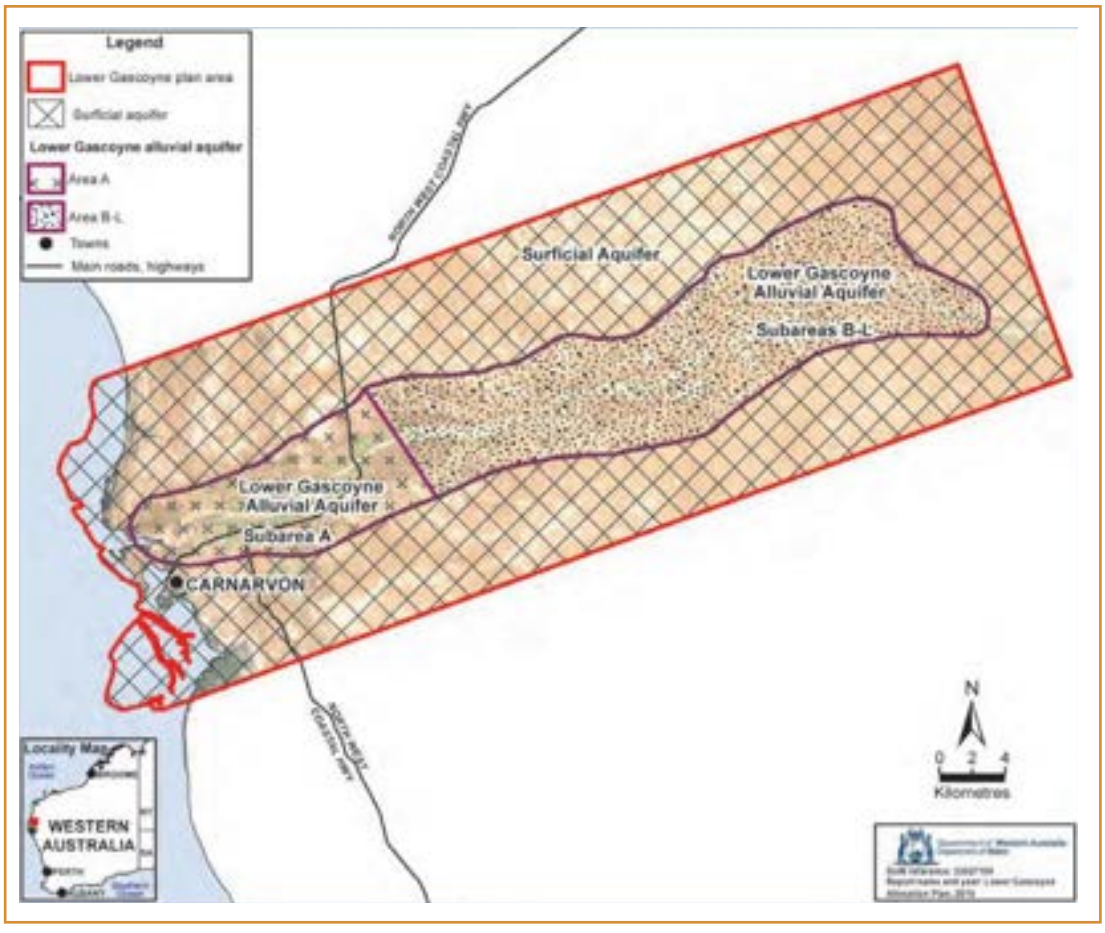


Figure 10: Resource boundaries used in the Lower Gascoyne water allocation plan.

Descriptions of annual implementation of groundwater extraction are available through annual horticultural production summaries (DPIRD, 2022).

Year	Description
2011	The Department of Water declared unrestricted pumping for the months January, February, March and April 2011. Whilst the river continued to flow, surface water measured above 1000 mg/L TDS in April 2011. This resulted in restricted pumping being declared until the end of the river flow in August.
2012	The Department of Water declared unrestricted pumping for the month of February. During March the river receded and the electrical conductivity increased to more than 1000 mg/L TDS. This caused saline intrusion into part of the aquifers which reduced the available storage of usable water.
2013	As there were no surface flows the Department of Water did not declare unrestricted pumping during 2013. Low Aquifer Storage (LAS) status declared in October 2012 remained in place for the irrigation district through 2013. In November 2013 the Minister of Water and the Department of Water in consultation with the Carnarvon Water Allocation Advisory Committee temporarily increased the salinity threshold from 1000 mg/L TDS to 1200 mg/L TDS for licences that met certain criteria to allow the take of the saline tainted water in the river bed sands.
2014	Gascoyne river flow in February allowed unrestricted pumping from the river bed sands for the months of February and March. These flows replenished the shallow river bed sands aquifer allowing Low Aquifer Storage (LAS) status to be lifted in April 2014. The flows significantly improved average salinity across subarea A, but some areas of elevated salinity were still evident. The recharge to the deeper older alluvium was much less with many production and monitoring bores in this resource showing no significant improvement post flows. Careful management of both northern and southern borefields was required to minimise drawdowns and salinity increases
2015	Salinity of the flows was much improved compared to 2011 and 2012 flows with the bulk of the water measuring around 230 mg/L Total Dissolved Solids (TDS). The salinity of the flows increased as the river levels dropped and salinity peaked at around 800 mg/L TDS by the end of the flow. The Department of Water declared unrestricted pumping for March through to June 2015, ending it prior to the cease to flow due to the salinity being higher than 500 mg/L TDS as per the Lower Gascoyne Water Allocation Plan (2011). The flows resulted in a good recharge to the Lower Gascoyne River aquifers with the Riverbed Sands aquifer being fully recharged, while the recharge from non-flooding flow events to the Older Alluvium Aquifer (OAA) storage is subdued and delayed. This is because the infiltration is slower due to the clay nature of the OAA system, lower pressure head and a smaller area of river bed being submerged. However, the final levels observed in the OAA were the highest since 2010-2011 floods. At the end of 2015, measurements of the aquifers indicated that the Riverbed Sands aquifer was 61 per cent full whilst the OAA still had adequate storage volumes of good quality water to allow 100% of Cooperative shares to be met from irrigation scheme water supplies through 2016.

Table 5: Descriptions of groundwater planning and license considerations (DPIRD, 2022)

Year	Description
2016	With no river flow reaching Carnarvon during 2016, aquifer storage has declined consistent with usage. As of December 2016, storage within the River Bed Sand in Subareas A and B-L is estimated at 20% full, with 3.9 GL in storage. Storage in the Older Alluvial Aquifer across the same area decreased by 1.0 GL between September 2016 and December 2016. Overall the salinity of water from the borefields remained stable during 2016 but it can fluctuate depending on which bores are operating. The salinity of the north and south borefields was about the same. From July 2016 to January 2017 the average salinity of Subarea A production bores was 760 mg/L TDS, which is an increase of 32 mg/L TDS compared to the first half of 2016. Since July 2015, 46 Subarea A bores have been recorded between 850 and 1000 mg/L TDS, whilst 31 have been recorded over 1000 mg/L TDS.
2017	As per the Lower Gascoyne Water Allocation Plan (2011), the Low Aquifer Storage policy was activated on the 1 December 2016. Approximately 0.2 GL of LAS was delivered in the December 2016 to February 2017 period. LAS status ceased when the 5 February river flow event reached Nine Mile Bridge. Salinity of the flows was as low as 119 mg/L with the bulk of the water measuring around 200 mg/L Total Dissolved Solids. The salinity of the flows increased as the river levels dropped and salinity peaked at around 700 mg/L TDS by the end of the flows. The Department of Water declared unrestricted pumping for February through to April 2017, ending it as the cease to flow was recorded on 21 March. The flows resulted in good recharge to the Lower Gascoyne River aquifers with the Riverbed Sands aquifer being 80 per cent recharged. At the end of 2017, measurements of the aquifers indicated that the Riverbed Sands aquifer was 30 per cent full while the Older Alluvium Aquifer still had adequate storage volumes of good quality water to meet the 2018 water Demand.
2018	Unrestricted pumping was declared for January to March then, due to declining river levels and water salinity rising above 476 mg/L TDS, restricted pumping was in place from April. Unrestricted pumping was declared for June only. Projections for 2019 indicate that without a river the borefield supply will meet predicted demand, with Subarea A predicted to become limited toward the end of 2019.
2019	Unrestricted pumping was declared for April and May then, due to declining river levels and water salinity rising, restricted pumping was in place from June. Projections for 2020 indicate that without a river the bore field supply will meet predicted demand, and Subarea A supplies would become limited toward the end of 2020.
2020	Unrestricted pumping was declared for February and March then, due to declining river levels and water salinity rising above 476 mg/L TDC, restricted pumping was in place from April. Projections for 2021 indicate that even without a river flow to recharge the aquifer, the bore field supply will meet predicted demand. Subarea A supplies, however, would become limited toward the end of 2021.

Table 5: Descriptions of groundwater planning and license considerations (DPIRD, 2022) cont.

Combining drought indicators

While different definitions of drought are measured using different indicators, a combination of the indicators can identify the overall regional impact of drought. Figure 12 shows graphically when droughts occurred in the Gascoyne region. The large grid shows the years from 1950 (left upper corner) until 2029 (right lower corner). Each year has a grid of 6 indicators and 12 months. The six indicators are

1. 12-month rolling rainfall for Gascoyne Murchison region,
2. Total standing dry matter in Exmouth,
3. Total standing dry matter in Upper Gascoyne,
4. Total standing dry matter in Carnarvon,
5. Total standing dry matter in Shark Bay,
6. Rolling 12-month total river flow in Gascoyne River at 9-Mile bridge.

Note that no data for groundwater extraction are publicly available, and no data on institutional restrictions leading to drought conditions are available. Further, the most comprehensive data available for river flows is for the Gascoyne River. Its is important to note that the Gascoyne River is not a reliable indicator of surface water availability in other parts of the region, including the Lyndon-Minilya or Wooramel River catchments.

Each indicator was evaluated on its own for 'drought' or no 'drought'. Twelve month rolling rainfall totals used decile 2 from the available data as a cutoff. For the available data, the decile 2 value was 168 mm. Thus, when the spatially averaged and summed monthly rainfall data for the Gascoyne Murchison, accumulated over 12 previous months, was less than 168 mm, a drought condition was assigned.

For the total standing dry matter (TSDM), a similar approach was used and decile 2 of the data was identified as being in drought. Note that these result in relative drought conditions, averaged over shire boundaries. Thus, the decile 2 values differ by shire, with Exmouth using less than 452 kg/ha TSDM as a drought condition, Upper Gascoyne using less than 212 kg/ha, Carnarvon using less than 300 kg/ha and Shark Bay using less than 605 kg/ha. This approach takes into account spatially variable the long-term landscape vegetation coverage over a period between 1890 and 2024.

The river flow was summed over a 12-month rolling average, and when no flow was measured, a drought condition was assigned. Note that data from 1950-1956 are not available for this indicator.

The resulting graphical presentation in Figure 12 shows that the different indicators identify drought conditions at different times from each other. This is a strong argument to consider more indicators than rainfall alone. Periods where most indicators converge are prolonged droughts that affected all sectors in the region. These periods appear to correspond with the years 1959-1960, 1978-1980, 2010 and 2019-2021. Early 2024, drought conditions were formed using the multiple drought indicators.

Since a binary condition is based on arbitrary conditions, despite the previous approach, normalised values for each indicator are displayed in Figure 13. Each dataset is normalised against the maximum value for each indicator, thus resulting in values between 0 and 1. The values for rain and flow were normalised against logarithmic values due to the nature of extreme high values in a relatively low number of observations. Using the logarithmic values allows for a better representation of medium rain and medium flow conditions.

The normalised value was inverted, so that a value of 0 indicates the maximum value in the time series, and 1 indicates the zero value in the time series. Some of the high rainfall events correspond with high river runoff values, but not consistently. While vegetation often reaches non-drought conditions after major rainfall events, this is also not a consistent relationship. This is likely the result of using different spatial extents for the datasets (with the river flow measurement being a point based rather than a spatially averaged value).

Standardised Precipitation-Evaporation Index (SPEI)

The U.S. Drought Monitor (USDM) identifies areas in drought and labels them by intensity (United States Drought Monitor, 2024). It uses an indicator that combines precipitation and evaporation demand. It classifies regions based on the intensity of estimated drought, with 6 classes:

1. Normal or wet conditions (SPEI > -0.5)
2. Abnormally dry, category D0 (-0.5 =< SPEI < -0.8)
3. Moderate drought, category D1 (-0.8 =< SPEI < -1.2)
4. Severe drought, category D2 (-1.2 =< SPEI < -1.6)
5. Extreme drought, category D3 (-1.6 =< SPEI < -2.0)
6. Exceptional drought, category D4 (SPEI > -2.0)

Spatial data worldwide are available from January 1901 until December 2023 in monthly averages, 12-month averages and 48 month averages (Climate Data Guide, 2024). Figure 11 shows a monthly average SPEI example for the Gascoyne region in December 2023. Time series for years with varying drought indicators are shown in Figure 14. The year 1953 showed a dry start followed by a healthy vegetation cover in Figure 13. The SPEI shows that 1953 had few drought indicators. The year 1979 showed a second year in drought using the indicators above, while the SPEI showed high drought risk in January, June and October, and exceptional drought in July. The year 2000 showed a year without drought using the previously defined indicators. The SPEI data show drought risk in June and September. In 2010, the drought indicators showed low vegetation cover, and small amounts of rainfall distributed over the year. The SPEI data for 2010 show January, February and November with severe drought indications. In 2019, indicators show little vegetation, and little rain in the second part of the year. The SPEI data show the months September to December in exceptional drought.

The high monthly variation in the SPEI dataset suggests that long term accumulated values may be more suited as a drought indicator. However, this would result in delayed reporting, making it less suitable as a tool for drought preparation. The SPEI indicator does clearly show the spatial variability within the Gascoyne and supports the observations that some properties may experience drought while at the same time other properties do not.

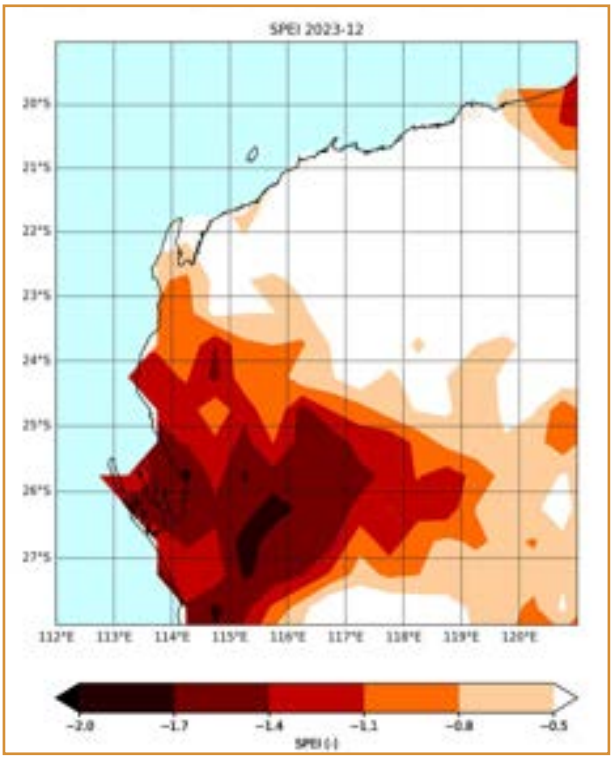


Figure 11: Standardised Precipitation Evaporation Index (SPEI) for Gascoyne region in December 2023.

The images above, from Bidgemia monitoring site illustrate the impact of landscape restoration works on vegetation growth from March 2024 (left image) to July 2025 (right image).

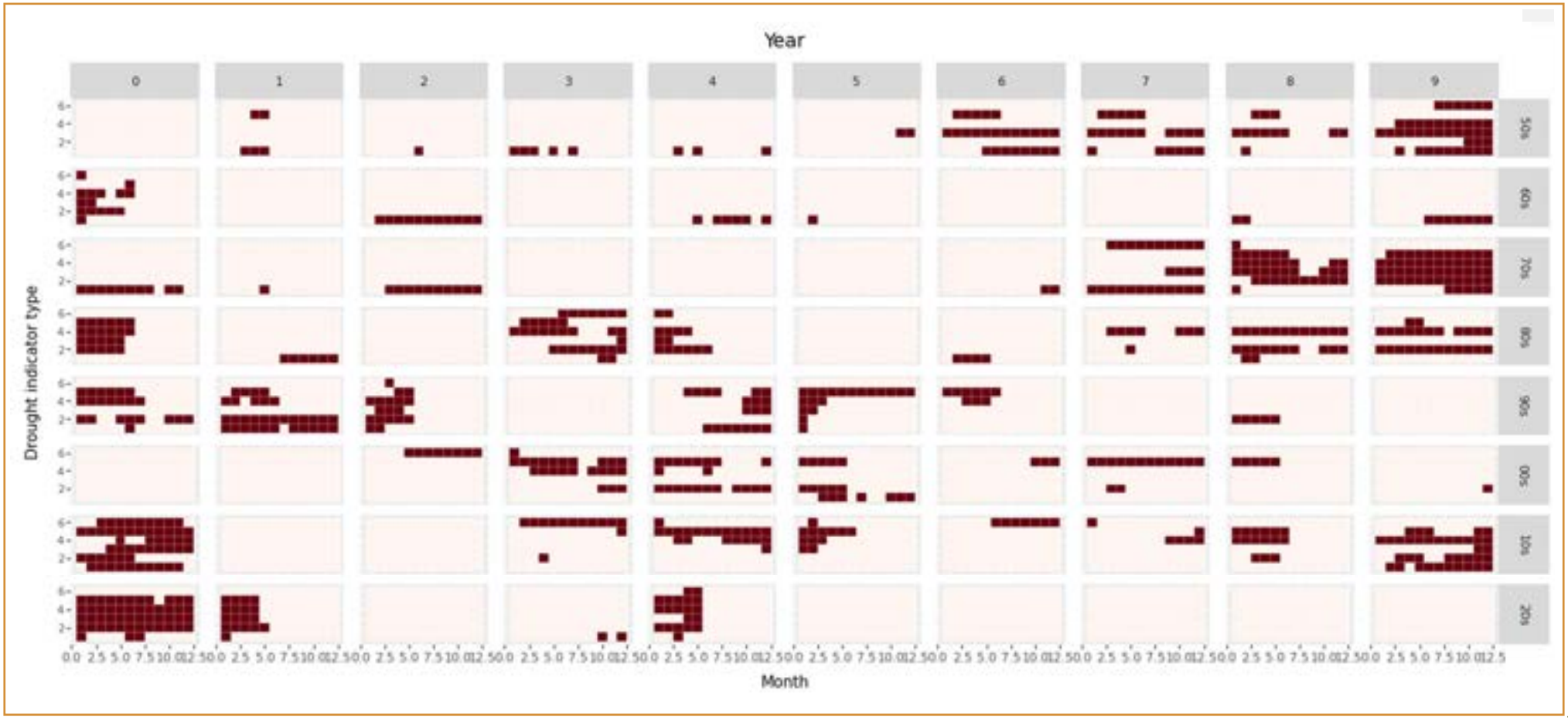


Figure 12: Combined drought indicators for the Gascoyne region from 1950-2024. Indicators are (1) 12-month rolling rainfall, (2) Total standing dry matter in Exmouth, (3) Total standing dry matter in Upper Gascoyne, (4) Total standing dry matter in Carnarvon, (5) Total standing dry matter in Shark Bay, (6) Rolling 12-month total river flow in Gascoyne River at 9-Mile bridge.

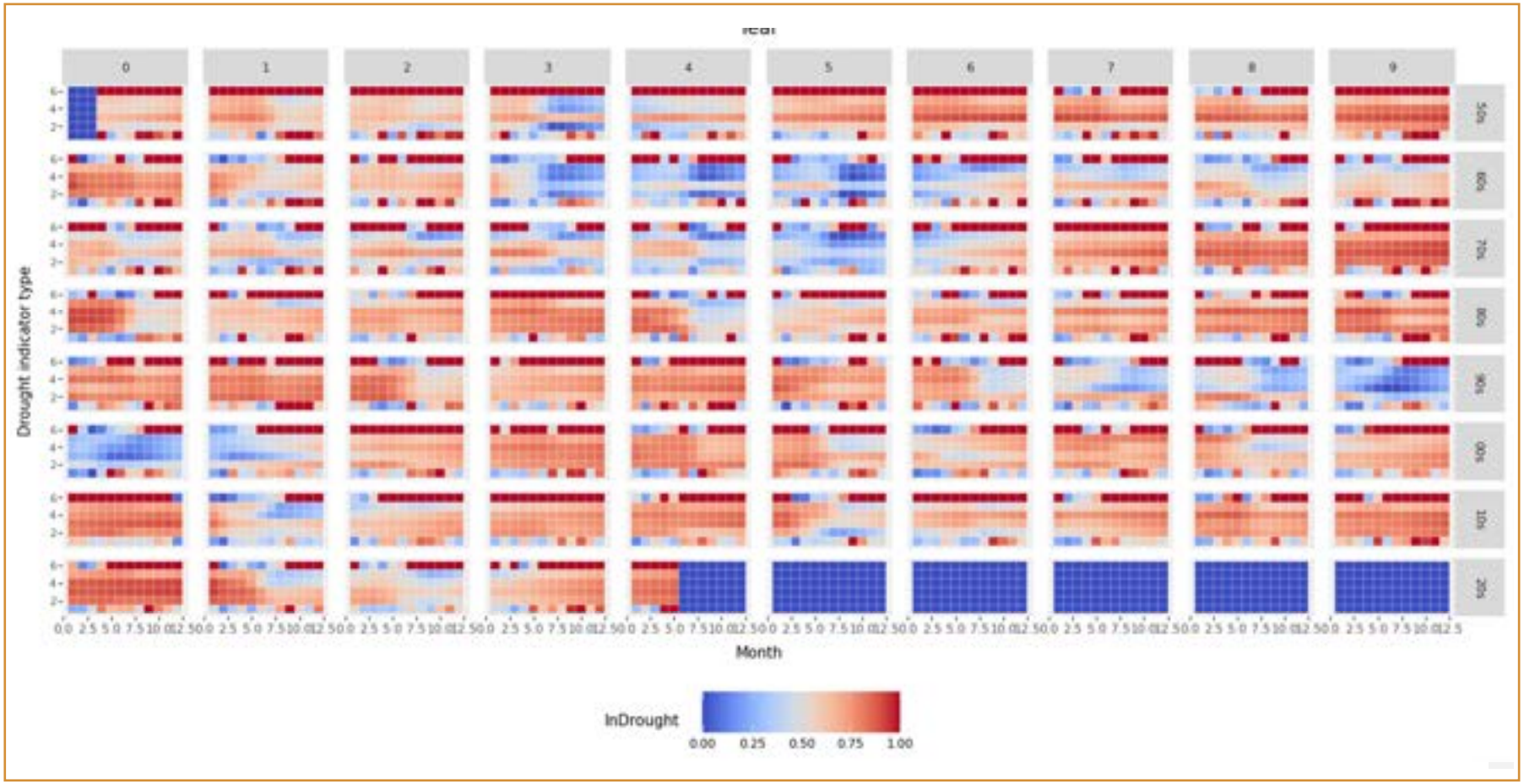


Figure 13: Drought indicators with values normalised against the maximum reading between 1950 and 1924. Same indicators are used as in Figure 12.

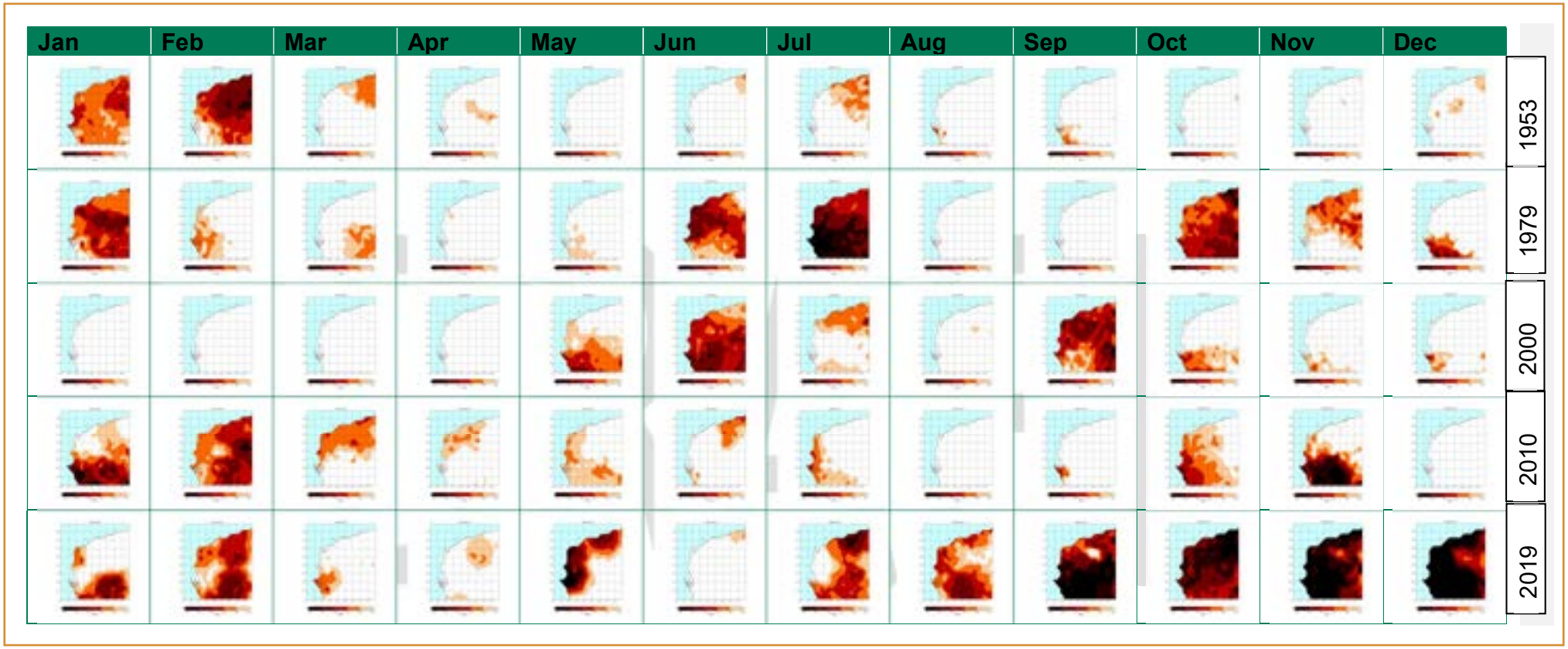


Figure 14: Monthly SPEI for 1953, 1979, 2000, 2010 and 2019 for the Gascoyne region.

Local experiences and impacts of drought

Communities and individuals feel and experience the impact of drought in many ways.

Through desktop review and consultation with communities and individuals across the region, this plan outlines the experiences of six major communities of the Gascoyne region: pastoralists, horticulturists, Traditional Owners, local government authorities, tourism industry representatives and fishers.

A summary of answers provided in an online survey designed to collect experiences and recommendations from stakeholders and conducted during the development of the Gascoyne Drought Resilience Plan is provided in appendix B.

Pastoralists: experiences and impacts of drought

Meteorological drought results in vegetative drought, which can have a large impact on pastoral operations and business productivity. Poor vegetation growth, limited soil moisture, reduced landscape rehydration, poorer topsoil condition and greater risk of topsoil loss can overall lead to a greater risk of lower productivity and higher risk of landscape condition decline. Pastoralists in the Gascoyne continue to manage these risks, in the knowledge that it is 'a matter of when, not if, there will be a poor season'.

In 2014, continuing drought resulted in stations destocking, reduced finances available to maintain station infrastructure, and a parched landscape (Australian Broadcasting Corporation News, 2014). In 2018 it was reported that in addition to destocking, some stations had to destroy stock due to a lack of adequate feed. To alleviate stress and prevent declining mental health, connections with other station owners was important. The article reporting on the drought also indicates that some pastoral stations had planned for a drought plan and had begun implementing drought plans (Australian Broadcasting Corporation, 2018).

In 2024, another period with a lack of rain resulted in drought conditions in the Gascoyne. One station started bottle feeding calves for the first time, and water and hay carting was required to ensure stock welfare. In addition to the physical impact, rising input cost, a depressed cattle market and high transport costs led to greater pressures on business operating conditions, and leading to greater pressures on mental and physical health among land managers on stations (Australian Broadcasting Corporation, 2024d).

To prepare for vegetative drought, reduced stocking rates are achieved by selling off stock. When drought conditions are experienced across large land areas, or across multiple production districts, resulting in an increase in supply to market, driving down market prices and business returns, further exacerbating challenging business operating conditions.

At the same time, growing demand for transport (e.g. delivering stock to market and for feed transport) results in higher business input costs, reducing revenue.

Large fluctuations in operating profits between financial years are common for the pastoral industry. There are many drivers: seasonal conditions, climate, market and economic conditions. While there is a sense of pride among many pastoralists, in overcoming challenging conditions from working on the land, the pastoral (and broader agricultural community) often report a lack of understanding from those outside the community, including for example, that the banking sector does not appear to recognise the nature of large boom and bust periods.

The on-station experience in a drought, and the interaction between station care, family, physical and mental health and financial worries is summed up by a response to an online survey for the Gascoyne Drought Resilience Plan:

"Very stressful, lots of decisions to be made using a variety of variables. Usually a lack of finance, due to extra costs associated with drought. Often less income due to lighter weight animals (and often lower prices during droughts). Work load increases - need to check water points more frequently, need to check cattle more frequently, need to muster and move animals more frequently, need to hand feed and care for early weaned calves. Mental health declines. Relationships get strained. No ability to take days off, leads to exhaustion and higher risk of accidents. Lack of finance inhibits social interaction, further exacerbating mental health decline. Lack of time to deal with personal health concerns, due to duty of care of animals and inability to leave the station. Children miss out on opportunities due to lack of finance and parents being unable to leave station."

Anonymous Gascoyne Region station owner.

There are also challenges around when land managers should begin preparing for drought. Land managers look for particular signals that indicate the need to take action – but there is a high degree of risk involved. In September 2023, an El Nino year was forecast prompting a sell-off of sheep and cattle. An ABC News article notes "Lamb prices for spring 2023 dropped almost half of what they were fetching the year before, with reports of sheep being sold for $1 each, while the main cattle value indicator dropped about 20 per cent over the same time" (Australian Broadcasting Corporation, 2024a).

In the Gascoyne, it is important to note that there is a variety of business models and objectives. Most stations focus on breeding with a variety of genetics in the region based on many generations. While some stations produce for the domestic market, others rely on export, particularly to the Middle East, some stations are continuing family farming traditions, while others are operated as a corporate business. This may impact drought preparedness decisions, with varying levels of emotional business decisions involved in making commercial decisions.

Horticulture: impact and experience of drought

Flood risk, cyclones (and storms) and market conditions are among the highest concerns for horticultural producers in the Gascoyne. Destructive floods and storms have caused widespread property and infrastructure damage to horticultural operations in the Gascoyne in the past, with significant financial losses for producers. Bushfire is also a concern. Most recently, a bushfire in the Carnarvon horticultural district in September 2024 caused widespread damage to property including water infrastructure, orchards and plantations on several properties (Australian Broadcasting Corporation News, 2024c).

However, drought is increasingly becoming a concern for Carnarvon's growers, particularly as a result of management measures designed to protect the groundwater resource. Pumping restrictions, salinity levels and conveyance capacity impacts water availability at individual farms. While the overall aquifer volume is adequate for current horticultural sector demand, flow rates during

peak demand periods (e.g. heatwaves) may limit the availability of water at the farm level. Groundwater abstraction restrictions are used to manage water resource use, including the risk of drawdown and salinisation. The water quality of recharge is also a factor for water managers. Further information is provided in Table 5: Descriptions of groundwater planning and license considerations (DPIRD, 2022).

In 2013, the media reported on impacts to growers after new restrictions on irrigation were introduced in the district (Australian Broadcasting Corporation Listen, 2013). With the introduction of alternate day irrigation (rather than daily), some banana plantations were left without adequate water. The impacts were reportedly felt across the entire community with a coinciding slowdown in the local economy. Two emergency water allocations were subsequently provided by the local water managers (an agency of the WA Government). In December 2013, plans were announced to form a Carnarvon Ministerial Advisory Committee focusing on the water crisis, and to better plan and prepare for drought conditions in the future (Australian Broadcasting Corporation News, 2013).

In 2015, the Carnarvon horticultural sector again experienced drought conditions with growers directed to limit water use to between 60 and 70% of their licence entitlement (Australian Broadcasting Corporation News, 2015a). New technologies were introduced to enable access to alternative water sources (Australian Broadcasting Corporation News, 2015b).

The Carnarvon Ministerial Advisory Committee released recommendations in 2016 (Government of Western Australia, 2022) to create a more secure water supply with recommendations under the themes:

- Upgraded and integrated water supply systems
- Improved Gascoyne Water governance and viability
- Commitment to the expansion of the Carnarvon horticultural industry
- Improved water resource planning and management

The implementation of the committee's recommendations have resulted in a more reliable water supply for the horticultural sector.

Traditional Owners: impact and experience of drought

Aboriginal people in the Gascoyne have maintained a deep relationship with Country over many thousands of years, with lore and law, culture and responsibilities closely linked to water, seasons and climate. Their traditional ecological knowledge of how rivers, groundwater, plants and animals respond to changing conditions has supported sustainable land management practices, including during dry times and periods of climate variability and supporting communities to live with and protect Country over 65,000 years of history in the Gascoyne.

Communities have developed many ways to live with long dry spells and sudden floods, including reading Country to find water and food, changing where and when they travel, and passing knowledge between families and language groups. These strengths and lived experiences provide a strong base for building drought resilience today.

Drought, and now climate change, are putting pressure on country. Rivers and waterholes are drying or flowing differently, plants and animals are affected, and fires are behaving in new ways. This makes it harder for people to visit and care for important places. These changes affect people's health, cultural practices and how knowledge is passed between generations. Even with these pressures, Aboriginal communities across Australia continue to care for country, repair damaged areas and develop new ways to adapt, using both traditional knowledge and western science.

For example, at Burringurrah, Traditional Owners are working on an important landscape restoration project that aims to restore natural hydrological patterns and improve the condition of land that is managed by and is the traditional Country of the Burringurrah people. Those practices also have far reaching public benefits – in providing benefits downsteam (for example by reducing sheet flow velocity and potential flood intensity, reducing topsoil erosion).

Local perspectives of Traditional Owners on drought, water and climate change are essential to guiding future resilience actions and ensuring responses are culturally appropriate and place based. Ongoing, respectful partnerships between Traditional Owners, governments and other stakeholders are needed to uphold cultural protocols around stories and knowledge, and to determine how local histories and experiences should be represented in future planning documents.

Mt Augustus / Burringurrah

ABC

HEYWIRE

We live in a beautiful place, but the tap water could give us cancer

By Kenneth from Burringurrah, WA, Wajarri Country

Posted Tue 12 Dec 2023 at 3:56am

We live in a beautiful place, but the tap water could give us cancer *(Supplied: Emily Shawcross)*

I live in Burringurrah.

It's a small community, 300 kilometres west of Meekatharra.

The hills tower over grass trees, mulga wattle and river gums. My favourite season is wet season when everything is beautiful and green.

At the tail end of the wet season, behind the grass trees, mulga wattle and river gums, the hills are purple and blue.

Our community was named after a boy — Burringurrah — who ran away from tribal initiation long ago.

Burringurrah is a place of learning.

I've learnt how to hunt for bush turkey and kangaroo.

I've also been taught to throw sand in the rivers near my community, to let the water snake — the guardian of the pool — know that I want to have a swim in its water.

When I was younger, I learnt how to play chess from a teacher at school. Now, I've started playing against people online from all over the world.

When I'm playing chess, I like to try and predict my opponents' moves to win the game, to be ahead of everyone else.

I have three little brothers and two sisters. I want them to have the same educational opportunities as me.

I'm worried about them because the water here has uranium in it.

I have googled what uranium does if you drink it, and it sounds horrible. It can cause cancer and damage your kidneys.

We rely on a truck that brings water every few weeks. We store the plastic water bottles in sea containers.

I'm worried that the kids in my community might drink the tap water.

People are thinking of moving because they're worried the truck might stop supplying water to our community. People have said it could take up to two years until we have fresh water again in our community.

I think we should find another bore close to community so people can travel there and get water.

Because if the water is not fixed, my family and I might have to move from our home where we have lived for generations.

I read an article about a community called Buttah Windee. They faced the same problems as us with uranium in their water.

Most of the people had to move out of there. But the people who stayed fundraised for solar hydro-panel technology to make their water clean and drinkable.

They have installed solar hydro-panels. So, they didn't have to leave their home.

I would like it if the government installed solar hydro-panel technology in Burringurrah to make the water here drinkable.

Because I want my community healthy and happy.

Gascoyne towns: impacts and experience of drought

Denham and Monkey Mia, in the Shire of Shark Bay, are supplied with potable drinking water through a scheme that is supplied through desalination (Denham and Monkey Mia). There are no surface water resources and, except for pastoral stations in the shire, there is limited rainfall dependency.

The towns are linked to the North West Coastal Highway with a single road, which provides all the supplies by road transport. The Monkey Mia airport provides an airlink to Perth via Carnarvon. Natural assets, particularly around the iconic World Heritage listed marine environment are enablers of the local economy and local livelihoods (including fisheries and nature-based tourism). Pastoralism is also an economic contributor. The single road in and out the shire increases risk of freight and transport disruptions, especially from storms, flooding and cyclones.

Carnarvon's town water is also supplied from alluvial groundwater associated with the lower Gascoyne. Recycled (treated) wastewater is also used for irrigating public green spaces. Primary industries, including pastoral and horticultural are important economic contributors. Local economic conditions are tied to the success or downturn in primary industries – drought and financial hardship in the agricultural sector impacts local supply chains and local businesses.

A flow event in the Gascoyne River is therefore both a driver of biophysical changes in the surrounding natural and production systems, but also has impacts on the local economy, and has flow-on social and emotional consequences for local residents.

Rainfall in the catchment, and river flow, lifts the spirits of local people, with anticipation rising as upstream river flow gauging station readings and hourly reports on the downstream advancement of the river are shared among the community.

Exmouth relies on groundwater to supply town and maintain green spaces. Due to the high reliance on tourism, landscape irrigation is important for the liveability of residents and tourists. As in Carnarvon, recycled treated wastewater is used to maximise water use efficiency. Expansion of water resources access is in the planning due to rising population and increasing tourist numbers, as well as an increase in military personnel located in the shire (Australian Broadcast Corporation, 2024e).

Towns in the Shire of Upper Gascoyne rely on groundwater resources. Gascoyne Junction has several green public open spaces, and has been recognised for its amenity values and sustainable water management practices as a Tiny Towns Sustainability Award winner in 2023.

At Burringurrah Remote Community, potable water was, for many years, provided through a scheme fed by local groundwater. Within the last decade, the quality of the supplied water was found to be outside safe standards for human consumption. While residents still use scheme water for non-potable domestic uses (washing, bathing, garden irrigation) bottled drinking water is supplied to community residents for drinking.

The community have continued to advocate for a permanent solution, such as a permanent water treatment facility. WA's Water Corporation, a government trading enterprise, have committed to deliver a permanent solution by 2027.

Building and Strengthening Resilience to Drought

Many communities in the Gascoyne self-identify as being highly resilient. Preparing for and recovering from significant events including drought, cyclones, floods, bushfire and heatwaves is a way of life for people that live and work in the Gascoyne.

Resilience is the capacity to withstand or to recover quickly from difficulties. Drought resilience can be described as the capacity to withstand or to recover quickly from the impact of drought.

Resilience in this context is defined as the ability to cope without the need for outside support, the ability to continue and adjust to remain living and doing business in the Gascoyne working with available, sometimes limited, regional resources.

While there are many inherently resilient communities in the Gascoyne, significant and/or prolonged periods of climate induced stress will erode the strength of even the hardiest of communities.

There is no "maximum" or final state of resilience. Resilience building is a continuous process of building and strengthening. Individuals and communities must constantly adapt and respond to changing economic, environmental and social conditions.

The Gascoyne Drought Resilience Plan is designed with the purpose of supporting ongoing and adaptive responses by individuals and communities.

Drought vulnerability

Drought vulnerability refers to the susceptibility of a community, environment or system to the negative impacts of drought (Li et al., 2015; Serkendiz & Tatli, 2023).

Vulnerability is a reflection of both the physical (e.g climate, geography, physical infrastructure) and socio-economic characteristics of individuals (e.g. wellbeing, wealth) and communities (strength of community relationships or social fabric) that influence the ability to respond and adapt.

The Gascoyne's communities, including its horticulturalists, pastoralists, Traditional Owner groups, business communities and local towns are characterised by a range of different drought vulnerabilities and adaptive capacities. A generalised assessment of impact of different droughts is provided in Table 6. For the horticultural sector, river flow, groundwater recharge licensing restrictions and direct river water extraction limitations have a large impact on the sector. While pastoralists are most vulnerable to rainfall volumes and seasonal distribution, and the resulting risk of vegetative drought. Where stock water is extracted from groundwater resources, pastoralists may be vulnerable to hydrologic drought. In towns, communities are, to varying degrees, exposed where hydrological drought impacts on resources that support domestic and potable uses. Burringurrah remote community is vulnerable as a result of inadequate water quality for potable use. Drought also impacts other economic sectors, particularly those that rely on natural capital such as nature-based tourism and fisheries. For example, dry riverbeds and wetlands lack the majesty and visual aesthetic of the lush green rivers that attract visitors to WA's north west. The marine environment, and its ecosystem benefits and services (including recreational and commercial fisheries) too rely on freshwater inflows – both surface and groundwater. The Gascoyne River in flood in Carnarvon delivers freshwater, nutrients and sediments to the adjacent marine environment. The Cape Range Karst system, surrounding Exmouth, supports critical freshwater/marine interactions that in turn support critical ecosystem processes.

A summary of the vulnerability of six Gascoyne communities (stakeholders) to four types of drought is provided at Table 6.

	Meteorologic	Hydrologic	Vegetative	Legislative
Horticulturalists				
Pastoralists				
Communities				
TO groups				
Tourism sector				
Fisheries				

Table 6: Generalised impact on Gascoyne stakeholder groups to four drought types (sensitivity and exposure combined). Impact risk scale from highest (red) to lowest (dark green).

There is a long history of communities facing extreme weather events, including droughts, floods and cyclones. This, combined with the highly remote and isolated communities of the Gascoyne, have driven an inherent level of strength and resilience. While climate-related events can have devastating impacts, experience has shown that resilient communities can rebuild.

It's vitally important that communities continue building adaptive capacity. This plan focuses on the adaptive capacity of the Gascoyne's communities through the lens of four types of capital:

- natural capital – environmental assets, and the benefits and services they provide to people and communities,
- human capital – the skills, knowledge, and experience of individuals and communities. Intellectual capital is also related,
- social capital – the networks relationships among people who live and work in a particular community or society, that allow people to work together and which enable a community to function effectively, and
- financial capital – the ability to gather and apply funds towards collective goals.

Financial capital and natural capital are among the weaker, or more vulnerable, elements to the impacts of drought (Table 7, yellow/orange).

	Natural capital	Human capital	Social capital	Financial capital
Horticulturalists				
Pastoralists				
Communities				
TO groups				
Tourism sector				
Fisheries				

Table 7: Generalised adaptive capacity elements for Gascoyne stakeholder groups
Vulnerability risk scale from highest (red) to lowest (dark green).

Communities in the Gascoyne are characteristically small, with low populations and high cost of living. Business and household costs, including access to finance, are a reflection of living in an environment where extreme weather events are more likely.

Communities, by definition, have a strong ability to bring people together. Nowhere is this more-true than in small, isolated and very remote communities, such as those in the Gascoyne. The strength of the region's social capital is important.

A vulnerability assessment was conducted across 6 communities (or stakeholders) of the Gascoyne, by combining the quantitative rating measures of impact exposure and adaptive capacity (Table 8) to indicate the vulnerabilities of different communities in the region. The scoring is relative (not absolute)[1] and is intended as a guide to understand where both vulnerabilities and opportunities exist, and to support actions that build drought and climate resilience.

	Impact	Adaptive capacity	Vulnerability class
Horticulturalists	-7	7	0
Pastoralists	-9	9	0
Communities	-5	6	1
TO groups	-9	6	-3
Tourism sector	-7	10	3
Fisheries	-2	9	7

Table 8: Vulnerability assessment based on drought impact and sectorial adaptive capacity

There are many methods to assess vulnerability. In a previous study, the important factors in vulnerability assessment for the Gascoyne were pasture growth, internet use and off-farm income (Sudmeyer et al 2016). It is observed that internet use in remote areas in the Gascoyne is still limited, but improving with commercially available satellite-based internet providers, pasture growth is restricted and highly dependent on available water resources, and off-farm income is slowly increasing through diversification, including into tourism, renewable energy and carbon farming. This does not mean that the vulnerability of the Gascoyne region to structural adjustment has decreased, but contributing factors to a vulnerability assessment may have changed.

[1] Note that a relative score was assigned for each colour class. Green class in the impact assessment was assigned a zero value, with yellow, orange and red assigned a value of -1, -2 and -3, respectively. Adaptive capacity followed a similar score, with orange being assigned a zero value, and yellow, light green and dark green a value of 1, 2, and 3 respectively. Note that the cumulative score is only relative score to compare the different stakeholder groups, and no conclusions can be drawn based on the absolute value of the score.

Floods

Flood and drought are two extreme weather events experienced in the Gascoyne. The impact of floods are felt across the region, including in Carnarvon, at the delta of the Gascoyne River. The Gascoyne River delivers significant volumes of water in flood, Table 9 gives flow volumes, rates and river level at Nine Mile bridge (Figure 15) near Carnarvon and indicates the historical frequency of significant flow events. Local communities – including the town centre and adjacent horticultural district – are at risk of property damage and economic losses. Three river flood events with impact on infrastructure and horticultural farms have occurred since 2000 with maximum flow rates exceeding 4000 m^3/s at Nine Mile bridge, namely in March 2000, December 2010 and February 2021. Between 2012 and 2014, flood protection levees were constructed to divert the excess water from horticultural and town infrastructure (Ward, 2014).

Month-year	Total monthly flow [GL]	Maximum flow [m^3/s]	Estimated river height @ 9 mile bridge (m)
Feb 1960	3560	6017	7.62
Feb 1961	2771	5997	7.61
Mar 2000	2420	5950	7.59
Dec 2010	1187	5836	7.53
Jun 1980	1762	5534	7.38
Mar 1995	958	5070	7.12
Feb 2011	2529	5047	7.10
Jan 2009	390	4897	7.01
Feb 2021	1302	4446	6.72
Mar 1999	1044	4108	6.49
Jun 1989	1042	3859	6.31
Jul 1974	1261	3830	6.29
Apr 2006	662	2857	5.51
May 1984	888	2778	5.44
Apr 2015	811	2760	5.43
Jan 1967	321	2312	5.03
Jun 1986	607	2294	5.01

Table 9: Maximum flow rates at Nine Mile bridge in the Gascoyne River with rates exceeding 2200 m^3/s since 1957.

Figure 15: Flood gauge at Nine Mile Bridge on the Gascoyne River showing historic flood levels

Date	Daily rainfall [mm]
17-Dec-2010	207.8
05-Feb-2021	137.2
02-Apr-2022	118.6
13-Jul-1998	102.6
09-Mar-2000	100.6
27-Jun-1965	96.3
03-May-1947	95
15-Jul-1996	90.8
06-May-1953	87.1
09-Jul-1952	81.8
03-Nov-1975	81.4
25-Feb-2024	78.4
16-Feb-1970	78.2
13-Dec-1995	77
27-Mar-1960	76.5
01-Apr-1975	75.6

Table 10: Maximum daily rainfall since 1945 as measured at Carnarvon Airport

Table 10 shows maximum daily rainfall totals at Carnarvon airport since 1945. For comparison, long-term average rainfall for the Gascoyne is approximately 210-220 mm. The listed rainfall events thus contributed amounts between 1/3rd and the full amount of long-term average annual rainfall.

Observations show an increase in the intensity of heavy rainfall events in Australia. The intensity of short-duration extreme rainfall events has increased by around 10% or more in some regions and in recent decades, with the largest increases typically observed in the north of the country. Note that the intensity of rainfall associated with tropical cyclones is also expected to increase (CSIRO and Bureau of Meteorology, 2024)

With its vast catchment area, the middle and upper reaches of the Gascoyne River also experience floods. In 2010, the Gascoyne Junction and the surrounding district was impacted by signficant floods causing widespread property damage.

In Exmouth, localised flooding in the townsite is common following any extended local rainfall event. Rainfall over the surrounding catchment will often force the closure of Minilya Exmouth road – the only road access to the town. Access to Learmonth Airport, approximately 35 km south of Exmouth, is also vulnerable when local flooding causes road closures. Further information, including flood response evaluation to improve preparedness is provided in Government of Western Australia Water Authority – Midwest Region, 1995 and Government of Western Australia Department of Water and Environmental Regulation, 2021.

Air temperatures

A heat wave is a prolonged period of unusually hot weather. Impacts are felt across communities. For example, among growers, heatwaves can result in reduced fruit and vegetable production. A heatwave in April 2024 resulted in reduced banana harvest in September that year. Figure 16 shows an increasing trend of extreme temperatures in Australia (CSIRO and Australian Government Bureau of Meteorology, 2024). A dry landscape potentially increases the occurrence of extreme temperatures. One strategy during heatwaves in horticulture is to apply irrigation water to keep the crop cooler.

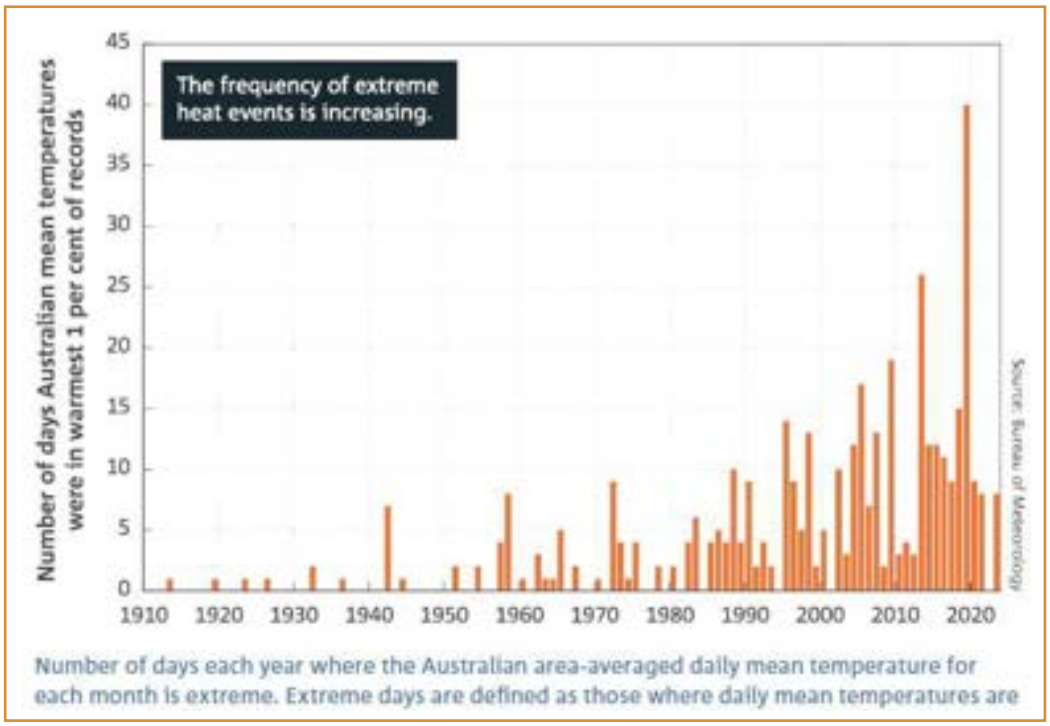


Figure 16: Increase of extreme temperature days in Australia (CSIRO and Australian Government Bureau of Meteorology, 2024).

Marine temperatures

Sea water temperatures have risen all around Australia in observations from 1950 onwards.

In 2022 bleaching was also observed on some reefs on Australia's west coast, including Ningaloo Reef. This was due to warm ocean temperatures, driven by the 2021–2022 La Niña. The region's previous severe marine heatwave was driven by the 2010–2011 La Niña, which resulted in bleaching being recorded for the first time on Ningaloo and the closure of several Western Australian fisheries. Climate models project more frequent, extensive, intense and longer lasting marine heatwaves in future (CSIRO and Bureau of Meteorology, 2024).

In addition to coral bleaching, damage to sea grass is another result of marine heatwaves. A five degree rise of ocean water in Shark Bay resulted in widespread impacts to sea grass beds (Australian Broadcasting Corporation News, 2024h). Initiatives are taken to revegetate ecologically important areas.

Most recently, a signficant marine heatwave event occurred in 2025 across Western Australia's north west coast. Significant coral bleaching was reported across the Ningaloo Reef. Tourism operators that depend on Coral Reefs report concerns that the reputation of the Ningaloo as a world class tourism destination is already being affected.

Tropical cyclones

In 2015 the Gascoyne River experienced its most severe flood since 2010 due to widespread rainfall following Tropical Cyclone Olwyn (DPIRD, 2022). In recent years, the Gascoyne has experienced a series of severe weather events, including the Ex-Tropical Cyclone Lincoln in February 2024, storm and associated flooding in March-April 2022 and March 2023, and Tropical Cyclone Seroja (April 2021), and Tropical Low and Associated Flooding (March 2020) (Australian Government Department of Home Affairs, 2024).

The frequency of tropical cyclones has decreased worldwide and in the Australian region (Figure 17). Future predictions indicate this decline will likely continue, including under a climate change scenario of a 2 degrees Celsius increase in global temperature (Australian Broadcasting Corporation News, 2024f). Conversely, over the last 40 years, the frequency of tropical cyclones has not changed significantly in WA, but there is some evidence that the frequency of the most intense cyclones has increased (Sudmeyer et al, 2016).

While frequency is expected to decrease, cyclone intensity in the Australian region is more difficult to predict, due to uncertainties in estimating the intensity of individual cyclones and the relatively small number of intense cyclones (CSIRO and Bureau of Meteorology, 2024).

Repairing the damage caused by severe weather events and securing the supply of essential goods and services into affected areas present not only logistical challenges, but also impose significant costs on business and governments.

Severe weather and emergency events are predicted to become more frequent and intense due to climate change, existing vulnerabilities must be mitigated.

Enhancing infrastructure resilience is an option to protect the region's economy and communities against recurring severe weather events and other emergencies (Government of Western Australia Department of Transportation, 2024).

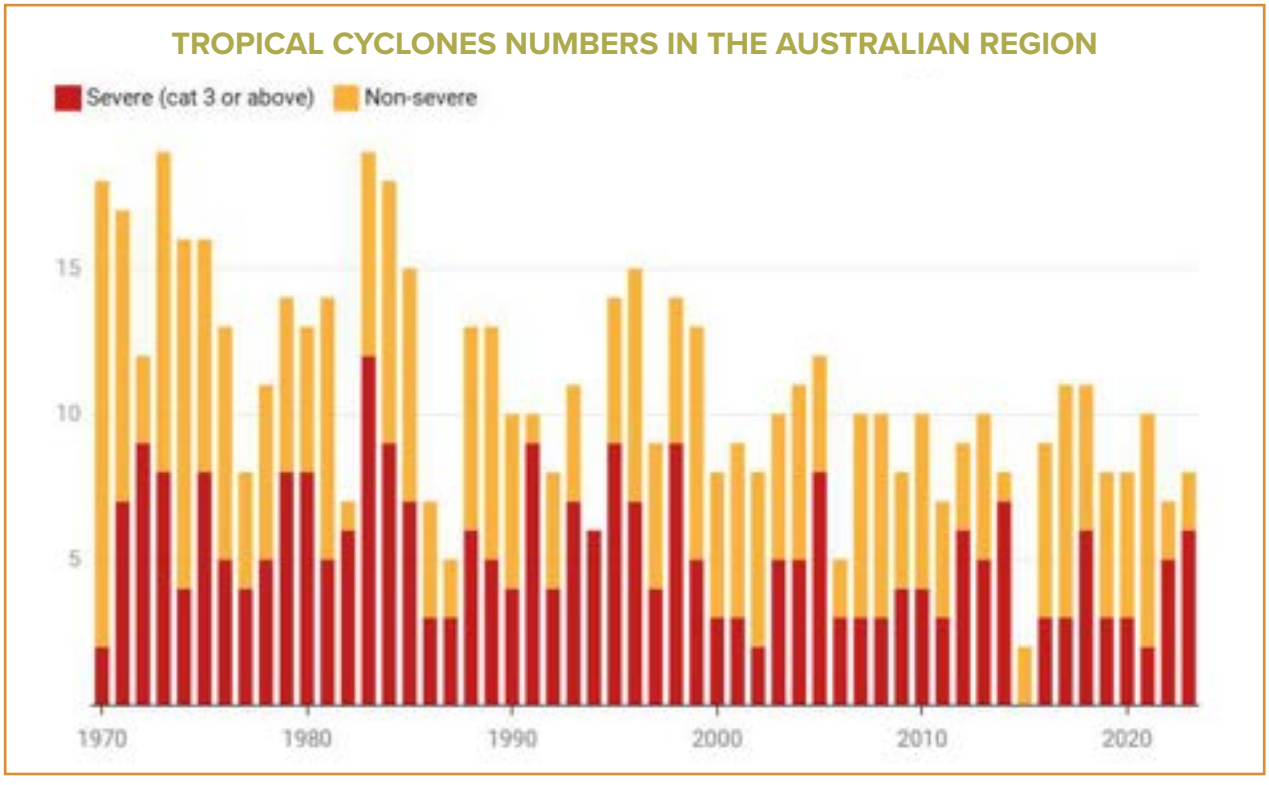


Figure 17: Decline of number of Tropical Cyclones in Australia (Australian Broadcasting Corporation News, 2024f).

Bush Fires

With increasing air temperatures, and the cyclic nature of drought and floods in the Gascoyne, bushfire is a risk. A bushfire in September 2024 damaged water infrastructure, orchards and plantations on several properties north of the Gascoyne river near Carnarvon (Australian Broadcasting Corporation News, 2024c). In 2022, and both at the beginning and end of 2023, large areas of pastoral land, including stock and infrastructure, were under threat of bushfires, with a 2-week fire causing significant impacts on stations in the Gascoyne (Australian Broadcasting Corporation, 2022b). The trend of increasing dangerous fire danger days is shown in Figure 18; the trend is expected to further increase in the future (CSIRO and Bureau of Meteorology, 2024).

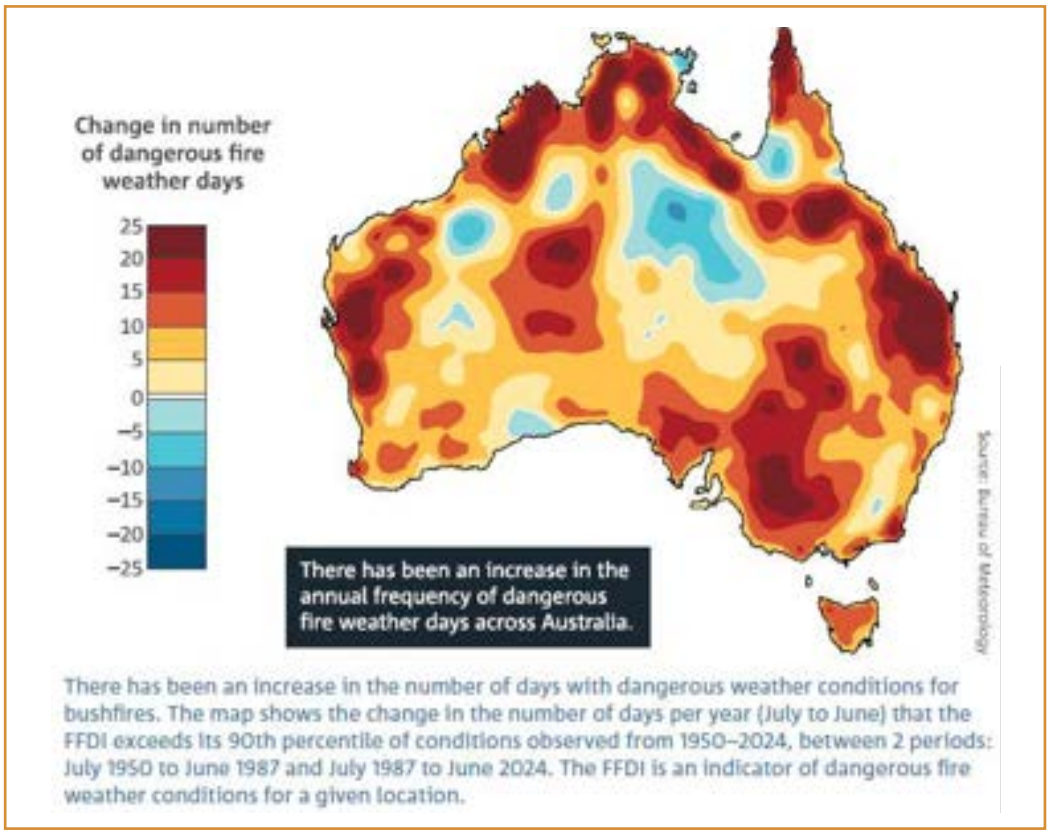


Figure 18: Increase of dangerous fire days in the Gascoyne between 1950 and 2024 (CSIRO and Bureau of Meteorology, 2024)

Photo credit: Jarrad Seng

Gascoyne River

Scenarios

Climate and water resources

Global and regional weather patterns are expected to change over time. In the Gascoyne, likely climate and water resource changes include increased rainfall, extreme rainfall events, and rising temperatures (Table 11; 12). These changes are concerning, given the vulnerability of communities in the Gascoyne (as discussed in previous sections).

Photo credit: Tourism WA

	Exmouth	Coral Bay	Carnarvon	Denham	Gasc. Junction	Burringurrah
Rainfall patterns						
Annual Rainfall	261 mm → 234 mm	223 mm → 230 mm	210 mm → 248 mm	204 mm → 207 mm	223 mm → 214 mm	255 mm → 259 mm
Autumn Rainfall	111 mm → 88 mm	78 mm → 74 mm	62 mm → 68 mm	60 mm → 62 mm	75 mm → 71 mm	84 mm → 81 mm
Winter Rainfall	84 mm → 79 mm	81 mm → 79 mm	95 mm → 92 mm	103 mm → 98 mm	57 mm → 61 mm	44 mm → 50 mm
Spring Rainfall	4 mm → 6 mm	6 mm → 8 mm	11 mm → 13 mm	15 mm → 17 mm	9 mm → 11 mm	15 mm → 18 mm
Summer Rainfall	58 mm → 61 mm	54 mm → 65 mm	43 mm → 66 mm	27 mm → 26 mm	76 mm → 66 mm	110 mm → 108 mm
Temperature patterns						
Avg max temp	30.2 °C → 31.3 °C	31.5 °C → 32.3 °C	28.2 °C → 28.9 °C	28.0 °C → 28.4 °C	32.5 °C → 33.8 °C	32.0 °C → 33.3 °C
Avg min temp	19.7 °C → 20.6 °C	18.3 °C → 19.5 °C	17.8 °C → 18.9 °C	17.3 °C → 18.3 °C	17.2 °C → 18.6 °C	16.6 °C → 18.1 °C
Annual hot days	67 days → 89 days	98 days → 124 days	30 days → 37 days	35 days → 37 days	144 days → 165 days	139 days → 161 days
Annual cold days	0 days → 0 days	0 days → 0 days	0 days → 0 days	0 days → 0 days	0 days → 0 days	1 days → 0 days
Water consumption patterns						
Autumn reference evapotranspiration	519 mm → 532 mm	536 mm → 552 mm	484 mm → 499 mm	478 mm → 472 mm	478 mm → 504 mm	468 mm → 494 mm
Winter reference evapotranspiration	352 mm → 362 mm	366 mm → 380 mm	331 mm → 346 mm	307 mm → 319 mm	300 mm → 323 mm	299 mm → 320 mm
Spring reference evapotranspiration	658 mm → 675 mm	682 mm → 706 mm	586 mm → 611 mm	595 mm → 592 mm	618 mm → 649 mm	621 mm → 652 mm
Summer reference evapotranspiration	758 mm → 775 mm	816 mm → 841 mm	714 mm → 738 mm	748 mm → 731 mm	785 mm → 817 mm	764 mm → 795 mm

Table 11: Forecasted values for select climate variables at multiple locations in the Gascoyne Region
Adapted from Bureau of Meteorology and CSIRO, 2024.

	Exmouth	Coral Bay	Carnarvon	Denham	Gasc. Junction	Burringurrah
Rainfall patterns						
Annual Rainfall	27 mm less	Inconclusive	38 mm more	Inconclusive	Inconclusive	Inconclusive
Autumn Rainfall	23 mm less	Inconclusive	Inconclusive	Inconclusive	Inconclusive	Inconclusive
Winter Rainfall	Inconclusive	Inconclusive	Inconclusive	Inconclusive	Inconclusive	6 mm more
Spring Rainfall	Inconclusive	Inconclusive	Inconclusive	Inconclusive	Inconclusive	Inconclusive
Summer Rainfall	Inconclusive	11 mm more	23 mm more	Inconclusive	10 mm less	Inconclusive
Temperature patterns						
Avg max temp	1.1 °C higher	0.8 °C higher	0.7 °C higher	Minimal	1.3 °C higher	1.3 °C higher
Avg min temp	0.9 °C higher	1.2 °C higher	1.1 °C higher	1.0 °C higher	1.4 °C higher	1.5 °C higher
Annual hot days	22 days more	26 days more	7 days more	Minimal	21 days more	22 days more
Annual cold days	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal
Water consumption patterns						
Autumn reference evapotranspiration	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal
Winter reference evapotranspiration	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal
Spring reference evapotranspiration	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal
Summer reference evapotranspiration	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal

Table 12: Forecasted changes for select climate variables at multiple locations in the Gascoyne Region
Adapted from Bureau of Meteorology and CSIRO, 2024.

Horticultural sector

There are no published long-term recent projections published or publicly available for the Carnarvon horticultural sector. With the high diversity of horticultural business objectives, products, cultural backgrounds and experience levels, the community is diverse and sometimes disparate.

A few drivers of change can be described that have impacted the sector in the past, and some scenarios can be put forward of how the horticulture sector might develop through to 2050.

Unique position in off-season production

The Carnarvon region has a unique, year-round production potential. Its climate is conducive to year round production, and the Carnarvon horticultural district is well positioned to support growing domestic markets in Perth and South East Asia.

Continuing improvements in cold chain transport and storage, extended shelf life of produce has increased competition of the market from other regions in Australia, but also allows Carnarvon's producers to access new markets on the east coast and overseas.

Cyclone impacts

Across Northern Australia, three main areas of tropical fruit production can be identified in Queensland, the Northern Territory, and North West WA. Previously, banana production was highly concentrated in relatively small regions. Cyclone destruction in Queensland provided a market boost to banana prices in the Gascoyne. However, with production regions expanding, the uniqueness of Carnarvon as an alternative production region has diminished.

Continuing development through immigration

Historically, several groups of immigrants have supported the development of horticultural systems in the Gascoyne. Migrants of English, Portuguese, Italian and Croatian backgrounds can still be found in the Gascoyne, as well as more recent Vietnamese and Malaysian growers. Each group has brought their experiences and approaches into the region.

Food Bowl Initiative

An initiative to intensify and expand the horticultural area resulted in the Food Bowl Initiative. Different phases included expansion of land for existing farms, as well as the development of new farms, based on further expansion of available groundwater extraction. The development of new land brings in larger, corporate growers, while the expansion of existing farms brought opportunities for risk spreading with more diverse cropping systems, or less flood-prone areas being brought in production.

Biosecurity threats

Similar to the Gascoyne being an alternative production source when other regions are impacted by climate, the Gascoyne also has the potential to provide an alternative growing region to regions affected by biosecurity threats. These include the TR4 type of Panama disease, a fusarium wilt impacting banana production, present in the Northern Territory and Queensland, tomato brown rugose fruit virus, currently affecting tomatoes, capsicums and chillies in South Australia, capsicum whitefly, affecting capsicum production, and Polyphagous shot-hole borer, potentially impacting avocado and mango trees.

Future of horticulture

It is difficult to foresee the changes that horticulture may face in the coming years. Continuing influx of migrant growers, new generations of growers, incoming corporate farms, and improved efficiency and marketing may lead to more intensive use of existing land. This could result in more protected horticultural systems, or in more conglomerate type systems. It is also possible that the number of lifestyle blocks expand, and that the horticultural production systems are not the main source of income of a household. It is most likely that future systems remain a mixture of family run businesses, corporate run businesses, and lifestyle blocks. Climate impact across Australia, biosecurity threats, and innovative new value-added products and marketing will likely remain the drivers of change in the Gascoyne.

Pastoral sector

A vision for the Gascoyne's pastoral sector is provided by the pastoral peak body, the Gascoyne Pilbara Rangelands Initiative Inc. (formerly the Gascoyne Catchments Group):

Resilent rangelands community built upon diverse and vibrant cultural connections, healing landscapes for a brighter future

This focus is reflected in the history of the sector and its plans for the future.

Transformational change from sheep to cattle

At one point, the Gascoyne was one of WA's most important wool producing regions. Since the 1990's, sheep production, especially merinos, has declined. Producers have increasingly shifted to cattle, predominantly Droughtmasters and Brahmans, with short horns also on a number of properties. This transformation of pastoral station management required replacement of on-farm infrastructure and a new set of knowledge and skills. This has been the base for common learning and frequent knowledge exchange meetings between pastoralists.

Socio-economic scenarios

A socio-economic analysis for regions in Western Australia identified several climate factors as region specific drivers for the Gascoyne regional economy (Duncan and Leong, 2014).

Photo credit: Jarrad Seng

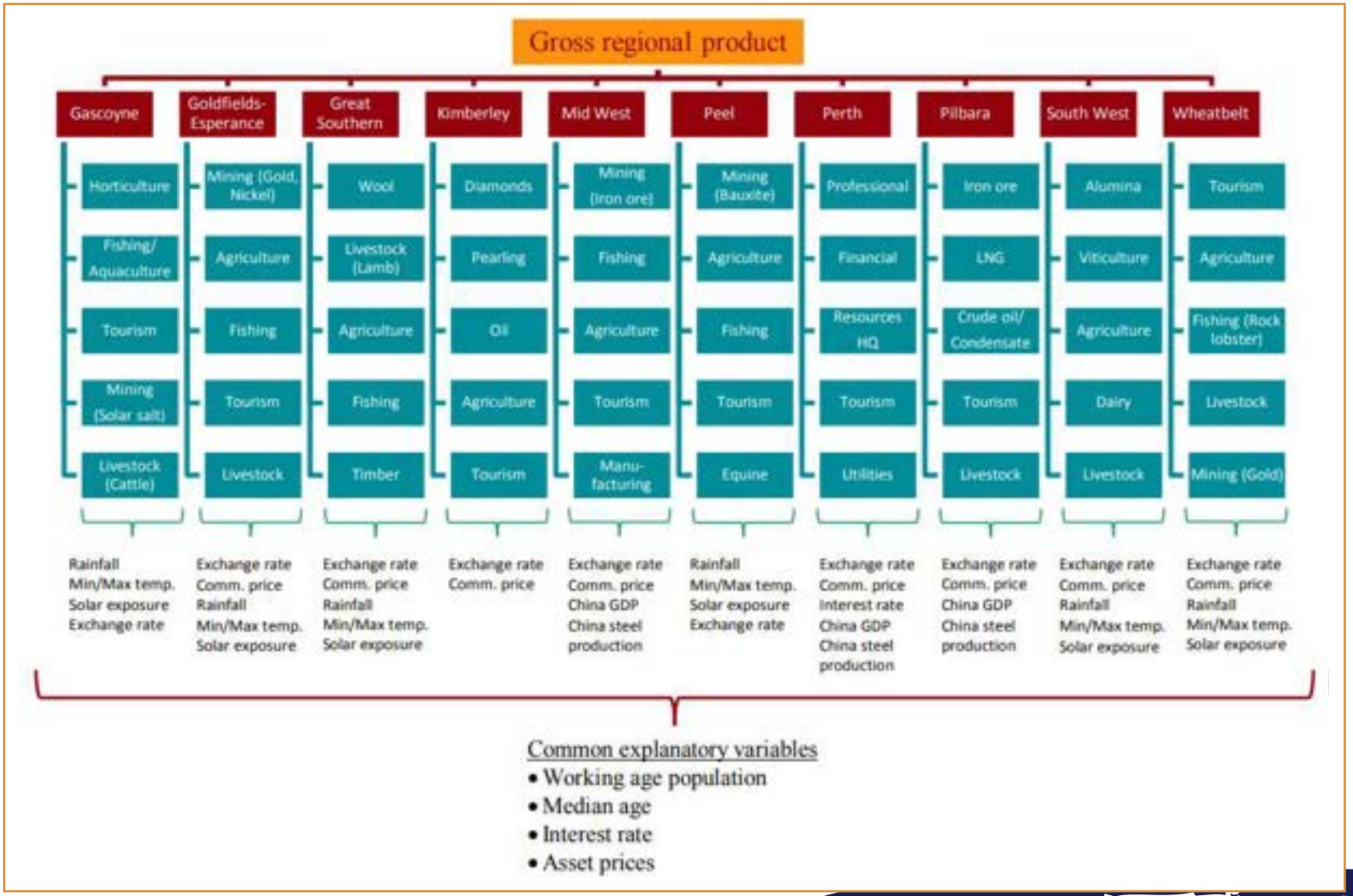


Figure 19: Common and region-specific drivers for WA economy growth (Duncan and Leong, 2014).

Their assessment is based on a regional disaggregation of state-wide economic data. From their analysis, they estimated the contribution of different sectors to the gross regional product.

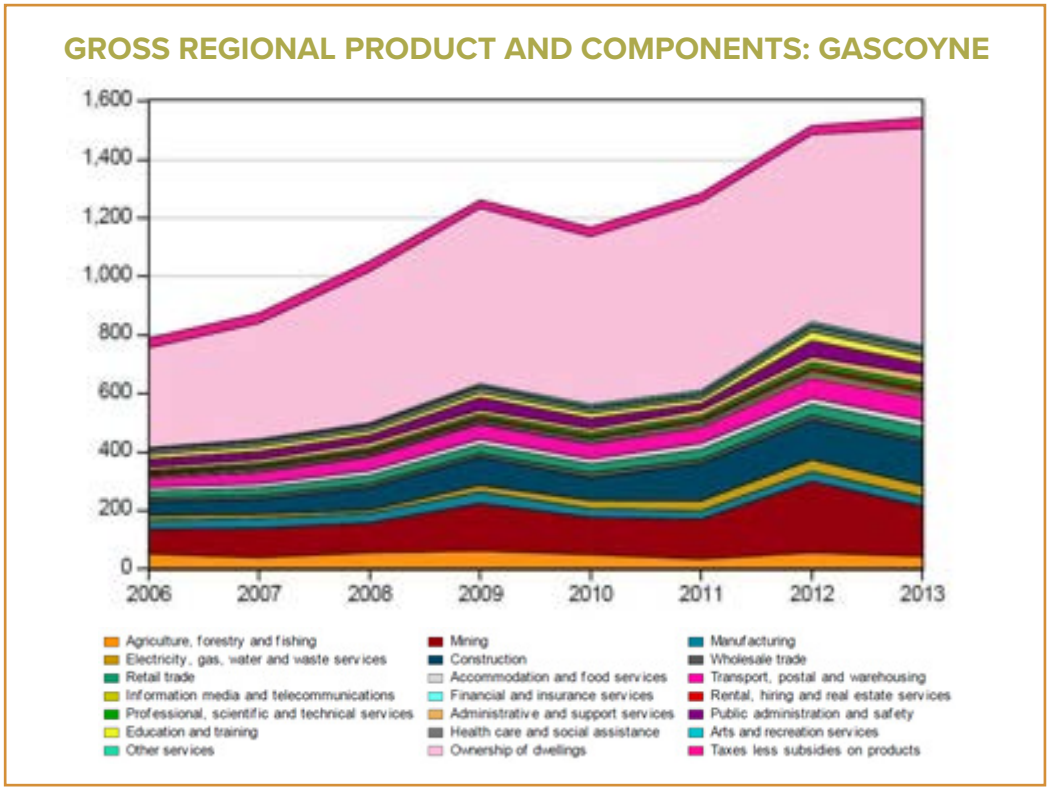


Figure 20: Economic components to Gross Regional Product in the Gascoyne (Duncan and Leong, 2014)

A study by Poruschi et al (2023) aimed at identifying socioeconomic indicators for tracking and monitoring short-term rural and regional drought impacts and reviewing the practicality of existing data and options available for capturing these indicators. They assess indicators within the themes of economic, health and social-demographic impact. The indicators they identified are described in Appendix C.

Socio-economic drought impact in the Gascoyne

The greatest contributor to economic output in the horticulture sector is from annual crops. Perennial species including bananas and mangoes contribute 17%.

Drought has different impacts on perennials than annuals. Generally, perennial plants tend to allocate fewer resources to reproduction structures, prioritising resources to storage structures for extended survival. Perennial crops are generally considered more drought tolerant than annual ones (Vico et al, 2014; Glover et al, 2010).

Banana production

Like many horticultural species, market prices (and business profitability) is a function of both local seasonal and climatic conditions, which drives local production (both product quality and volume) and broader market conditions which are also driven by seasonal and climatic conditions in other growing regions. Climatic conditions in other crop growing distributs or regions can have dramatic impacts on markets and wholesale prices. In 2006, Tropical Cyclone Larry impacted banana growers in North Queensland, the primary supplier to Australia's domestic market. Banana prices increased by approximately 400% (Ellis, 2024).

In 2011, Tropical Cyclone Yasi again impacted North Queensland, damaging up to 75% of the national banana crop. Retail prices reportedly increased from $3/kg to $15/kg in major supermarkets (Larkin, 2011). Consequently, the value of Carnarvon's banana production following Tropical Cyclone Yasi increased significantly (Figure 21).

Inter-annual variations in production exist, with a heat wave in April 2024 impacting production volumes and driving a shortage of supply to the market in September 2024. With irrigation water sourced from aquifers, the generally reliable supply of water does not result in clear drought impacts on banana production in Carnarvon.

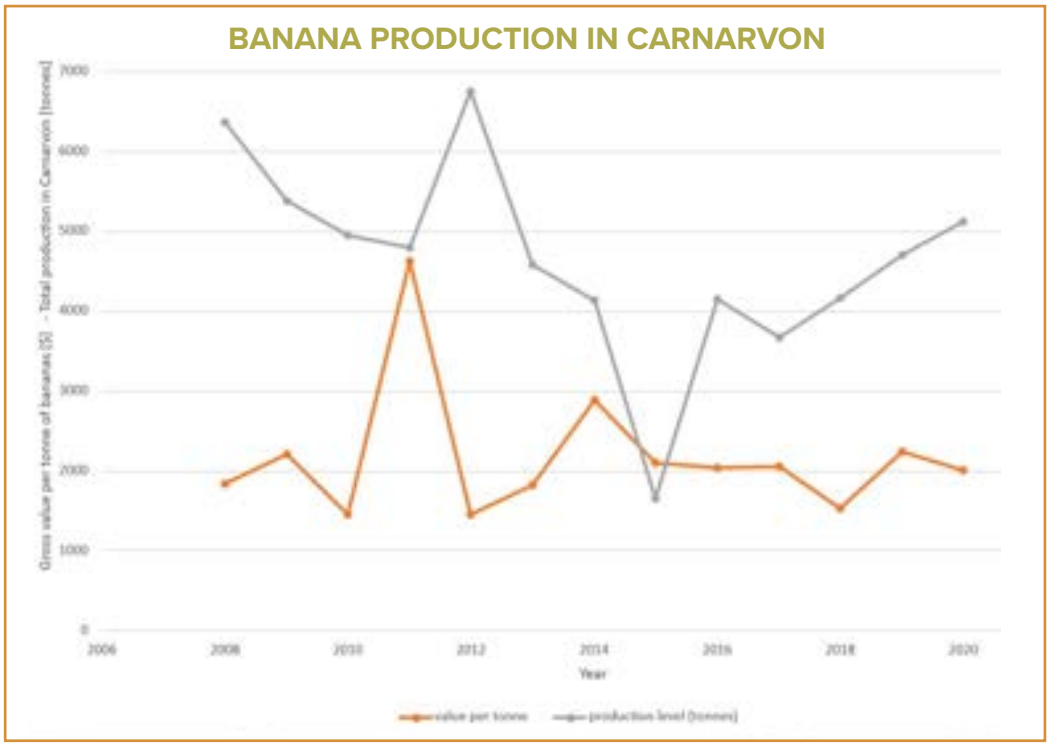


Figure 21: Annual average banana value and production in Carnarvon, WA. (DPIRD, 2022)

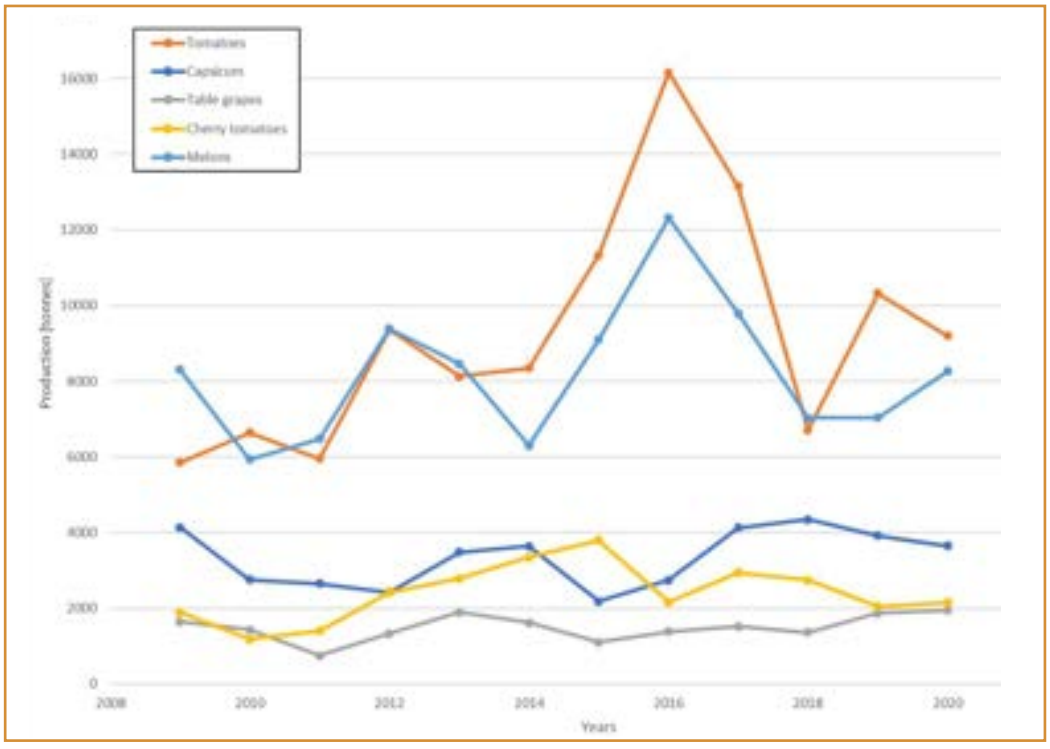


Figure 22: Main vegetable production in horticultural district in Carnarvon, WA. (DPIRD, 2022)

Vegetable production

Annual vegetable production in the Gascoyne region has remained relatively constant over the period 2009-2020. Tomato and melon production show a peak in 2016 and 2017, which may have been a recovery period from the destructive impacts of Tropical Cyclone Olwyn that passed the WA coast in 2015.

Due to the relative security of aquifer water supply, no regional impact of drought can be observed in the available datasets. Despite the reported impact of water shortages in 2013-2014, there is no obvious reduction in production. However, individual businesses may still experience a shortage of water, or salinity impacts on their production.

Production is impacted by other factors, including biosecurity issues, flooding and cyclone events.

Meat cattle production

Drought conditions inevitably lead to a decline in herd populations. Since the 1970's, drought conditions have also been associated with a decline in market prices of approximately 12% when compared to the preceding (pre-drought) year (Meat and Livestock Australia, 2015a). A direct relationship between market prices and drought conditions in the Gascoyne (as indicated by total precipitation and normalised vegetation cover) was not demonstrated when data was analysed for this drought plan, noting that Gascoyne producers are a relatively small contributor to domestic Australian cattle supply, and are therefore price-takers (as opposed to price-makers). There are also many other factors affecting domestic and international markets. This illustrates that the Gascoyne's cattle producers are vulnerable to drought conditions in the Gascoyne, but are also impacted by conditions in other districts that supply domestic and export markets.

"What was described as a '1-in-100 year drought' occurred in 2002-03 and then again in 2006-07, causing the cattle herd to fall by around 1 million, or 4%, on each occasion. These severe drought years, and lack of above average rain in between, created a dry decade, preventing any further gains in productivity (despite growth in lot feeding) and resulting in a 1 million head fall in the national cattle herd over the ten years.

Respite was finally received at the end of the decade, with much of the country receiving well above average rain in 2010 and 2011, but this was then followed by two drought years, 2013 and 2014, during which the cattle herd fell by an estimated 2.5 million, or 8.5%.

The three significant droughts, from 2000 onwards, saw real prices collapse about 12% year-on-year on each occasion but in the two wet years of 2010 and 2011, real prices lifted 4% and 11% year-on-year, respectively."

Meat and Livestock Australia, 2015

Sheep, wool and production

Similar to the price decline for meat cattle during droughts, the price of sheep and lamb has seen declines during droughts as well. However, multiple factors impact the supply, demand, and subsequently the price. The Gascoyne is also a producer of goat meat.

"The new millennium commenced with higher turnoff placing downward pressure on prices. A sharp but brief recovery occurred in 2001-02 (due to intense export demand and a low A$), before a downturn in seasonal conditions resulted in seven consecutive years of drought, including two of the worst ever recorded in 2002-03 and 2006-07. Real prices entered a prolonged period of decline, with real trade lamb prices falling 25% and mutton 33% from 2003-07.

It is worth noting that the price declines of the millennium drought were softened to an extent by the rapidly rising domestic and export demand for lamb. [...] With the dry times continuing through 2013-14, slaughter and export volumes broke record after record as many producers had no option but to de-stock. Global demand, driven by the increasing middle class in developing markets (mainly China, which entered as a major player on the

international market), was strong enough to absorb the higher production, seeing average real lamb and mutton prices rise to 519 ¢/kg cwt and 312 ¢/kg cwt, respectively, in 2014."

Meat and Livestock Australia, 2015b.

Further insights from pastoral producers in the Gascoyne is provided in Appendix B.

Environment and ecosystem services

Ecosystem services (sometimes referred to as ecosystem services and benefits) are the things that support human wellbeing, that are directly and indirectly provided by nature and natural ecosystems. For example, wetland ecosystems act as filters to provide clean water. Plants provide oxygen, food and fibre. Plant roots hold fertile topsoil in place, which prevents erosion, while storing water and nutrients. Trees provide shade – especially in built environments where black road base and concrete buildings store heat in the height of summer.

The concept of ecosystem services has become part of an approach to managing biodiversity, water, primary industries, human settlements, regional planning and climate change (Australian Government Department of the Environment, Water, Heritage and the Arts, 2010).

The economic contribution of ecosystem benefits and services is significant. For example, Deloitte estimated the Ningaloo Reef contributes roughly $110 million annually (in 2020 dollars) and supports over 1,000 jobs. It plays a critical economic role for the local and regional community. The economic value of ecosystem benefits and services is illustrated at Figure 23. Outside the Ningaloo, the ecosystem benefits and services of natural assets in the Gascoyne is not well known.

A system of financial accounting for natural assets (that is, calculating the financial value of a producer's natural assets – like land condition, topsoil) is already in place and is continuously being aligned. The banking sector – particularly institutions involved in rural communities and commodities – is working with governments and land managers to implement improved natural capital accounting. Work with WA's land managers on natural capital accounting approaches is also underway (University of Western Australia, 2024).

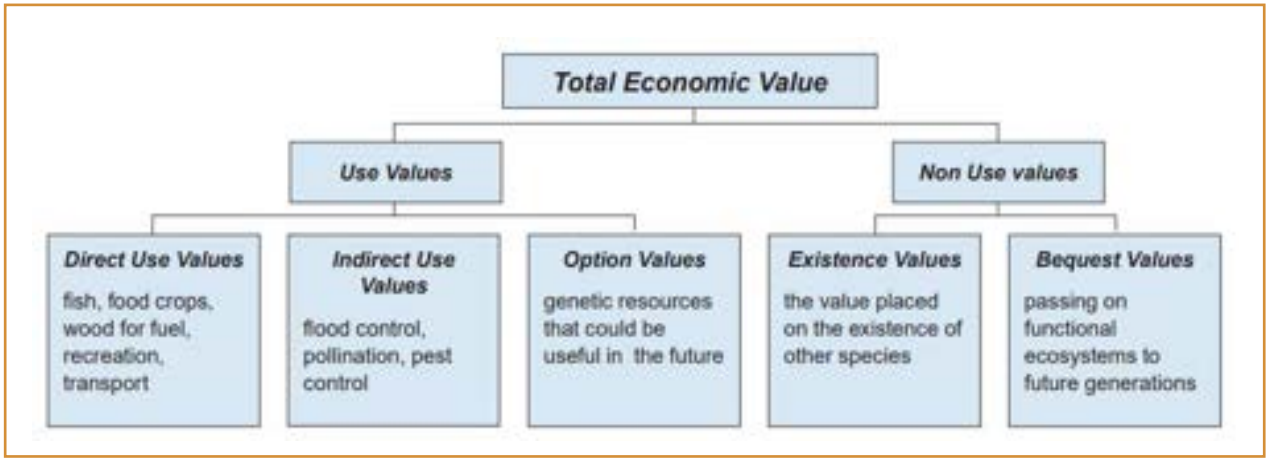


Figure 23: The components of total economic value of ecosystem services (Australian Government Department of the Environment, Water, Heritage and the Arts, 2010)

Gascoyne drought scenario

Drought and climate impacts are part of the Gascoyne's future.

The likelihood of drought, and the associated impact of drought, were modelled for this plan, and show the long-term impact could be severe, across the whole region, due to the propulsive aspects of horticulture in Carnarvon shire and pastoral production in Upper Gascoyne shire (Figure 24). With currently available data, it is not possible to put definite values on economic, health and demographic impact due to drought and other climate events. Further work is needed to better understand the impacts of drought and climate on the economic benefits and services of natural assets in the Gascoyne.

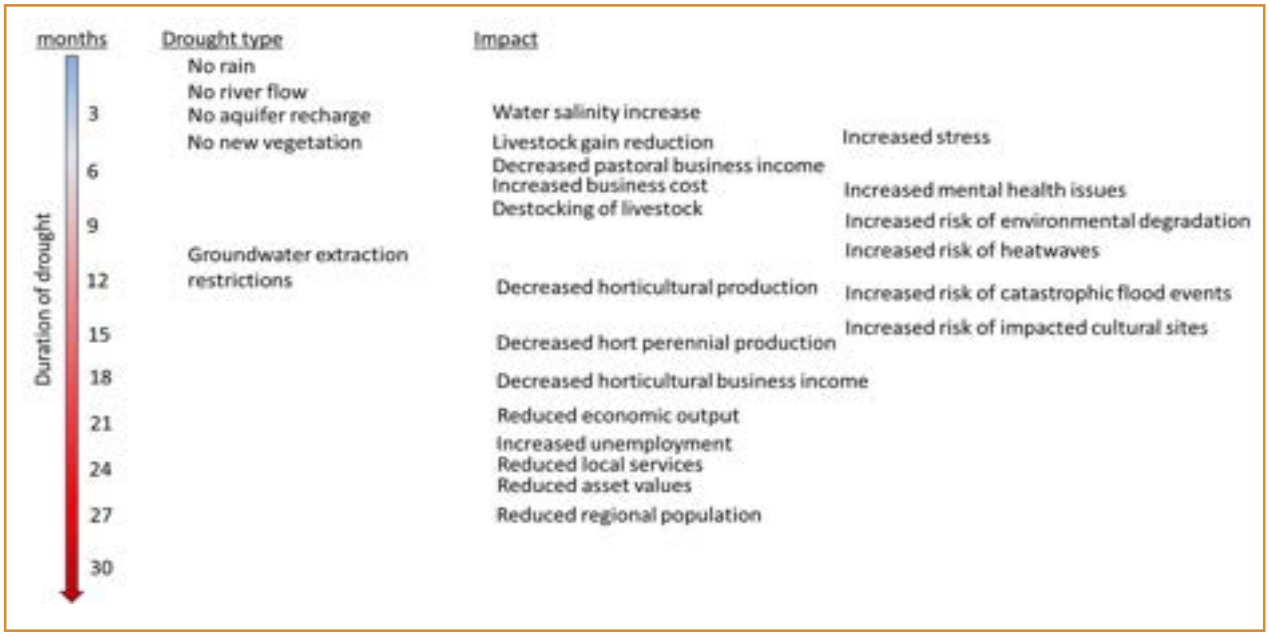


Figure 24: Possible progression of drought related impacts in the Gascoyne.

Drought in the Gascoyne is not an independent climate event. Intensive rainfall and cyclones breaking a drought often result in large runoff contributing to soil erosion and flooding. Drought periods are frequently associated with periodic heatwaves and its impact on horticultural production. Strengthening the resilience to drought in the Gascoyne includes strengthening resilience to associated climate events.

The interconnection between socio-economic impact on the pastoral and horticultural sector on regional economy, the labour opportunities, and the need and pressure on supporting services, including health related services, show the need for integrated approaches to strengthen resilience.

Water security is vitally important for all communities across the Gascoyne. Yet already, water insecurity exists in several places. At Burringurrah Remote Community the community's scheme water is not suitable for human consumption. Land, housing and commercial development is critically constrained by the limitations of the town's scheme water, and the fully allocated groundwater resource that supports it.

With a likeliness that the horticultural future systems remain a mixture of family run businesses, corporate run businesses, and lifestyle blocks, and a diversifying pastoral industry, with the main elements of the business a continuing focus on livestock grazing resulting from restrictions in pastoral leases, resilience strengthening actions will focus on holistic, cross-sectoral integrated approaches focused on reducing uncertainties (in knowledge, management options and availability of support services) and reducing risks (environmental, economic and social).

Vision for the Gascoyne Drought resilience plan

The vision
for building and strengthening drought resilience in the Gascoyne is:

To work together to build long term climate resilience with a focus on process and progress.

This vision represents several important factors raised by community representatives during the planning process:

- the people of the Gascoyne see drought as one of several climate events impacting the region,
- climate resilience must take a broader view than just drought,
- that the path relies on collaboration and working together.

Regional resilience to climate events is ongoing. There is no moment in time that the region will be declared 'climate resilient'. It is recognised as a continuing process to enable adjustments to unforeseen events. This plan aims at building and strengthening climate resilience based on a strategic, long-term vision for the future.

Mt Augustus National Park
Photo credit: Tourism WA

Action plan: what can we do to be more climate resilient?

Resilience actions are critical to mitigate the impacts of a changing climate on the Gascoyne's diverse communities, and the health and economic wellbeing of our people.

Building and strengthening resilience requires efforts at different scales: individual and community; governments, non-government and private sectors; local and regional; short medium and long term. A framework of three types of change underpin the Gascoyne Drought Plan: incremental, transitional and transformational change (Figure 25).

This plan is not prescriptive. It is high-level, outlining a set of priorities for action. Although, people seeking a more prescriptive list of options to prepare and cope with drought may refer to Appendix D for more information.

As previously discussed, this is a 'first pass' plan – intended to bring individuals and communities together and intended as the first step in an iterative (or ongoing) planning process. A more detailed implementation is in progress, to help guide delivery of this plan.

This plan is unfunded. The actions described here outline a set of priorities to help build drought and climate resilience among communities of the Gascoyne. Implementation of any or all of these priorities is contingent on securing resources (including financial and human resources) for delivery.

Type of change	Definition	Types of activities
Incremental change	The ability to preserve or restore a system (including its basic structures and functions) by preventing, preparing for or mitigating the impacts of an event or risk	• diversifying income with off-farm employment • using farm management deposits to make tax deductible deposits during good periods and withdraw them during bad periods • changes to crop variety
Transitional change	The ability to maintain the essential functions and structures of a system by modifying or changing some of its characteristics in response to future adverse events or risks	• changing aspects of a production system (such as seed varieties or agronomic practices) to continue the production of certain commodities in a region
Transformational change	The ability to undertake wholesale change of a system when adverse events or risks make the current system untenable	• shifting up-stream and down-stream supply chain infrastructure to reflect changed production systems • adopting new production systems such as grazing or carbon farming • revegetating pasture with native vegetation • establishing conservation corridors across farmland

Figure 25: Type of change categories as evaluated by the Productivity Commission (Australian Government Productivity Commission, 2023).

"During my time working in the Gascoyne region during the 2010 dry seasons, I spent a large amount of time working on properties and with pastoralists. My observations and memories of that period are clear in my mind as it was a preceding very dry time to the large Gascoyne River flood of early 2011.

I have spent time working in a similar role (as a pastoral landscape ecologist) during the 2025 season. During these two seasons, the rainfall in the dry year and the year preceding has been similar (less than 80 mm in general across the region). My observations in comparing these two seasons is as follows:

1. That the apparent approach to this dry season has been more proactive and less reactive than the 2010 season. Pastoralists that I have worked with in 2025 (some of who are the same as I worked with in 2010) are feeling more prepared and relaxed about the seasonal conditions due to the preparations made during previous seasons, and the improvements made in infrastructure, cattle quality and grazing management in the years between the two dry seasons.
2. That the landscape in general appears to be in better condition at the end of the 2025 than at the end of 2010. While there is a significant amount of variation in condition between and within stations, in comparable sites the increase in ground cover (particularly through the increase in Buffel grass in those areas it is present) is evident. Native grasses and palatable shrubs appear to be recolonising significant areas of the scrub-invaded country, which has likely improved the landscape resilience.
3. That the cattle observed in my travels around the region are in better condition, with less in body score condition 1.5 or lower animals."

Richard Marver
Landscape Rehydration Specialist and Director of Contour Environmental and Agricultural Consulting

This image shows the imapct of rehydration works with saltbush on a grader bank in September 2025.

Strategy 1: Regional coordination and social capital

Support integrated catchment management

With three expansive river catchments (the Gascoyne, Wooramel and Lyndon-Minilya), and a broad variety of competing demands for constrained water resources, integrated catchment management is key. From furthest reaches of the inland catchment, to the downstream UNESCO World Heritage areas at Shark Bay and the Ningaloo.

Management at catchment level is highly organised in the Gascoyne region. The peak body for pastoral land managers in integrated catchment management is the Gascoyne Pilbara Rangelands Initiative Inc, (formerly the Gascoyne Catchment Group) has a strong member base and strong internal capacities, strengthened over the course of the last two decades following its establishment in 2009.

A 'whole of catchment' approach requires broad, community wide engagement with a focus on landscape-scale outcomes. It involves all industries and stimulates solutions that are targeting 'root causes' rather than responding to impact.

Drought resilience in the Gascoyne will be strengthened by:

- leveraging existing integrated catchment management initiatives,
- ensuring integrated catchment management initiatives are adequately resourced,
- supporting new and existing initiatives that foster information sharing within communities (for example, information sharing about landscape rehydration practices among pastoralists),
- supporting initiatives that foster information and land/marine management practices,
- supporting initiatives that bring different types of land and sea managers together (for example, bringing pastoral land managers together with fishers and other users of the Ningaloo and Shark Bay World Heritage areas).

Create a regional drought management and response network

During climate-based emergencies like cyclones, flooding or major bush fires, formal emergency management committees bring emergency response agencies and stakeholders together to enable rapid response. Formal coordination structures allow for clear communication, ensure that accurate information is used to inform decision-making, and that relevant perspectives and interests are included.

A coordinated local response to drought is equally important, but the arrangements and platforms for coordination are less structured and informal. This limits the potential for information sharing, it limits the opportunity for affected communities to advocate for immediate response, and limits the opportunity to review and evaluate lessons-learned to support continuous improvement in drought preparedness.

Drought resilience in the Gascoyne will be strengthened by:

- Establishing formal regional drought management networks.

Build a governance framework for regional drought resilience

Collaboration is the foundation of this Drought Plan. It leverages the Gascoyne's strengths in its inherent and existing capacities and resilience to climate change and severe weather events.

Drought resilience in the Gascoyne willl be strengthened by:

- Creating a formal governance structure to support climate resilience building and to oversee implementation of this plan.

Support and build local leadership

Rural and regional leadership is critical for climate resilience because it drives locally tailored, context-specific solutions that are more effective and equitable than top-down approaches.

Local leaders are uniquely positioned to bring local knowledge, build strong social networks, and coordinate collective action in response to the specific and unique vulnerabilities of a community.

Drought and climate resilience champions are individuals, communities, businesses or organisation that actively lead and inspire action to prepare for, adapt to, and mitigate climate change impacts, focusing on building strong, sustainable and equitable futures through local projects, policy advocacy, innovative solutions and sharing best practices.

They can be grassroots volunteers, award winners, or trained leaders working on everything from net-zero initiatives and infrastructure resilience to protecting vulnerable populations and promoting climate justice.

Drought resilience in the Gascoyne will be strengthened by:

- Delivering programs that build local community leaders and support and elevate local champions.

Improve access to mental health supports

While availability of all health services is critical to resilience of the Gascoyne region, there is a broad understanding of mental health risks following critical incidents and emergencies, for example destructive floods, fires and cyclones.

Drought can be insidious in its impact on mental health. Mental health training and awareness-raising actions have been highly successful in the Gascoyne, with high levels of participation among communities. And while mental health is more openly discussed in the Gascoyne's remote community more than in the past, there remains work to be done in supporting communities. Particularly as it relates to suicide prevention and especially among men.

Drought resilience in the Gascoyne will be strengthened by:

- Supporting increased access to mental health services,
- Securing resources for programs that support suicide prevention,
- Providing local, face-to-face programs for mental health in communities in the Gascoyne.

Strategy 2: Pathways for knowledge sharing

Supporting knowledge brokering

The Australian Government's Future Drought Fund has generated increased capacity for drought preparedness and resilience in regions across Australia, as several initiatives are delivered across the region.

Access to information about new initiatives and opportunities can be haphazard, especially without a central knowledge broker or coordinator. The Gascoyne Pilbara Rangelands Initiative Inc (previously Gascoyne Catchments Group) play an important role in drought resilience extension in the Gascoyne, including extending the reach of the Northern Drought Hub across the Gascoyne. Their role is to connect landholders, communities and industry with projects, resources and practical solutions that build climate and drought resilience. They represent the Hub at events, deliver workshops, identify local needs, and foster collaboration between producers, researchers and agencies to ensure regional voices are heard and innovative, on-the-ground outcomes are achieved.

Access to information about support services such as financial counselling, business planning and mentoring services (including free services) is also vital.

Drought resilience in the Gascoyne will be strengthened by:

- Ensuring adequate resourcing of knowledge brokering across all stakeholder groups and communities in the Gascoyne.

Increase awareness through formal training and education

Young people are the Gascoyne's future decision-makers, innovators and community leaders. Building knowledge and resilience

early helps young people develop sustainable habits, adapt to challenges like climate change and drought, and influence their peers and families.

Young people are also highly connected through social networks, making them powerful advocates who can amplify messages widely. By engaging them now, we create a long-term impact, ensuring preparedness and proactive solutions for generations to come.

Schools in the region have expressed interest to include these drought and climate resilience in the curriculum.

Drought resilience in the Gascoyne will be strengthened by:

- Developing locally-focused tools, such as lesson plans, that integrate with the school curriculum to raise awareness of drought and climate resilience.

Strategy 3: Resilient economies

Strengthen freight and logistics to support market access

The Gascoyne is described as very remote, reflecting very limited access to goods, services and social opportunities. Exmouth, in the Gascoyne's north, is over 1200 km from the Perth, Western Australia's capital. Exmouth is also more than 350 km from the closest administrative centre.

Remoteness affects logistics and the cost of doing business. As a result of being very remote, with demand for transportation increasing during droughts, additional cost pressures and logistical stresses are put upon Gascoyne businesses.

While market competition for Gascoyne growers and graziers has increased as a result of national improvements to transportation and cold-storage transport, the Gascoyne region has benefitted less from these improvements. Infrastructure that supports market access, multiuser port facilities, road network improvements and transport regulation (including air transport) are key.

Drought resilience in the Gascoyne will be strengthened by:

- Continued advocacy for improved transport infrastructure.

Brand awareness and marketing

The Gascoyne is a unique region in Australia and has strong marketing potential. Many pastoral operations are family businesses, reflecting a deep connection and custodianship of people on the land. There is a significant value-add opportunity in meeting growing consumer demand for product origin and provenance information and in experiential tourism (including station stays and food trails).

Collective branding contributes to a stronger market, allowing agricultural businesses to build up reserves during production boom years to absorb shocks in bust years. Initiatives to collaborate between the sectors in the Gascoyne Food Council, and marketing through the Gascoyne Food Festival and the Gascoyne Food and Beverage guide (Food Industry Innovation Program and Gascoyne Development Commission, 2024) should continue.

Drought resilience in the Gascoyne will be strengthened by:

- Continuing work to build brand Gascoyne and local product brand awareness.

Land rehydration

Regenerative agriculture, and in particular landscape rehydration, is a key focus for pastoral land managers in the Gascoyne. Key principles include slowing rainfall runoff, increasing water infiltration into the soil, increasing vegetation cover and density and reinstating natural hydrology pattern (e.g. Gascoyne Catchment Management Group, 2022; Gascoyne Development Commission, 2022).

Grazing management, and grazing resting techniques, support healthy and productive landscapes. Fences are a tool for improved grazing and resting management. Understanding livestock grazing behaviour is another tool that supports grazing management (Kennedy, no date; Thorne, 2009).

Drought resilience in the Gascoyne will be strengthened by:

- Securing resources to support community-based landscape rehydration.

Water use efficiency

Water resources in the Carnarvon horticultural area are sufficient to meet current demand, and have allowed for the recent expansion of the Carnarvon horticultural district. However, water use restrictions are in place when aquifers are not being recharged as a result of lack of rain and lack of Gascoyne River flow.

At the level of the irrigation distribution system, some farmers at the end of the main distribution system are experiencing limited water supply during high-demand periods. During a heat wave, for example in April 2024, irrigation systems can run in excess of crop water demand, since water is used as a cooling method and crop protection against leaf burn and fruit damage. Despite this, the impact of a 1-week heat wave resulted in a dip in banana availability in September 2024.

Under the current licencing model, water prices are a fixed cost based on licenced volume, rather than actual consumed water.

Even when overall water supply is not limited, efficient irrigation scheduling and volume can contribute to improved quantity and quality in vegetables, plantations and orchards. Efficiency of fertilizer, herbicides and pesticides can be increased with optimized irrigation water scheduling.

The promotion of increased irrigation water productivity as an element of overall crop and farm management supports a more sustainable use of extracted groundwater for horticultural use, thus contributing to drought resilience in the sector.

Drought resilience in the Gascoyne will be strengthened by:

- Supporting growers to consider and implement on-farm water use efficiency measures.

Diversification

Diversification of agricultural systems are often cited as an opportunity to strengthen climate and economic resilience.

For the extensive land systems managed by pastoral stations and the intensive land systems managed by the horticultural sector this requires regional infrastructure to be available for diversification into renewable energy (e.g. Crowley, 2024), carbon farming (e.g. Baumber et al, 2020), and tourism (e.g. Government of Western Australia Tourism Western Australia, 2018). Communities in the Gascoyne region have the potential to work collaboratively to access new market opportunities at scale.

Drought resilience in the Gascoyne will be strengthened by:

- Supporting initiatives that support diversification – on farms and stations, and in local economies.

Strategy 4: Resilient natural and cultural assets

Support Traditional Owner-led landscape restoration

Aboriginal people have a vital role in protecting natural and cultural assets - including via drought and climate preparedness. Aboriginal people hold deep knowledge of Country, that has guided sustainable land management over thousands of years.

In the Gascoyne, Aboriginal people are also managers of land, including vast areas of jointly managed conservation estate, and the land including and surrounding Burringurrah remote Aboriginal community.

Traditional Owners at Burringurrah Community have long advocated for the need for more traditional and sustainable land management practices as a tool for repairing land degradation, and improving water quality and reducing flood risk.

The Burringurrah community are Traditional Owners in the Wajarri Yamatji Native Title

determination area. Their Country was once resplendent with swimming holes and food, but has been heavily degraded.

In December 2010, a storm caused widespread flooding at Carnarvon (700kms from Burringurrah) and across the catchment, causing the loss of an estimated 9 million tonnes of soil from erosion and a damage bill of an estimated $90 million. The degraded condition and low vegetative groundcover following an extended period of dry seasons, in combination with a legacy of historic overgrazing and continuous stocking were identified as factors contributing to the floods. Similar widespread flooding occurred subsequently, including in 2017 and 2021, causing damage to roads and buildings, and the horticulture and fishing industries in Carnarvon. Restoring ecosystem function is vital.

Drought and climate resilience could be strengthened by:

- Assisting Burringurrah remote Aboriginal community to secure adequate resources – including financial and human resources – to executive their governance and land management responsibilities over Country that the community and Traditional Owners manage.
- Securing project and operational funding to allow Burringurrah community to deliver practical land management actions on the ground.

Support sustainable use of natural assets

The Gascoyne's conservation estate (e.g. national parks and marine parks) support an array of ecosystem benefits and services. The habitats that are protected in the Ningaloo and Shark Bay World Heritage areas support important nature-based tourism and recreational and commercial fisheries (including specialised products like sea cucumber). They also provide benefits like cooling and water filtration.

One example of marine environmental rehabilitation is a program to re-establish sea grass, a collaboration between Tidal Moon Sea Cucumbers, Malgana Aboriginal Corporation and the University of Western Australia (University of Western Australia, 2020; Sinclair et al, 2024). Another example is the protection and tourist accessibility to an area containing stromatolites in Shark Bay.

Drought resilience in the Gascoyne will be strengthened by:

- Working with land managers of the conservation estate on initiatives to support sustainable economic development in ways that protects the 'stock' or natural asset for the future.
- Delivering the recommendations of the Ningaloo Resilience Plan (Government of Western Australia Department of Biodiversity, Conservation and Attractions, 2023).

Strengthen bushfire management

With the extended size of the Gascoyne, it is impossible to prevent bushfires, especially in the rangelands. However, bushfire prevention in and around urban centres like Carnarvon aid in reducing bushfire impact. The Gascoyne River bushfire brigade is extending their prevention program, which includes fuel management. Note that drought creates high risk bushfire periods, especially when following a wet period where natural vegetation grows well.

Drought resilience in the Gascoyne will be strengthened by:

- Supporting local bushfire management initiatives.

Strategy 5: Resilient towns

Secure potable water supplies for domestic use

Water for domestic use is critical for the towns and settlements in the Gascoyne region, including Exmouth, Coral Bay, Carnarvon, Denham, Gascoyne Junction and Burringurrah. Water quality is as important as water quantity.

Desalination of domestic water is required in Coral Bay, Denham, Gascoyne Junction and

Burringurrah. Exmouth water supply is currently at the maximum of the available licensed water, and planning for expansion of water supply is on-going. Options under review are expansion of the bore well fields, or desalination of seawater.

For long-term climate resilience in the Gascoyne, maintaining and growing population are required, and continuous and sufficient levels of domestic water supply is critical.

Drought resilience in the Gascoyne will be strengthened by:

- Ensuring all towns have reliable access to scheme water that is safe for drinking,
- Ensuring scheme water can accommodate planned growth (including new residential and commercial connections).

Flood management infrastructure and integrated catchment management

With the Gascoyne region fluctuating between droughts and floods from season to season, regular studies are conducted to review opportunities to increase flood water storage, improve aquifer recharge, reduce flood peaks and protect lands and properties through engineering interventions. With expected changes in climatic events, likely resulting in more concentrated, intensive rainfall patterns and thus higher likelihoods for intensive floods, it is recommended that interventions are assessed within a “whole of catchment” vision.

Drought resilience in the Gascoyne will be strengthened by:

- Flood mitigation infrastructure (existing and new) being planned and implemented as part of a broader integrated catchment management approach.

Gladstone Scenic Lookout
Photo credit: Andrew Robinson

Implementation, monitoring and evaluation

Theory of change

The theory of change links outcomes, outputs and recommended actions (similar to a logical framework or program logic) but is more flexible and adaptable to complex and dynamic contexts, where there may be multiple pathways and actors influencing change. This is particularly important for a regional program that intends to target a regional change in attitude through the use of existing networks, forums and structures. The impact of actions in the Gascoyne Drought Resilience Plan is dependent on champions in the region, and the willingness of residents and visitors to consider changing approaches and attitudes. Thus, the theory of change for the Gascoyne Drought Resilience Plan is not linear and cannot always be measured in absolute terms.

An overall framework for the Gascoyne Drought Resilience Plan, adapted from the framework for Western Australia, is represented in Figure 26.

Implementation pathways

The Gascoyne Drought Plan is strongly focused on the shared process to strengthen climate resilience in the Gascoyne. The proposed actions bring this together in a strong regional focus, across sectors and stakeholder groups. It is recognised that the actions are not a set of sequential or linear steps.

The actions are focused on the process to build regional resilience, and the implementation of the same action may have different implementation pathways when delivered within and by different communities or different locations.

Open and transparent sharing of information, where appropriate, is important.

Further, more detailed implementation planning is recommended as an action in this Plan.

Impact	A drought and climate resilient Gascoyne region		
	Environmental resilience	Economic resilience	Social resilience
Long term outcomes	Gascoyne's stakeholder work collaboratively and holistically with a shared vision towards resilience		
	Gascoyne's environment is thriving, natural capital is supporting the region's economic, social and environmental expectations	Gascoyne's economy is diverse, adaptable, able to transform, and remains thriving under impact of changing climatic conditions	Gascoyne's communities are prepared, able to bounce back, able to adjust, and able to transform to the impact of changing climatic conditions
Intermediate outcomes	Gascoyne's drought resilience actions are effectively contributing to an integration of economic, social and environmental outcomes		
	Gascoyne's Drought Resilience Plan is informing strategic decision making	Climate resilience networks are strong and active	Gascoyne's stakeholders have increased climate resilience skills, capabilities and knowledge

Figure 26: Framework linking impact and overall goals with long term and intermediate outcomes of the Gascoyne Drought Resilience Plan.

Outcome-based monitoring evaluation learning and improvement

Two levels of monitoring, evaluation and learning are relevant to the Gascoyne Drought Plan:

- Output: for example, development of this Plan, the delivery of actions, the value of expenditure on drought resilience activities, the participation of land managers in practice change. Although the number of activities like engagements, forums and discussions held in itself is not a measure of success, it provides an insight in the outreach that the process of resilience building has. In other words, did we do what we said we'd do?
- Outcomes on the long-term objective of building and strengthening drought resilience in the Gascoyne. Did it achieve the desired impact?

Resilience can be seen as the opposite (or reciprocal) of vulnerability. In the vulnerability assessment section of this Plan, different sectors were evaluated for the impact that drought and climate events have on the sector, but also what access to tools (natural, human, social and financial) these sectors have to cope with the impact. An action of this plan is to continue exploring and refining that knowledge, based on new information and lessons-learned.

This Plan marks a point in time in an ongoing and continuous approach to drought and climate resilience building. This Plan is one version in an iterative, ongoing, planning process.

Photo credit: Tourism WA

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Appendix A: Pastoral stations in the Gascoyne Region

Station Name	LGA Name	RDC Name	Percentage in LGA	Tourism
BOOLATHANA	CARNARVON	Gascoyne	100	
BOOLOGOORO	CARNARVON	Gascoyne	100	
BRICK HOUSE	CARNARVON	Gascoyne	100	
CALLAGIDDY	CARNARVON	Gascoyne	100	
CARDABIA	CARNARVON	Gascoyne	100	
COORALYA	CARNARVON	Gascoyne	100	
DOORAWARRAH	CARNARVON	Gascoyne	100	
EDAGGEE	CARNARVON	Gascoyne	100	
ELLA VALLA	CARNARVON	Gascoyne	100	
GNARALOO	CARNARVON	Gascoyne	100	Y
HILL SPRINGS	CARNARVON	Gascoyne	100	
LYNDON	CARNARVON	Gascoyne	100	
MANBERRY	CARNARVON	Gascoyne	100	
MARDATHUNA	CARNARVON	Gascoyne	100	
MARRILLA	CARNARVON ASHBURTON	Gascoyne	55.3 44.7	
MARRON	ASHBURTON	Gascoyne	100	
MEEDO	CARNARVON	Gascoyne	100	
MEERAGOOLIA	CARNARVON	Gascoyne	100	
MIA MIA	CARNARVON	Gascoyne	100	
MIDDALYA	CARNARVON	Gascoyne	100	
MINILYA	CARNARVON	Gascoyne	100	
QUOBBA	CARNARVON	Gascoyne	100	
WAHROONGA	CARNARVON	Gascoyne	100	
WANDAGEE	CARNARVON	Gascoyne	100	
WARROORA	CARNARVON	Gascoyne	100	Y
WILLIAMBURY	CARNARVON UPPER GASCOYNE	Gascoyne	87.1 12.9	
WINNING	CARNARVON	Gascoyne	38.6	
WOORAMEL	CARNARVON	Gascoyne	100	Y

Station Name	LGA Name	RDC Name	Percentage in LGA	Tourism
YALBALGO	CARNARVON	Gascoyne	100	
YARINGA	CARNARVON	Gascoyne	100	
BULLARA	EXMOUTH	Gascoyne	100	Y
EXMOUTH GULF	EXMOUTH	Gascoyne	100	
CARBLA	SHARK BAY	Gascoyne	100	
CARRARANG	SHARK BAY	Gascoyne	100	Y
COBURN	SHARK BAY	Gascoyne	100	
FAURE	SHARK BAY	Gascoyne	100	
GILROYD	SHARK BAY	Gascoyne	100	
HAMELIN	SHARK BAY	Gascoyne	100	
MEADOW	SHARK BAY	Gascoyne	100	
NERREN NERREN	SHARK BAY	Gascoyne	100	
TALISKER	SHARK BAY	Gascoyne	100	
TAMALA	SHARK BAY	Gascoyne	100	
WOODLEIGH	SHARK BAY	Gascoyne	100	
YALARDY	SHARK BAY	Gascoyne	100	
BIDGEMIA	UPPER GASCOYNE	Gascoyne	100	
CAREY DOWNS	UPPER GASCOYNE	Gascoyne	100	
DAIRY CREEK	UPPER GASCOYNE	Gascoyne	100	
DALGETY DOWNS	UPPER GASCOYNE	Gascoyne	100	
DOOLEY DOWNS	UPPER GASCOYNE	Gascoyne	100	
EDMUND	UPPER GASCOYNE	Gascoyne	100	
ERRABIDDY	UPPER GASCOYNE	Gascoyne	100	
EUDAMULLAH	UPPER GASCOYNE	Gascoyne	100	
GLENBURGH	UPPER GASCOYNE	Gascoyne	100	
JIMBA JIMBA	UPPER GASCOYNE	Gascoyne	100	
LANDOR	UPPER GASCOYNE	Gascoyne	100	
LYONS RIVER	UPPER GASCOYNE	Gascoyne	100	
MANGAROON	UPPER GASCOYNE	Gascoyne	100	
MINNIE CREEK	UPPER GASCOYNE	Gascoyne	100	
MOOLOO DOWNS	UPPER GASCOYNE	Gascoyne	100	
MT AUGUSTUS	UPPER GASCOYNE MEEKATHARRA	Gascoyne	95.4 4.6	
MT CLERE	UPPER GASCOYNE	Gascoyne	100	

Station Name	LGA Name	RDC Name	Percentage in LGA	Tourism
MT PHILLIP	UPPER GASCOYNE	Gascoyne	100	
PINGANDY	UPPER GASCOYNE MEEKATHARRA	Gascoyne	98.6 1.4	
TOWRANA	UPPER GASCOYNE	Gascoyne	100	
WANNA	UPPER GASCOYNE	Gascoyne	100	
WINDERIE	UPPER GASCOYNE	Gascoyne	100	
YINNETHARRA	UPPER GASCOYNE	Gascoyne	100	

There are 61 active pastoral properties in the Gascoyne (either wholly, or with the majority of the lease area in the Gascoyne). There are several others (current or ex-pastoral) that are no longer being managed for pastoral use as the primary land use or income source.

Stations with majority of area outside the Gascoyne Region

Station Name	LGA Name	RDC Name	Percentage in LGA	Tourism
MT VERNON	UPPER GASCOYNE MEEKATHARRA	Gascoyne	1.6 98.4	
MT GOULD	UPPER GASCOYNE MEEKATHARRA	Gascoyne	3.8 96.2	
WOODLANDS	UPPER GASCOYNE MEEKATHARRA	Gascoyne	8.5 91.5	

Appendix B: Drought resilience survey feedback

During the planning stage for the Gascoyne Drought Resilience Plan, a simple on-line survey was promoted from August to November 2024 to invite broad levels of input from the region. The survey was a combination of questions with multiple choice and open-ended answers.

Although the response size was low (7 participants on 14 Oct 2024), the results provide an insight in overall experience of drought throughout the region. A summary of responses is provided here as a selection of experiences of drought.

Respondents background

1. Where do you spend most of the time (work/life)

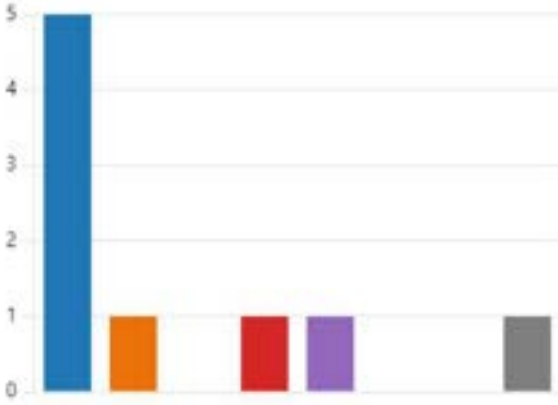
More Details

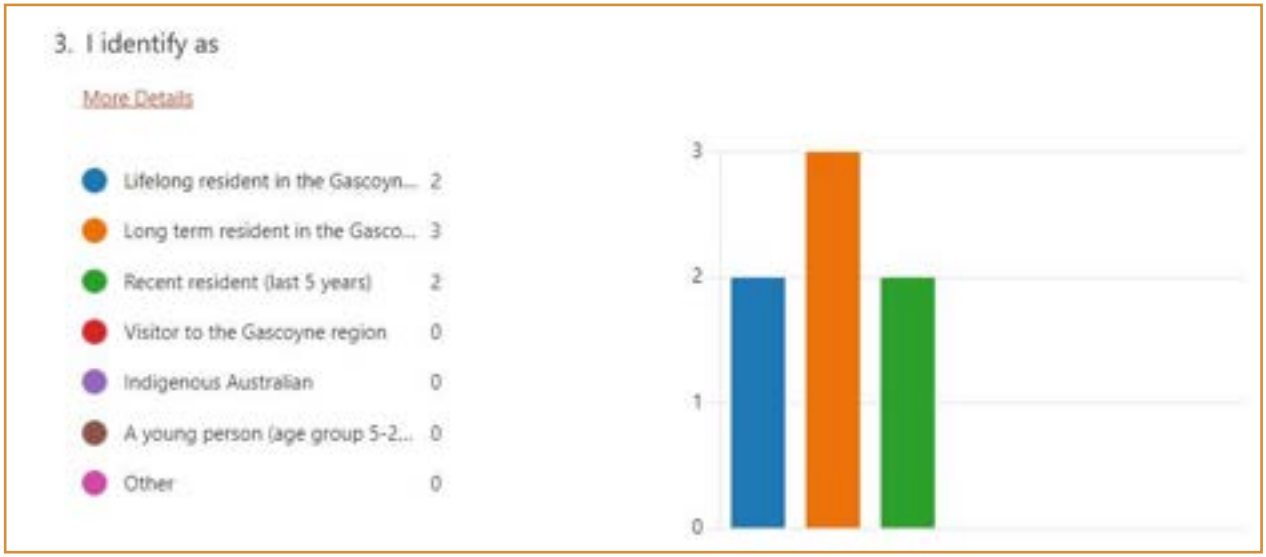
Shire of Upper Gascoyne	5
Shire of Exmouth	0
Shire of Carnarvon	2
Shire of Shark Bay	0
Other	0

2. What sector do you work in?

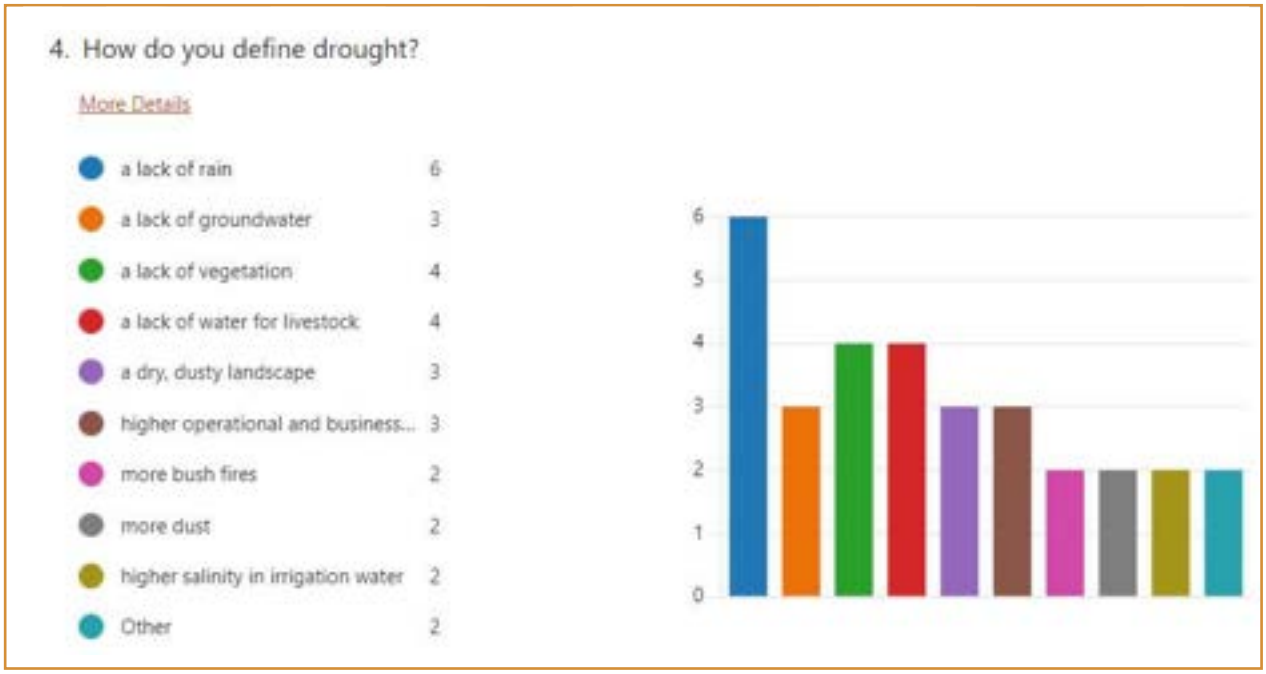
More Details

Pastoralist	5
Horticulturalist	1
NRM / Landcare	0
Tourism	1
Community services	1
Mining	0
Construction	0
Other: LGA	1





Drought experience



Note: multiple answers were possible.
Other: “The above and below amount of rain outside the long-term medium area”; “Reduced ground water”

Other: "Need to destock livestock as what food or water is eaten by goats or camels”. “The cost of transport, fuel including water & hay cartage for stock"

6. What is your experience with past droughts and other extreme climate events?

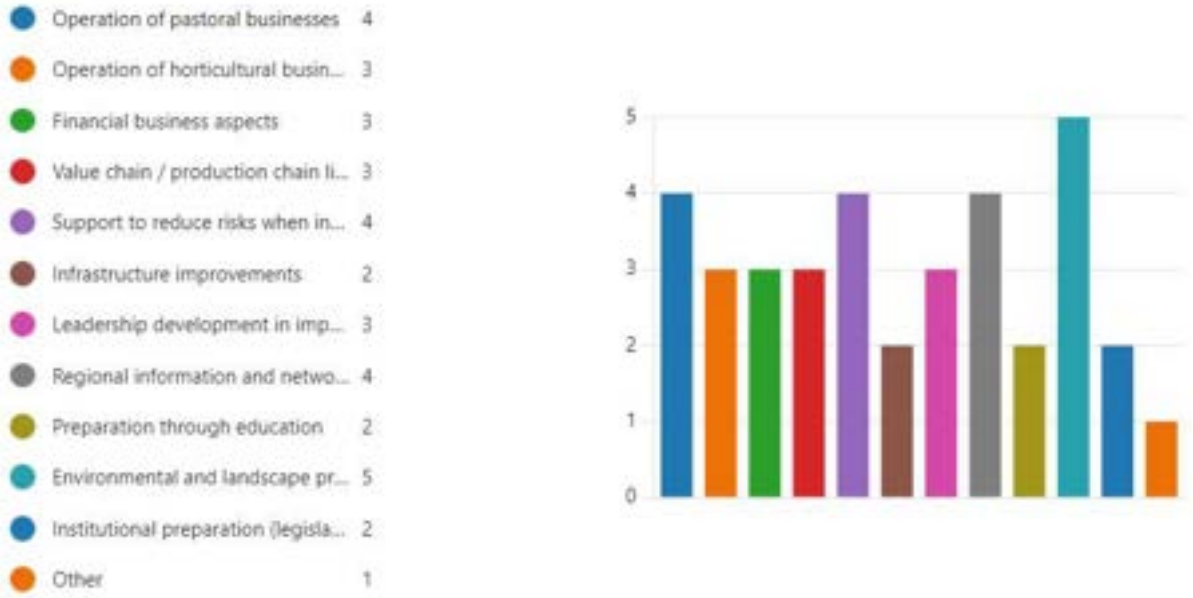
- I'm not really sure what this question is asking - droughts suck, so the experience has been awful.
- Long time to recover from impact.
- Very stressful, lots of decisions to be made using a variety of variables. Usually a lack of finance, due to extra costs associated with drought. Often less income due to lighter weight animals (and often lower prices during droughts). Work load increases - need to check water points more frequently, need to check cattle more frequently, need to muster and move animals more frequently, need to hand feed and care for early weaned calves. Mental health declines. Relationships get strained. No ability to take days off, leads to exhaustion and higher risk of accidents. Lack of finance inhibits social interaction, further exacerbating mental health decline. Lack of time to deal with personal health concerns, due to duty of care of animals and inability to leave the station. Children miss out on opportunities due to lack of finance and parents being unable to leave station.
- Vehicles and machinery become run down, due to lack of finance to repair properly - usually a bandaid approach is used to get by.
- As an emergency services volunteer we see more call outs for fire and people in stress and at risk. Some of our volunteers are pastoralists who are directly affected from drought and then the ensuing floods when the rains come. My personal experience is in assisting where I can to help lessen the mental and emotional stress of drought where I can.
- It takes so long to recover
- Devastating financially, mentally and physically, takes years to recoup. It takes 5 years to recover from 1 year loss. More needs to be done to help what pastoralist are left, they are being sold out to mining companies. The uptake of tourism on stations stays are a slight help, but before it gets to that they should focussing on supporting the people that put food on the plate. No good spending millions of dollars on tourism if there is none of what the Gascoyne represents, its not all whalesharks and bananas, look at how many EX stations there is in this region. As for DPAW that take over stations, it ends up being worse off as not properly maintained, look what happened at Giralia Station they wouldn't renew the tourism lease to the Great Grandson of the original owner. I think instead of having a holiday in Exmouth go and have a look at the real country. Labour is killing off the farmers in WA, now what hope is left, they want to stop Live Sheep export, they have already wrecked the abattoirs prior to this so have a good hard look at the damaged caused and spend the money where needed most.

7. Do droughts and other climate events change the way you operate, and how?

- Yes absolutely. Managing livestock and landscapes both which are hugely affected by effective rainfall/lack of rain fall/drought.
- Yeah, bit limits investment as you have to react to the change in operations.
- Yes. More work to do, but due to lack of finance, less people to do the work, so everything falls on to landowners.
- Need to monitor stock and waters more frequently and be assessing forecasts often to determine if cattle need supplementary feed, moving to different areas, weaning calves early, or destocking in a timely manner. Need to be able to act quickly before stock become to weak to travel.
- Finance is directed away from capital works and into keeping stock alive.
- Not particularly, other than being more mindful and economical with water resources. Changing the landscape of my homes gardens from a cottage garden style, when I bought the house to a water wise sustainable garden would be the may change to the way I operate.
- Yes, I have a major issue with flooding
- Answered above in depth silly question

8. What priority areas do we need to prepare for droughts and climate impact?

More Details



Other: "Management of landscapes to reduce the impacts of drought"

9. What can or should be done to prepare for future drought and other extreme climate events in those priority areas indicated above?

- Better management of landscape systems so that the effects of drought are not felt so harshly.
- It is not a good use of taxpayer funds to support landholders to manage their businesses better in drought. Landholders should be working much better at looking after the landscapes to make the country more drought resilient, and the funds should be targeted specifically at things that would make a difference (for example freight subsidies if pastoralist need to feed stock).
- Transformational scenario planning for base case, extreme droughts multi-year and measurement to prepare for droughts.
- Rehydration work throughout the Gascoyne catchment.
- Fencing infrastructure to better manage stock grazing area and numbers.
- Control feral animal numbers.
- Staff accommodation infrastructure to enable employment of staff to implement drought preparation projects. Tax concessions / incentives for businesses employing people in remote areas, so we can afford to hire staff to achieve the projects.
- Access to training courses.
- Mental health education & resources. Also need access to face to face help for mental health. A lot of farmers don't want to pour their heart out to a computer screen. They also don't have time (or money) to travel 1-2 days (and hundreds of km) for each appointment, to access a 15-30 minute appointment in Carnarvon (appointments are often required frequently for treatment). These trips should be covered by PATS if they are required to travel to town. On station visits by medical professionals would see more people getting the treatment they need (perhaps government could fund RFDS to run this service?).
- Funding to assist all of the above.
- studies with actionable outcomes in diversity, risk mitigation to improve practices to minimise impact of doing pastoral and horticultural business and expanding water resources.
- Help people financially during hardship
- Availability of Communication. We are in 2024 still many blackspots existing in many areas, water storage and stronger and larger emergency shelters on high ground. Improve airport structures and or landing strip's in isolated areas when the roads/ rail is flooded. Millions spent on tourism should go to improve / build hospitals in country areas.

Question 10 provided an opportunity to share contact information for further follow-up. Three of the seven respondents provided a contact number.

Appendix C: Potential indicators for drought impact

Economic

Potential indicator	Order of effect and temporal considerations	Data sources available	Timeliness | Spatial Unit | Accessibility
Labour market: Occupations in demand, job creation/vacancies	Secondary order / short-term to medium-term	a) Internet Job Vacancy Index (IVI): by region and occupation[32] b) Labour force by occupation (NERO)[33] c) Labour force, participation rate[34]	a) Monthly. IVI region.[35] Published with up to two months lag. Public data. b) Monthly. SA4. One month lag. Public data. c) Monthly. State. One month lag. Public data.
Unemployment rate Underemployment Hours worked	First order / short to medium-term	ABS Labour Force Survey (LFS)[36]	Monthly. SA4 / state. Published with up to a quarter of year lag. Public data [37].
Gross Regional Product	Secondary order / short-term to medium-term	ABS: a) Household consumption b) Business investment c) Dwellings investment d) Public demand e) Inventories and ownership transfer costs f) Exports and imports Gross State Product	a) Retail turnover: Monthly. State. 1 month lag. Public data.[38] Sales of New Motor Vehicles. ABS Data: Monthly. State. Ceased in 2017. Public[39]; FCAI Sales of New Motor Vehicles: Monthly. State. Subscription[40]. Consumer Price Index: Quarterly. Capital City only. 1 quarter lag. Public data [41] b) Private New Capital Expenditure: Quarterly. State. 1 quarter lag. Public [42] c) Construction Work Done: Quarterly. State. 1 quarter lag. Public [43] d) Government finance statistics: Quarterly. State. 1 quarter lag. Public [44] e) Business indicators Quarterly. State. 1 quarter lag. Public [45]

			f) Exports and imports: international trade and trade between states. [46] Monthly data. Publicly available but with a fee. g) ABS Gross State Product. [47] Yearly available. Free. 1 year lag.
Housing demand and supply; Vacancy rates;	Tertiary / long-term	SQM Research[48]	Monthly. 1 month lag. Public[49]
Income inequality	Tertiary / long-term	ABS Census	Every 5 years. 1 year lag from collection to publication. Public
Economic disadvantage or resilience	Tertiary / long-term	Eg. a) SEIFA based on Census b) LEVER – dependence on carbon-intensive industries. Labour force based modelling.	a) Every 5 years. 2 years lag from collection to publication. Public b) Potential to align with ABS LFS
Agricultural activity and output	First order / short-term	a) Agricultural Lending	a) Lending to agribusiness data is not standardised and has poor spatial resolution[50]
Fodder and waterassistance deliveries		a) NEMA b) Rural Aid / RawTas	a) And b) Fluctuations in website traffic. b) Number of fodder or water truck deliveries
Tourism and recreation demand and services	Secondary order / short-term to medium-term	a) Domestic and international tourism visitors and expenditure b) Employment in tourism-related services	a) Monthly. State. Up to 1 year lag. Public data [51] a and b) Yearly. Tourism region level. Up to six months lag. Public [52]
Construction sector activity and costs	Tertiary / long-term	e.g. ABS Construction Work Done	Quarterly. State. 1 quarter lag. Public [53]
Water costs	First order / medium-term	e.g. ABS Water Accounts: Monetary Supply and Use, by Industry and Water Type	Yearly. National. 1 year lag. Public [54]

Food prices	Secondary order / short-term to medium-term	e.g. ABS Consumer Price Index: Food and non-alcoholic beverages prices	Quarterly. Capital City only. 1 quarter lag. Public data
Personal financial hardship	Secondary order / short-term to medium-term	e.g. Number of debtors undergoing personal insolvency - Australian Financial Security Authority[55]	Updated monthly or quarterly. SA3 or state. Published with up to a quarter lag. Public data

Health

Mental health challenges			
Social withdrawal	Likely to be a strong effect on early warning	No systematic data sources.	Observations made locally by family, friends and community members, and by rural service providers, both private enterprises and non-government organisations.
Distress (Kessler 10)	Secondary order / short-to-medium-term	Household, Income and Labour Dynamics in Australia (HILDA) Survey	Data becomes available approximately yearly, multiple spatial units available, and data available on request.
		ABS National Health Survey	It has been conducted sporadically, multiple spatial units available, and data publicly available through ABS website.
Other self-rated measures of mental health and wellbeing, with potential applicability for both short- and long-term. E.g. panic disorder, social phobia, PHQ-(depression)	Secondary order / short-term to medium or long-term	Household, Income and Labour Dynamics in Australia (HILDA) Survey, Department of Social Services	Yearly data. Detail down to SA1. Free data is available on request for research purposes.
		National Study of Mental Health and Wellbeing, Australian Bureau of Statistics	Relies on WHO International Classification of Diseases. Run in 1997, 2007, 2020-21 and 2021-22. Multiple spatial units are available, and data is publicly available through ABS website for 2007 and 2021 samples in DataLab for registered users.

Mental health-related emergency department visits, episodes of residential mental health-related care, and mental health-related community contacts General practitioner visitations rates, types of services, including script and mental health	Secondary order / short-term to medium or long-term	Mental Health Services Data, Australian Institute of Health and Welfare	Data becomes available approximately yearly, multiple spatial units available, community State/Territory, degree of remoteness, Primary Health Network (PHN), and sometimes Statistical Area Three (SA3).
A range of self-ratings	Secondary order / short-term to medium or long-term	Australian Rural Mental Health Study by Centre for Rural and Remote Mental Health Research	Centre closed in 2022. Data may still be available on request and for use of baseline building.
Reduced access to utility services			
Infectious disease monitoring	Depending on the disease, and association with environmental indicators of drought, can be a meaningful effect that informs of impact and timing of drought cycle, and collection timely done for early warning.	Australia's National Notifiable Diseases Surveillance System	Updated daily, state/territory and postcode units available publicly.
Illness from persistent/extreme heat and/or reduced air quality			
Ambulance attendance (both temperature and quality)	Important effect and timely for early warning but constrained by access to data not being timely.	State/territory ambulance services	Timeliness unknown, high spatial resolution and formal data submission are required to access data.

Deaths (both temperature and quality) Hospitalisations for cardiovascular and respiratory problems (primarily ar quality) Emergency department presentations with asthma (primarily air quality)	Likely to be meaningful effects and collection timely for early warning but constrained by access to data not being timely.	The Australian Institute of Health and Welfare	Data becomes available approximately yearly, multiple spatial units available, commonly State/Territory, degree of remoteness, Primary Health Network (PHN), and sometimes Statistical Area Three (SA3).

Socio-demographic

Potential indicator	Order of effect and temporal considerations	Data sources available	Timeliness | Spatial Unit | Accessibility
Change in the age structure of population	Tertiary / medium to long-term	ABS[71] and Centre for Population[72]	Public data. Observed data is collected every five years, and available at SA1 level (Census). Modelled predicted data is made available quarterly and available at SA4 level.
Social security payments	Secondary / medium to long-term	Australian Department of Social Services[73]	Public data updated quarterly. Count data available at SA2 and LGA levels. Revenue obtained from outside sources (remittances, social security payments, retirement funds, etc) helps to increase absorptive capacity in a region as the average household would face fewer financial impacts from loss of production or salary income as a consequence of drought events.

Housing – median value	Tertiary / long-term	ABS[74] and CoreLogic (and similar providers)	Public data (ABS) are available at 'metropolitan area' and 'rest of state' level. Private data can be obtained at the property address level for multiple years.
Housing – change in the proportion of renters	Secondary / medium to long-term	ABS Housing Data[75] and Survey of Income and Housing (SIH)[76]	Public data, but only available at 'metropolitan area' and 'rest of state' levels in two-year periods—when the SIH is conducted. The Census can also provide this indicator, for every five years.
Accessibility and remoteness	Primary (mostly to inform resilience capacities)	ABS[77] and other methods	Region remoteness categories: ABS data are provided at SA1 level and updated every five years with each census. Distance from main urban centres can also be frequently updated using road GIS layers data. Changes in population of nearest urban centre can also point to changes in remoteness, as the growth of a neighbouring region can bring more market access to a particular region.
Migration	Secondary / medium-term	Regional Australia Institute – Regional Movers Index[78]	Public data provided at quarterly and annual intervals. Available at LGA and State levels.

Source: Poruschi et al, 2023

Appendix D: Ideas for households to cope with drought

Listed ideas are based on previous works referenced at the bottom of this appendix.

Water management at home

- Take shorter showers,
- Collect wastewater to re-use elsewhere,
- Upgrade to more water-efficient appliances, taps and toilets,
- Switch to a low-phosphate detergent when washing clothes and recycle the rinse water on the garden.

Water Management for the garden

- Don't give up on your garden as it is your oasis – do your research and make the most of the resources you have,
- Install a grey-water system and use water timers and drippers to reduce garden water use,
- Replace water-hungry lawn with stones or native groundcover,
- Install a water-wise garden using more plants that are local to your area, succulents and low water lawns,
- Check the system for leaks, clogs and wear that are wasting gallons of water,
- Cap sprinklers or bubblers that are no longer being used to prevent waste,
- Adjust sprinkler nozzles to eliminate overspray onto hardscapes,
- Check your irrigation system pressure – your system should not need more than 60 psi / 3.1 bar,
- Spray heads being fed too much pressure will likely cause misting. Water coming out in smaller particles is much easier to get carried away by wind and doesn't penetrate the soil as it should,
- Optimal pressure for a spray head is 30 psi / 2.1 bar, and 40 psi / 2.8 bar for a rotator,
- Install a pressure regulator on your irrigation valves, if needed,
- Sprinkler heads that have built-in pressure regulation can be purchased online or at a local irrigation supply store,
- Apply water at a rate that allows soil to absorb it and limits runoff. For example, instead of watering once for ten minutes, water five times for two minutes each time,
- Plant responsibly – keep turf only where it's practical and replace thirsty plants with native and drought-tolerant plants. Consider a low water-use groundcover,
- Consider installing a weather-based irrigation controller so that you're watering the right amount for each day's weather,
- Install shade structures to protect vulnerable plants, such as vegetables, against extreme heat,
- Water between 4:00 and 6:00 AM when evaporation is low. This gives the ground a chance to soak the water in and reach the root system of the plants before the heat of the day,
- Create water zones by putting plants together that have similar water needs,
- Put a layer of mulch around your trees.

Heat management

- Make the most of public green spaces,
- Cool off with a swim at the local pool,
- Be prepared for hotter days by creating shade at home and in the garden,
- Take an afternoon siesta on hot days and go back outside in the evenings,
- Don't stop community tree planting, just mindfully choose plant species that are adapted to the local environment.

Fire risk management

- Prepare your property to reduce the risk of fire and limit activities during high fire danger conditions,
- Develop an emergency or bushfire plan for your family and community,
- Monitor weather forecasts and warnings and be prepared to change plans.

Cyclone risk management

- Develop an emergency or cyclone plan for your family and community,
- Monitor weather forecasts and warnings and be prepared to change plans.

Stress management

- Focus on the positives and proactively consider adaptation and mitigation actions that you and or your community can take,
- Stay connected – regularly keeping in touch with friends and family and others who are going through similar challenges, face to face or on the phone,
- Learn from those who have lived this before,
- Have faith – our ancient landscape is enduring and resilient,
- Attend, organise or volunteer at community events to maintain your social connections and motivation,
- Arrange social activities to keep people coming to the local club,
- Take the opportunity to try a new hobby,
- Limit alcohol and strive for a healthy diet,
- Don't skip your regular doctor's appointments for both your physical and mental wellbeing,
- Be an attentive listener when interacting with others and show empathy,
- Organise or attend Mental Health First Aid training for community members,
- Be kind to each other and open minded to solutions,
- To support others, follow the CARE action plan:
  - ◊ Call to act: Recognising the signs and symptoms enables a response when someone is struggling,
  - ◊ Action: Having the conversation and supporting a person to seek assistance in a timely manner,
  - ◊ Reach out: Following up and following through after the conversation,
  - ◊ Energise: Engage in self-care activities to ensure your own wellbeing. Initiate a self CARE plan if appropriate.

Personal Finance management

- Set a budget and look for opportunities to save money.

Information adapted from these sources:

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