Department of Primary Industries
and Regional Development

# Irrigated Wheat

## Results Report

Climate Vulnerability Assessment

NSW GOVERNMENT

*Authors*

The NSW Department of Primary Industries Climate Vulnerability Assessment and Broadacre Cropping teams.

*Funding*

The Climate Vulnerability Assessment has been completed as part of the NSW Primary Industries Climate Change Research Strategy funded by the NSW Climate Change Fund.

*Suggested citation*

NSW Department of Primary Industries and Regional Development (2025) Climate Vulnerability Assessment Irrigated Wheat Results Report. https://www.dpi.nsw.gov.au/dpi/climate/climate-vulnerability-assessment/publications-and-reports/Climate-Vulnerability-Assessment-Irrigated-Wheat-Results-Report.pdf, accessed on [insert access date].

*Acknowledgement of Country*

The NSW Department of Primary Industries and Regional Development acknowledges that it stands on Country which always was and always will be Aboriginal land. We acknowledge the Traditional Custodians of the land and waters and show our respect for Elders past, present and emerging. We are committed to providing places where Aboriginal people are included socially, culturally and economically through thoughtful and collaborative approaches to our work.

TITLE: Irrigated Wheat Results Report
ISBN: 978-1-76058-918-9



## Table of Contents



## Contact us

For more information, please get in touch with
vulnerability.assessment@dpird.nsw.gov.au

# Introduction

Primary industries in New South Wales operate a wide variety of production systems within diverse landscapes while facing the challenges of a changing and highly variable climate. The Primary Industries Climate Change Research Strategy invested $29.2 million in projects to help the state's primary industries adapt to climate change. As part of this work, the Climate Vulnerability Assessment undertook impact assessments for primary industries in the broadacre cropping, marine fisheries, forestry, extensive livestock, and horticulture and viticulture sectors, and key related biosecurity risks to improve our understanding of the impacts of climate change.

The Climate Vulnerability Assessment has delivered consistent and comparable understandings of potential climate change impacts across the state, providing a deep insight into sectoral impacts. This strategic information is invaluable for policymakers and industry bodies, providing insights into 28 commodities and 14 biosecurity risks considered valuable or important to NSW.

This comprehensive assessment allows primary industries to understand the risks ahead, to prepare for and adapt to identified climate vulnerabilities, and to be well-placed to take advantage of future opportunities to expand production in NSW.

## Purpose of this report

This report contains results for the irrigated wheat study within the Climate Vulnerability Assessment. The report introduces the wheat industry in NSW and provides an overview of the model, its key features, assumptions, and exclusions. The main results and findings are presented to provide insights into future climate vulnerabilities and opportunities. Where appropriate, the report also discusses adaptation options.

# Climate within NSW

The climate in NSW varies across the state, influenced by topography, weather patterns, and proximity to the Great Dividing Range and the Tasman Sea. The state's diverse climates include arid and semi-arid inland regions, humid subtropical coastal areas, temperate coastal regions and alpine areas.

Extensive broadacre agriculture extends through the state's centre from Goondiwindi on the Queensland border, through the Liverpool plains, Southwest Slopes and plains, to the Riverina and the Victorian border.

## The changing climate is impacting primary industries

Australia has one of the world's most variable climates, and its primary producers have always managed climate variability. Now, they are planning for and adapting to climate change arising from anthropogenic greenhouse gas emissions. These changes in long-term climate patterns at global and regional scales are adding a new dimension to the challenge of producing food and fibre in Australia. Changes in climate include increasing temperatures and alterations to rainfall patterns, alongside increasing challenges from extreme events.

This $23.1 billion sector supports economic growth and development, contributes to food security at the state and national scale and plays a vital role in biosecurity management. The limited availability of practical and targeted information on the impact of climate change on commodity productivity or the changing prevalence of biosecurity risks has limited adaptation to climate change in this sector.

## Projected climate change impacts

A review of research literature on the impacts of projected climate change on primary industries in Australia revealed disparities in research efforts across the primary industry sectors and in our understanding of what is likely to occur.

Broadacre cropping in Australia has been well-researched, but it is challenging to draw a consistent and comprehensive understanding of the effects of climate change from these studies because of differences in assumptions, methodology and climate projection data used[1]. Broadacre cropping was also found to have a skewed research effort towards wheat, which accounted for 72% of cropping studies and 25% of the total research effort, whilst other broadacre crops in NSW were completely missing. These studies did draw out some impacts from climate change, which are likely to challenge the production of broadacre crops in some areas due to changes in temperature and rainfall. Some potential opportunities arise from decreases in frost events in some parts of the cropping zone in NSW under the future climate.

## Assessing the impacts of climate change

To address these issues, the Climate Vulnerability Assessment examined the potential impacts of climate change on a wide range of economically important primary industry commodities and biosecurity risks. This has enabled us to identify those industries most at risk and, thus, most in need of adaptation strategies, as well as those where climate change might bring new opportunities and relief from existing challenges.

[1]Darbyshire RO, Johnson SB, Anwar MR, Ataollahi F, Burch D, Champion C, Coleman MA, Lawson J, McDonald SE, Miller M, Mo J, Timms M, Sun D, Wang B, and Pardoe J. (2022). Climate change and Australia's primary industries: factors hampering an effective and coordinated response. *International Journal of Biometeorology*, 1-12.

# Wheat in NSW

Wheat was one of the first crops sown following European settlement in Australia and it has become one of Australia's largest and most valuable agricultural commodities. In 2022- 23, Australian wheat accounted for almost 14% of global wheat exports. Wheat in NSW is grown as both a dryland and irrigated crop. Irrigating wheat crops can provide a higher yield and a higher degree of confidence in productivity but is dependent on the availability of irrigation water. Plantings of irrigated wheat in NSW are increasing, especially in southern NSW. NSW wheat production was recorded to be 7.1 million tonnes across 3.3 million hectares in 2023-2024[2].

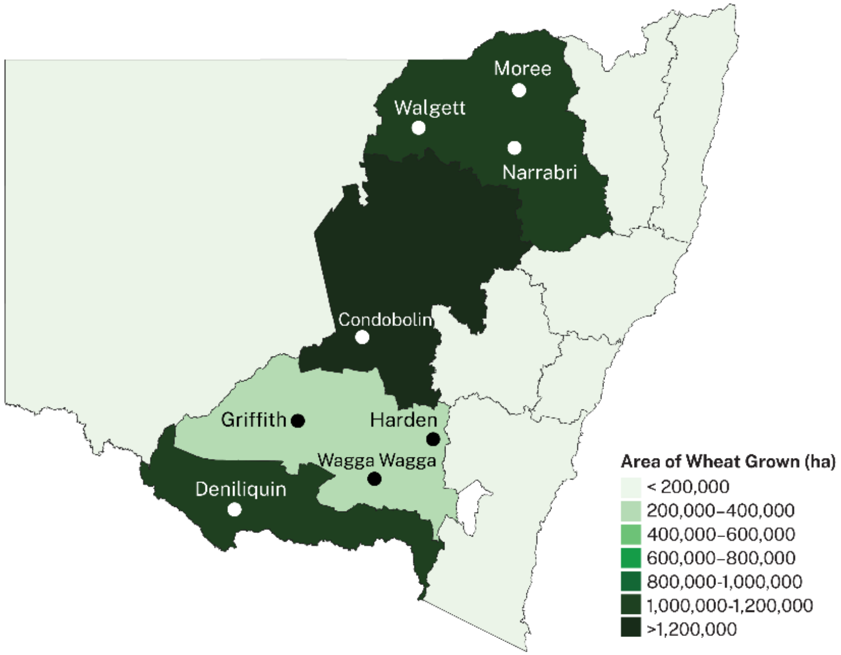



*Figure 1: Wheat production in NSW. Sourced from the ABS 2021.*

[2] https://www.dpi.nsw.gov.au/about-us/publications/pdi/2024/wheat

# Climate Vulnerability Assessment framework

The Climate Vulnerability Assessment was designed to provide an overview of the impact of future climate change on all stages of production for the commodities and biosecurity risks assessed. To achieve this, a modelling approach was adopted that would produce assessments for the commodities and biosecurity risks in a consistent, and therefore comparable, way.


*Figure 2: Outline of expert engagement in the assessment framework developed by the Climate Vulnerability Assessment. Internal and external experts are involved throughout the process, helping to develop and refine the model of their primary industry commodity or biosecurity risk.*

The assessment framework, outlined in Figure 2, provides a rigorous, flexible and transparent process for assessing vulnerability to climate change. It begins with a literature review, used to inform a draft model of the commodity or biosecurity risk. External experts review the model at three points during the model development, as a small focus group. The participation of experts throughout the process was critical for integrating expert knowledge into the models developed by the Climate Vulnerability Assessment.

Over 100 NSW Department of Primary Industries staff contributed to this process, and almost 200 experts participated in focus groups to support the review and refinement of the models. External experts were drawn from industry bodies, producers, academia, and elsewhere.

## MCA modelling approach

The steps in the framework developed for the Climate Vulnerability Assessment are designed to identify and compare the climate variables important in the production of each commodity and the survival of each biosecurity risk assessed. The chosen modelling approach, using multi-criteria analysis (MCA) models, allows knowledge obtained about these climate variables from scientific literature, expert focus group knowledge and other sources to be combined in a way that is consistent across all commodities and biosecurity risks.

A simple MCA model with customisable assumptions and exclusions (detailed below) was developed for each commodity and biosecurity risk. A hierarchical structure underpins the MCA modelling approach, and the models were developed using a combination of empirical data and expert judgment. The commodity or biosecurity risk sits at the top of the hierarchy, which is then divided into the key production phases, each of which contains the climate variables that influence that production phases.

Each production phase is weighted relative to the others to reflect the importance of its contribution to the overall success in the growth of the commodity or the survival of the biosecurity risk. The weightings are derived using the analytical hierarchy process[3] and reflect the consensus reached by the focus group experts.

[3] Saaty, T.L. (1980) The Analytic Hierarchy Process, McGraw-Hill, New York

The MCA model is not designed as a yield estimating model but as a climate suitability model. Climate suitability is defined as the extent to which climatic conditions satisfy the requirements of plant or animal growth in the absence of other limiting factors[4].

The MCA model provides an assessment of climate suitability (ranging from unsuitable to highly suitable) for each individual climate variable, for each production phase, and for the overall model. Climate suitability is modelled for both historical (recent past) conditions and for projected (near future) climate to understand how climate suitability for irrigated wheat may be affected by climate change.

Experts reviewed the historical and future assessments and provided insights and interpretations, highlighting findings of importance for future planning. The following sections of this report provide an overview of the model structure for irrigated wheat and key results showing important changes to future climate suitability in NSW, as identified by the assessment.

For further details on the Climate Vulnerability Assessment framework, MCA models, and climate data (historical observations and future projections), please refer to the Climate Vulnerability Assessment Methodology Report.

The project limitations and exclusions are briefly summarised to the right, and specific assumptions for the irrigated wheat model are summarised on the next page.

## Project scope and exclusions

The scope was limited to the assessment of vulnerability to future climate change. The assessment captures the response of wheat to changes in future average climatic conditions. The project was designed to support policy and regional investment decisions, not provide farm-scale advice. The following were not considered:

- topography,
- other non-climatic biophysical parameters,
- socio-economic factors, and
- water availability into the future.

These exclusions should be considered alongside the project's findings when examining the ongoing or future viability at a given location.

Certain climate data were excluded due to future climate projection data limitations. Models excluded wind due to its variability on short timescales and the use of relative humidity on timescales shorter than a month. Extreme weather events such as intense rainfall, heatwaves, storms, drought, floods, and bushfires were also excluded due to their unpredictable nature and the complexities of their interaction with the climate. Future work incorporating more sophisticated future climate projections as they become available is likely to provide an improved capacity for describing the impacts of extreme weather events and climate variability.

[4] Zhao, J., Yang, X., Liu, Z., Lv, S., Wang, J. and Dai, S. (2016) Variations in the potential climatic suitability distribution patterns and grain yields for spring wheat in Northeast China under climate change. Climatic Change, 137:29-42.

# Overview of the irrigated wheat model

For more information, see the Climate Vulnerability Assessment Methodology Report.

## Climate variables

The climate variables used in the irrigated wheat MCA model were minimum temperature (Tmin, °C), mean temperature (Tmean, °C), maximum temperature (Tmax °C) and rainfall (Rain, mm). Note that in the irrigated wheat model, rainfall is used to determine the timing of germination.

## Categorising climate variables

The hierarchical structure of the MCA model (Figure 3) categorises climate variables to assess their impact on wheat. Each category (for example, a temperature between 15 and 20°C) is assigned a rating, R, between 0 and 1 that indicates how well it suits wheat, from unfavourable (R=0) to optimal (R=1). This is repeated for each phenophase.

## Modules used in the irrigated wheat model

The irrigated wheat MCA model uses the following standardised modules to produce ratings from the climate variables:

- **Proportional module:** examines the duration (in days) spent in each climate category during a given phenophase.
- **Damage penalties:** define extreme climate conditions that are damaging to a particular phenophase. If these limits are reached, then the phenophase receives a reduction in climate suitability.

The ratings for each climate variable, together with the weighting assigned to each branch in the hierarchical structure and the climate data itself, produce the climate suitability for wheat.

## Irrigated wheat model assumptions

In addition to the global assumptions and exclusions, the commodity model also contains the following:

- the model is designed for a Gregory-type variety of spring wheat with a yield potential of 6 tonnes per hectare,
- the model does not assess the quality of the crop,
- best practice management is undertaken,
- the crop is free of pests and diseases,
- irrigation is not limited by availability of water,
- crop development proceeds according to growing degree days, and
- crop pollination takes place.

## What are phenophases?

In broadacre crop production, a 'phenophase' denotes a specific stage in a crop's life cycle, marked by distinct developmental events, such as leaf emergence, flowering, or grain filling. These stages, influenced by environmental cues, are pivotal for understanding growth progress and crop responses.

One key climatic driver of crop development is the accumulation of heat over time (thermal time), measured by 'growing degree days' (GDD). GDD can predict the length of a phenophase.

The irrigated wheat model used here employs a 'dynamic phenology' approach that assigns a GDD thresholds to each phenophase. The start and end dates for each phenophase thus vary across the state according to average temperatures, with crops developing more rapidly in warmer regions and in warmer seasons.

## What triggers germination? What is crop completion?

Crop completion arises when a crop firstly, has germinated and then receives enough thermal time for the growing season to complete.

Germination depends on the crop receiving the sufficient water soon after sowing, and 'germination reliability' measures the proportion of years in which this happens.

The growing season is complete when the required GDDs for the crop are achieved (see Table 1). Crop completion measures the proportion of years in which this happens.

Along with maps of climate suitability, maps of germination reliability, growing season completion and the length of the growing season are also provided in this report.

## Irrigated wheat phenology

The irrigated wheat model has been divided into key growth stages, referred to as phenophases (Table 1), and used dynamic phenology to track crop growth and phenophase development. The irrigated wheat model assumes that irrigation is not applied to induce germination.

Rainfall was used to determine germination timing. Sowing of wheat occurs on a fixed sowing date of 1 May and germination is triggered when at least 15mm of rain is received in any 14-day period within 8 weeks of the sowing date.

When these germination conditions are met, the crop begins to grow. If the germination conditions are not met within 8 weeks of sowing, the crop does not germinate and there is no yield for that year. Following germination, the crop begins to accumulate thermal time, measured as growing degree days (GDD) with a base temperature of 0°C, for all phenophases[5]. The crop must receive the required number of GDD within 365 days to complete its growing season (see Table 1). Crop completion fails if it does not achieve the required number of growing degree days or an appropriate amount of rainfall in that time.

[5] Manschadi, A.M. et al., 2006. APSIM-Wheat model – Adaptation of a wheat model to simulate wheat growth and development. In: 13th Australian Agronomy Conference, Perth WA.

*Table 1: Key phenophases for irrigated wheat and the required number of growing degree days per phenophase.*

| | Phenophase | Number of GDD |
|---|---|---|
| Temperature | Vegetative Growth | |
| | Germination trigger | 1 May up to 8 weeks when 15 mm of rain has accumulated |
| | Germination | 0 to 194 GDD |
| | Tillering | 195 to 625 GDD |
| | Early Stem Elongation | 626 to 733 GDD |
| | Late Stem Elongation | 734 to 841 GDD |
| | Reproductive Growth | |
| | Booting | 842 to 1057 GDD |
| | Heading | 1058 to 1488 GDD |
| | Early Grain Fill | 1489 to 1704 GDD |
| | Late Grain Fill | 1705 to 1919 GDD |
| Damage Penalty | Frost | |
| | Mild | 1319 to 1488 GDD |
| | Moderate | 1489 to 1597 GDD |
| | Severe | 1598 to 1704 GDD |
| | Heat | |
| | Mild, Moderate, Severe | 1319 to 1704 GDD |

## Final irrigated wheat model

A summary of the irrigated wheat model with weightings (W) for all the variables is shown on the following page (Figure 3). This model is complex and has been summarised for ease of understanding to show only the weighted variables. To see all levels of the model, including the ratings for each weighted variable, please refer to the appendix.

The first level of the model identifies the key drivers of wheat growth and production: temperature and frost and heat damage penalties.

Mean temperature is assessed for the vegetative and reproductive phenophases. Temperature is more important during reproductive growth than vegetative growth, with the heading phase being the most important.

Finally, the frost and heat damage penalties only apply during the booting, heading and early grain fill phenophases. These damage penalties have three levels (mild, moderate and severe) and they are applied for every day that they occur within the model. They are not weighted and directly impact overall suitability when they occur. Frost and heat damage to wheat around flowering is calculated using daily yield penalties of 0.1 and 0.2 for mild and moderate damage. However, for severe frosts the damage penalty is 0.9, and for severe heat it is 0.3. The damage penalty for a given year is the multiple of all the daily penalties.

In the irrigated wheat model, rainfall is not considered relevant to climate suitability except for germination, which remains rainfall-dependent: irrigation is not applied to induce germination.

While irrigation water requirements have been assessed alongside climate suitability, this work does not assess whether there will be sufficient water supply available for irrigation. Please see page 33 for more information on water supply.

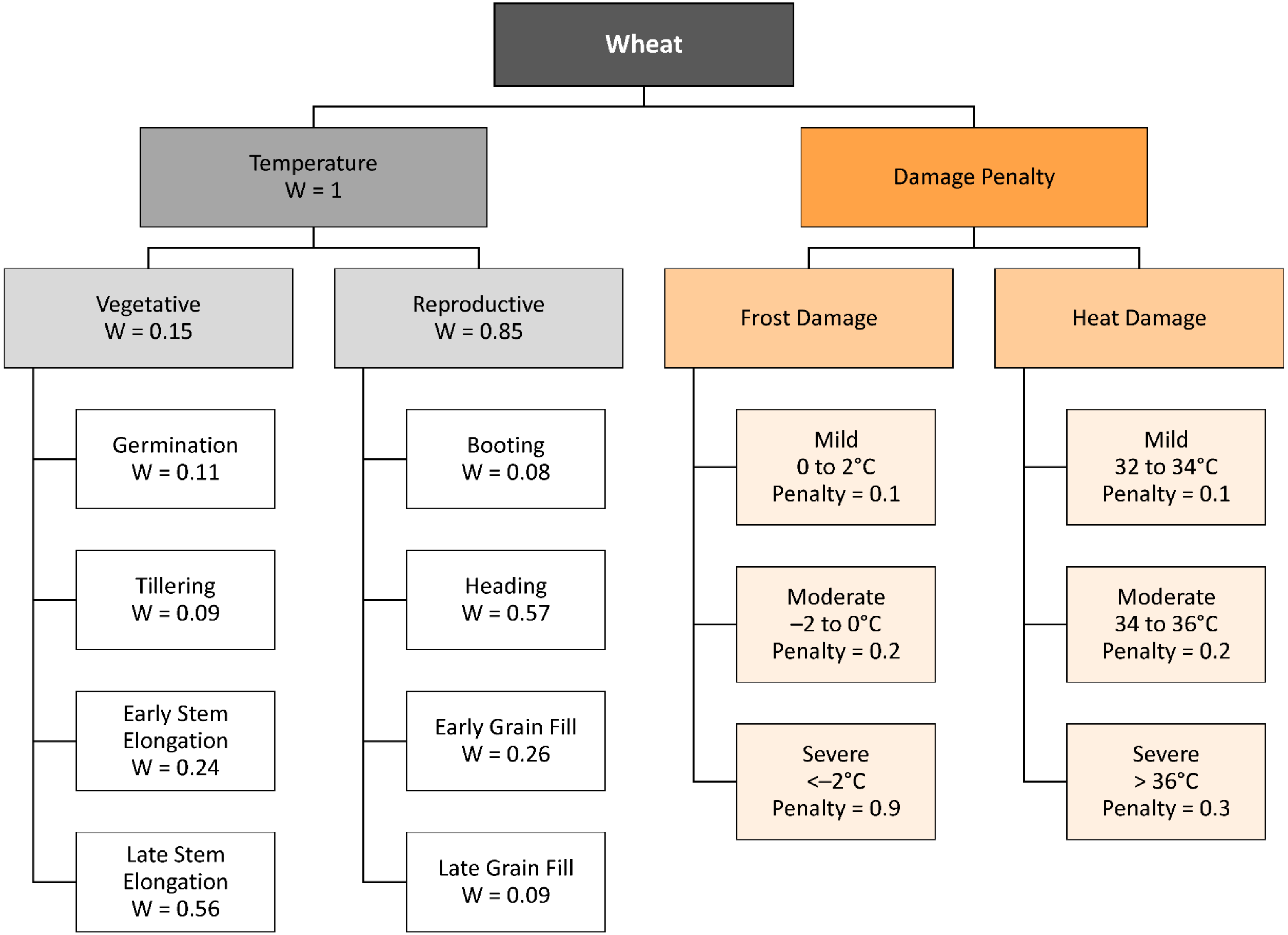



*Figure 3: MCA model structure for irrigated wheat. The top-level of the hierarchy is the commodity. The second level contains the key drivers of wheat growth and production as identified by the literature review and expert judgment. The full irrigated wheat MCA model can be found in the appendix.*

# Interpreting the results

The results are presented as panels of 7 maps, comparing historical climate suitability with climate suitability under the two future emissions scenarios (RCP4.5 and RCP8.5; see Figure 4). For the future emissions scenarios, maps of change (Figure 5) and confidence in change (Figure 6) in climate suitability are also presented.

The historical climate suitability map shows the mean suitability for 30 years (1981 to 2010). For future projections, the mean suitability for 30 years (2036 to 2065) was calculated for 8 global climate models[6], and the median of these models was used to produce ensemble future projection climate suitability maps.

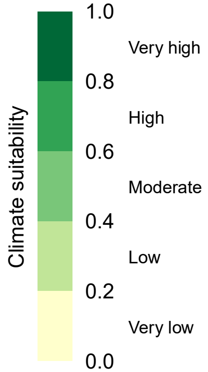



*Figure 4: Colour scheme for the climate suitability maps*

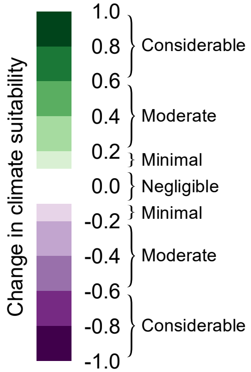



*Figure 5: Colour scheme for the change in climate suitability maps*

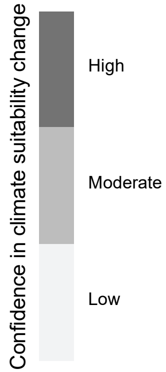



*Figure 6: Colour scheme for the confidence in the change in climate suitability maps*

### *Historical and future climate suitability maps*

The 'climate suitability' maps show the climate suitability on a scale of 0 to 1. Pale yellow is very low suitability, and dark green is very high suitability.

### *Change in climate suitability maps*

The 'change in climate suitability' maps use a green-white-purple colour scheme with 11 categories: positive change, where the future climate becomes more suitable, is shown in shades of green; negative change is shown in shades of purple. Darker shades of green or purple show more considerable change (values closer to −1 or 1), and the lightest shades of green or purple show minimal change. Negligible change is represented by white and occurs for values between −0.1 and 0.1; in these areas, the future climate suitability will be very similar to the historical suitability.

### *Confidence in the change in climate suitability maps*

The 'confidence in change in climate suitability' maps represent the level of agreement across the ensemble of 8 global climate models on the direction and magnitude of change in climate suitability. The lightest shade of grey represents low confidence, and the darkest shade of grey represents high confidence.

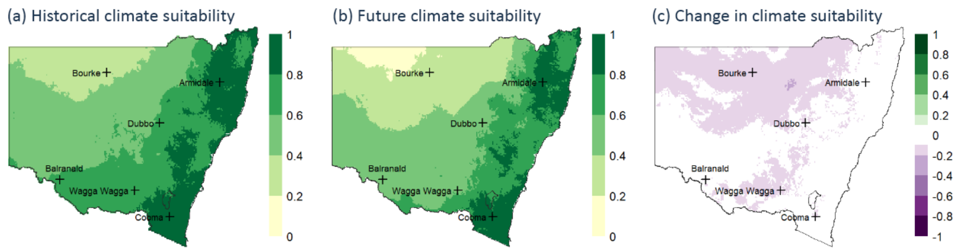
[6] Data was sourced from Climate Change in Australia: Application Ready Data

## Understanding climate suitability: a guide to map interpretation

The Climate Vulnerability Assessment has strived for accuracy and clear interpretation in our data representation, particularly when there is uncertainty. The MCA models produce continuous climate suitability values. To help readers interpret the maps, these suitability values have been grouped into 5 categories between 0 and 1 (each shown in a different colour). Changes in climate suitability values are also continuous but have been grouped into 11 categories between –1 and 1. Negligible change is shown in white and is defined as –0.1 to 0.1, and the values within this range are considered uncertain. However, this categorisation can occasionally lead to our maps showing results that are not immediately intuitive. Below are two circumstances that arise, and we have described why and how this occurs.

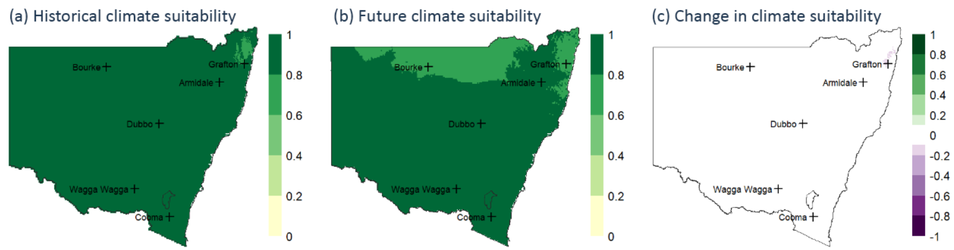
***Why does the 'change in climate suitability' map show changes in some places where the historical and future climate suitability maps have the same colour?*** There are instances where historical and future climate suitability maps show the same category of climate suitability, yet the change in suitability maps indicates a positive or negative shift. This occurs when the climate suitability has changed, but not sufficiently to move it from one category to another.

**In the example below**, you can see this south of Bourke when comparing the historical, future and change maps. The climate suitability of Bourke changes from 0.35 in the historical map to 0.22 in the future map. This leads to no change in the suitability category (both maintain low suitability), but as the change is 0.13, this is categorised as minimal change and is shown in the change in suitability map in purple.




***Why is there negligible change (white) on the change map in places where the historical and future climate suitability maps have different colours?*** Sometimes, the categories change between the historical and future climate suitability, but the 'change in suitability' maps show negligible change (white). This happens when the climate suitability changes enough to move into a different category, but the change in the value is small (less than 0.10).

**For example**, you can see this around Bourke when comparing the historical, future, and change maps below. The climate suitability of Bourke changes from 0.85 in the historical map to 0.79 in the future map, leading to a change from very high to high climate suitability, but as the change is 0.06, this is considered negligible.



# Interpreting the germination reliability and growing season completion maps

A completed crop year occurs when both germination is successful and growing season completion occurs. The proportion of years when these occur is referred to here as 'reliability'. The results are presented as panels of 7 maps, comparing the historical reliability with the future reliability under the two emissions scenarios (Figure 7).

Maps of change in the reliability (Figure 8) and confidence in the change (Figure 9) are also presented. Polygons and key sites are displayed on each map to indicate the areas where the crop is currently grown in NSW.

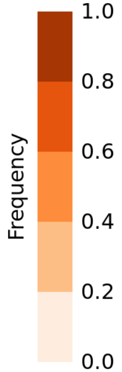



*Figure 7: Colour scheme for the reliability maps*

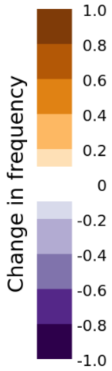



*Figure 8: Colour scheme for the change in reliability maps*

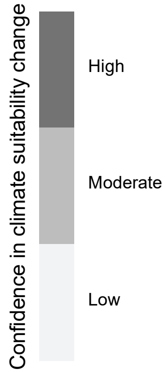



*Figure 9: Colour scheme for the confidence in the change in the reliability maps*

*Historical and future reliability maps*

The maps show the reliability on a scale of 0 to 1. Paler orange corresponds to a low reliability, and darker orange corresponds to a high reliability.

*Change in the reliability maps*

The 'change in reliability' maps use a purple-white-orange colour scheme with 13 categories: positive change, where the reliability increases in the future, is shown in shades of orange; negative change (future decrease) is shown in shades of purple. Darker shades show considerable change, and lightest shades show minimal change; negligible change, between –1 and +1 months, is shown as by white. In these areas, the future reliability will be very similar to the historical reliability.

*Confidence in change maps*

The 'confidence in the change in the reliability' maps represents the agreement level across the ensemble of 8 global climate models on the direction and magnitude of change in reliability. These maps use a grey colour scheme with three categories: the lightest grey represents low confidence, and the darkest grey represents high confidence.

# Interpreting the growing season length maps

The growing season length is defined as the number of days that it takes the crop reach maturity. For wheat this is the number of days to reach 1871 GDD. The results are presented as panels of seven maps, comparing the historical growing season length with projected future season length under the two emissions scenarios (Figure 10).

Maps of change in the growing season length (Figure 11) and confidence in the change (Figure 12) are also presented. Polygons and key sites are displayed on each map to indicate the areas where the crop is currently grown in NSW.

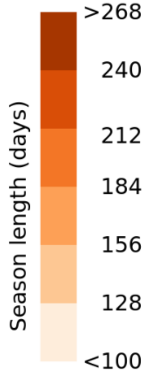



*Figure 10: Colour scheme for the season length maps*

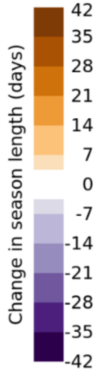



*Figure 11: Colour scheme for the change in season length maps*

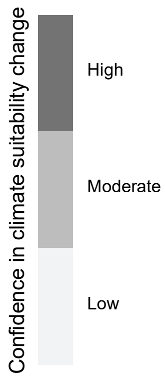



*Figure 12: Colour scheme for confidence in the change in season length maps*

### *Historical and future season length*

The maps show the season length in days. Paler orange corresponds to a shorter season length, and darker orange corresponds to longer season length.

### *Change in season length*

The 'change in the season length' maps use a purple-white-orange colour scheme with 13 categories: positive change, where season length increases in the future scenarios, is shown in shades of orange; negative change (decreasing the season length) in shades of purple. Darker shades show more considerable change, and the lightest shades show minimal change.; negligible change (–3.5 to +3.5 days) is shown as white.

### *Confidence in change in the season length*

The 'confidence in the change in the season length' maps represent the agreement level across the ensemble of 8 global climate models on the direction and magnitude of change in season length. These maps use a grey colour scheme with three categories: the lightest grey represents low confidence, and the darkest grey represents high confidence.

# Projected changes in climate suitability for irrigated wheat

*Climate change offers opportunities and challenges to irrigated wheat growing in NSW by 2050.*

This section provides a selection of results for the irrigated wheat model. The section begins with an overview of the main impacts, vulnerabilities, and opportunities, followed by the maps from the assessment that show notable changes. The relevant interpretation and findings are provided in text on the bottom left corner of each map panel.

Analysis of the model outputs has been undertaken spatially across NSW, presented as panels of seven maps. Each map includes the outline of the NSW wheat belt and several key towns within the region (Figure 13).

## Overall climate impacts for irrigated wheat

For irrigated wheat, the NSW wheat belt is likely to also maintain a predominantly moderate climate suitability (Figure 14), with some areas of high climate suitability, by 2050 under both emissions scenarios (*moderate to high confidence*).

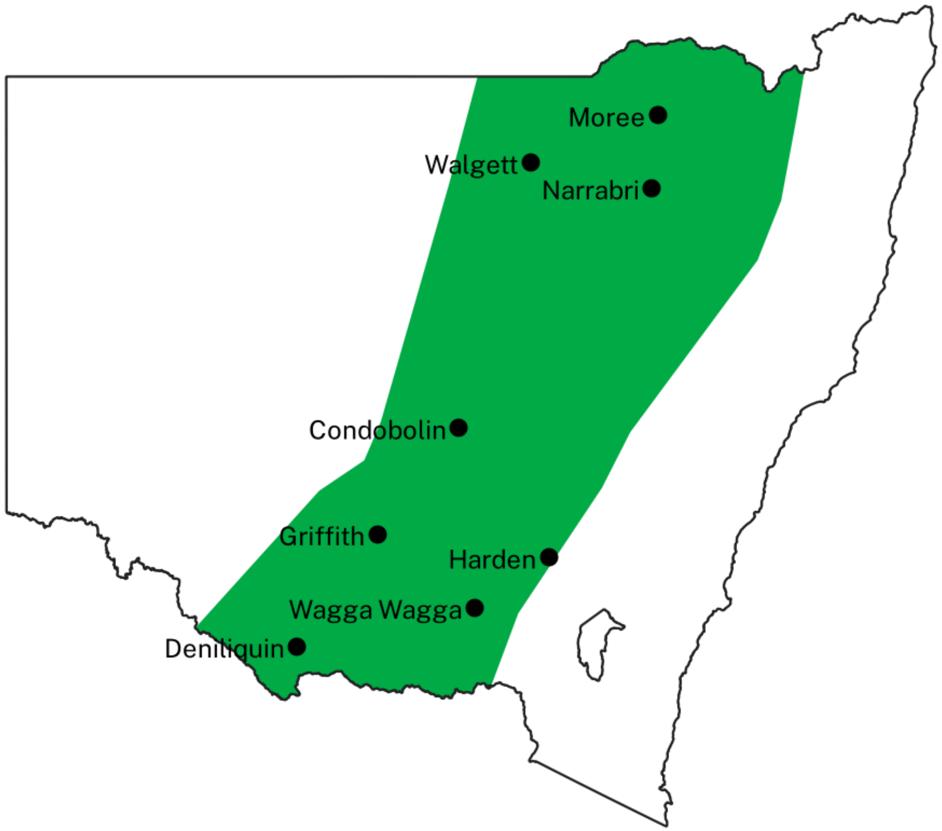



*Figure 13: The NSW wheat belt is highlighted in green, with key towns marked by black dots.*

## Climate impacts on irrigated wheat germination reliability

The historical germination frequency across the NSW wheat belt has been very high (Figure 15) (*moderate to high confidence*). The reliability of germination near Walgett and Moree is likely to experience a minimal decrease under the higher emissions scenario (*low to moderate confidence*). This would lead to lower reliability of irrigated wheat growing in these parts of NSW.

## Climate impacts on the irrigated wheat growing season

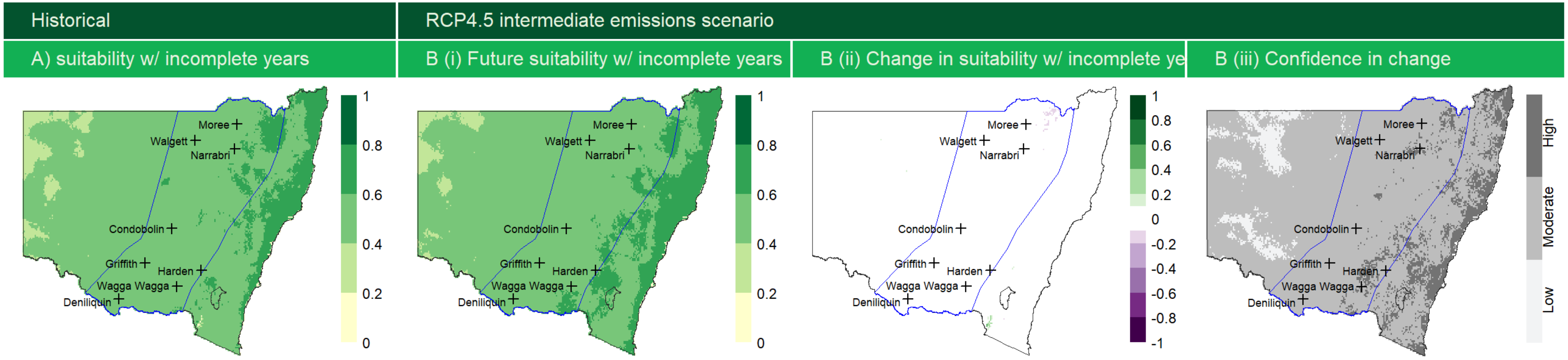
The growing season has very high completion frequency across the NSW wheat belt (Figure 16), and this is expected to be maintained under both future emissions scenarios (*high confidence*). Crops that are established under future climates are highly likely to mature (*high confidence*).

Accelerated plant development due to warmer temperatures is likely to lead to shorter phenophases and a shorter overall length in the growing season under future climates (Figure 17) (*high confidence*). By 2050, irrigated wheat crops in NSW are likely to mature 1 to 2 weeks sooner than they have historically under the intermediate emissions scenario, and 2 to 3 weeks sooner under the high emissions scenario (*high confidence*). Individual phenophases may also vary in length (Figure 18).

## Climate impacts on successful years

In years in which irrigated wheat crops complete, defined as years when the crop successfully germinates and growing season completion also occurs, there is likely to be low to moderate climate suitability across the NSW wheat belt (Figure 19) under both emissions scenarios (*moderate to high confidence*). This is similar to what has historically been experienced.

# Irrigated wheat: overall climate suitability




**Findings:** changes in climate suitability for irrigated wheat are likely to be negligible across the NSW wheat belt. Climate suitability is likely to remain moderate throughout most of the wheat belt, although high suitability areas around Moree and Narrabri may decline to moderate suitability (*moderate confidence*).

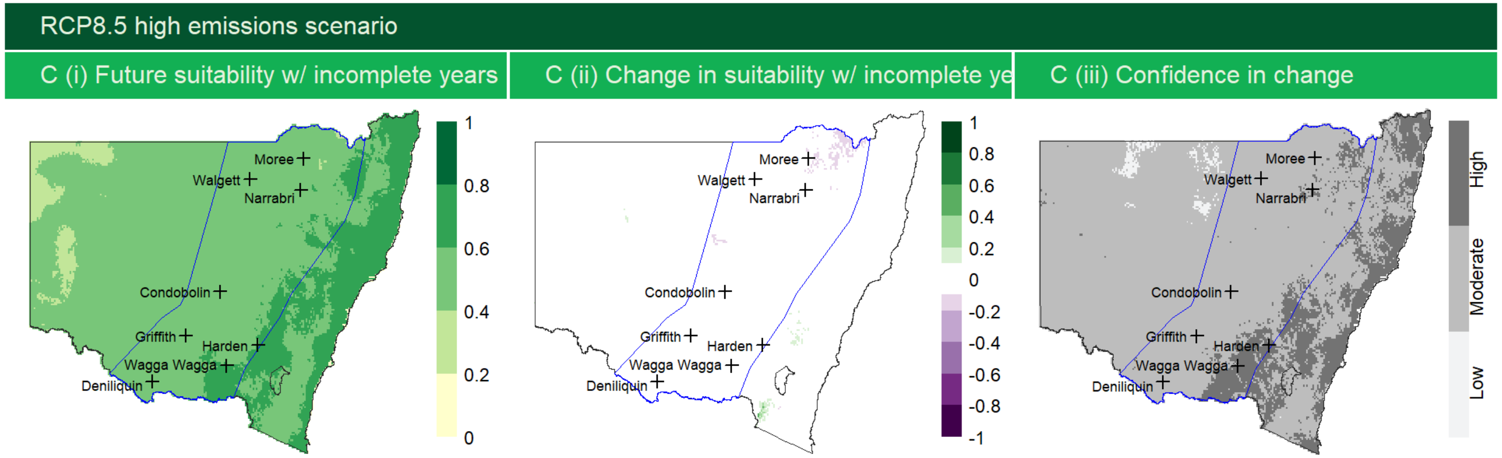
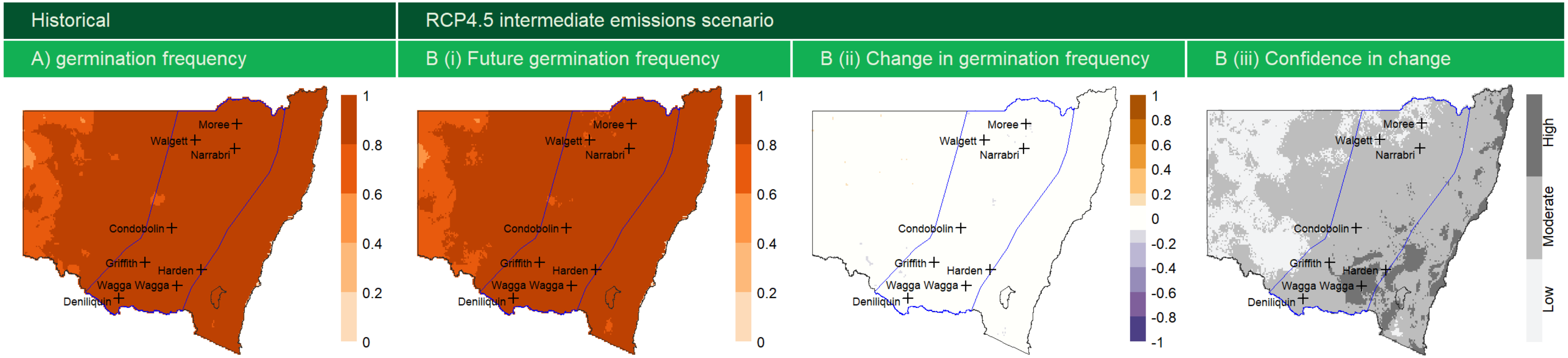



*Figure 14: Overall climate suitability for irrigated wheat production. The figure is comprised of 7 maps: A) shows historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). The NSW wheat belt is shown by the blue polygon, with representative sites shown by black crosses.*

# Irrigated wheat: germination reliability




**Findings:** negligible change is likely to occur for wheat germination reliability across the NSW wheat belt. Germination reliability is likely to remain high to very, but disagreement between the underlying GCMs means that confidence in these changes is moderate across much of the wheat belt.

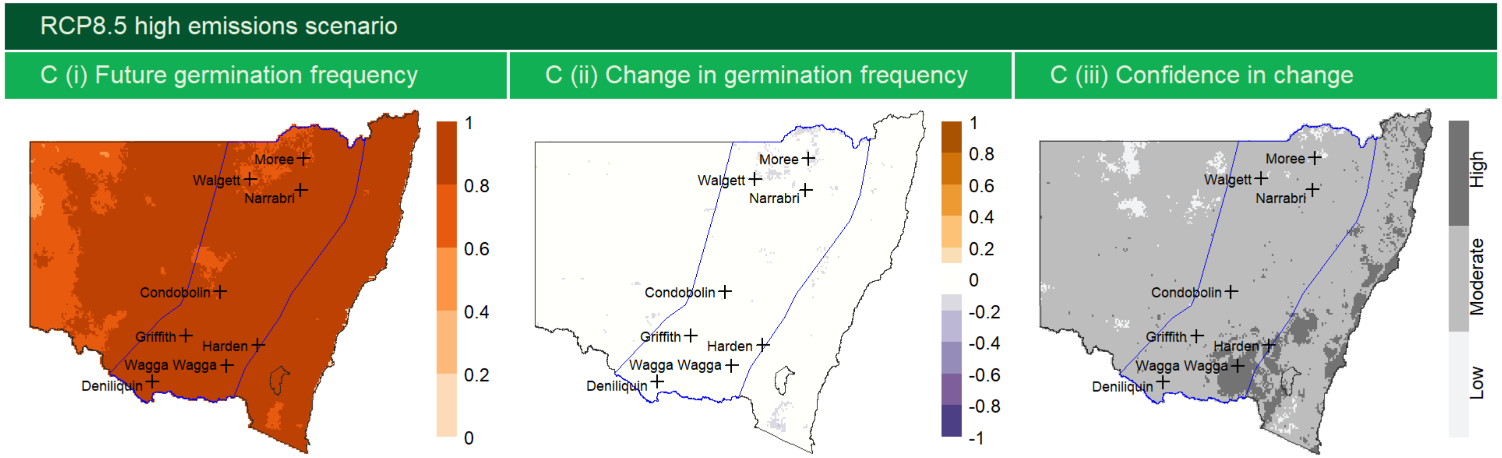
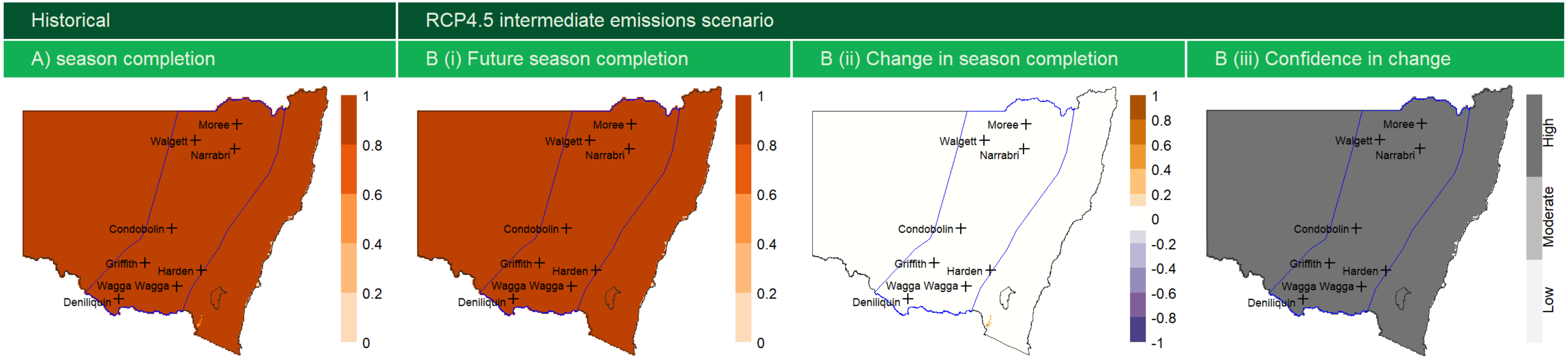



*Figure 15: Frequency of germination reliability for irrigated wheat in NSW. The figure is comprised of 7 maps: A) shows historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). The NSW wheat belt is shown by the blue polygon, with representative sites shown by black crosses.*

# Irrigated wheat: growing season completion (dependent on germination)




**Findings:** negligible change is expected for wheat growing season completion across the entire state, with high confidence, under both emissions scenarios.

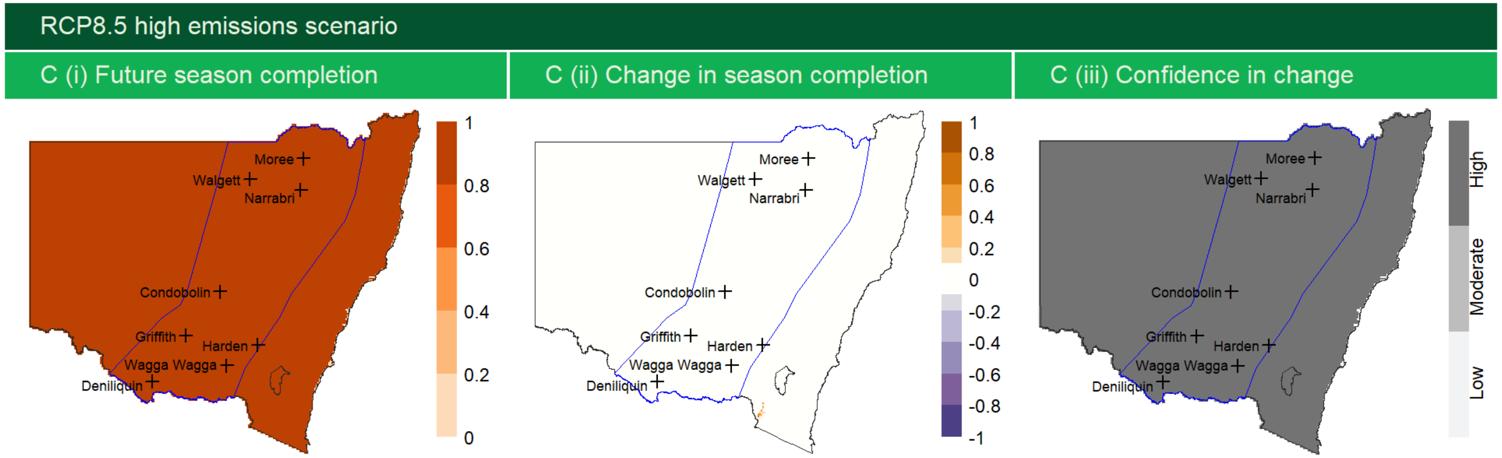
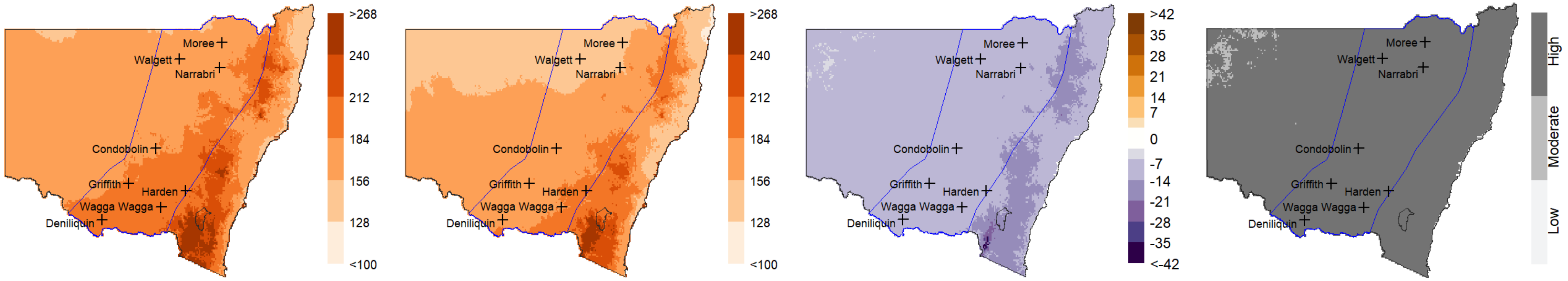



*Figure 16: Frequency of growing season completion for irrigated wheat in NSW. The figure is comprised of 7 maps: A) shows historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). The NSW wheat belt is shown by the blue polygon, with representative sites shown by black crosses.*

# Irrigated wheat: growing season length in days

| Historical | RCP4.5 intermediate emissions scenario | | |
|---|---|---|---|
| A) Season length (days) | B (i) Future season length (days) | B (ii) Change in season length (days) | B (iii) Confidence in change |




**Findings:** Growing season length for wheat crops is likely to decrease across the wheat belt by 1 to 2 weeks across the under the intermediate emissions scenario and by 2 to 3 weeks under the high emissions scenario. Decreases are likely to be greatest in areas which have historically had longer growing seasons.

| RCP8.5 high emissions scenario | | |
|---|---|---|
| C (i) Future season length (days) | C (ii) Change in season length (days) | C (iii) Confidence in change |

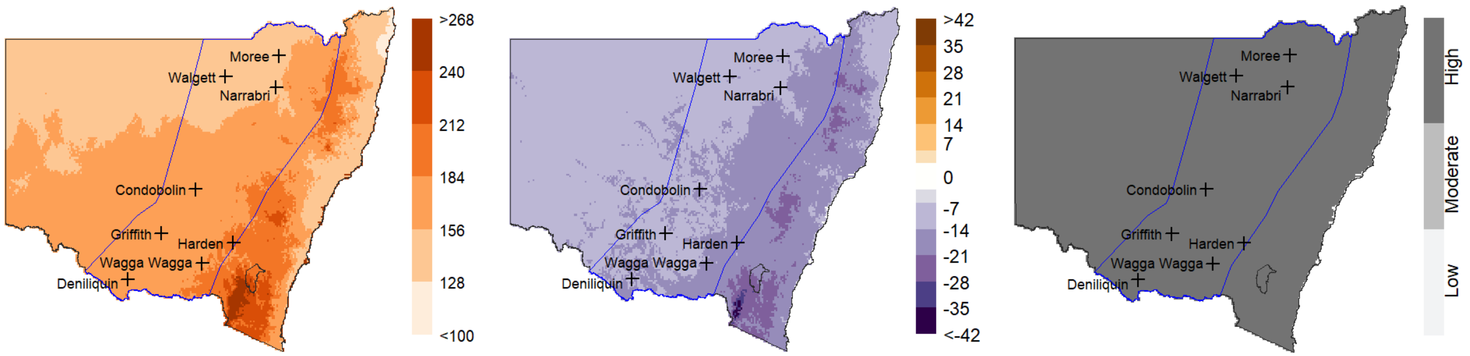



*Figure 17: Season length, in number of days, for irrigated wheat in NSW. The figure is comprised of 7 maps: A) shows historical season length; B) and C) show future season length for the intermediate and high emissions scenarios, respectively; (i) shows future season length, (ii) shows the projected future change in season length as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). The NSW wheat belt is shown by the blue polygon, with representative sites shown by black crosses.*

# Irrigated wheat: climate suitability calendar

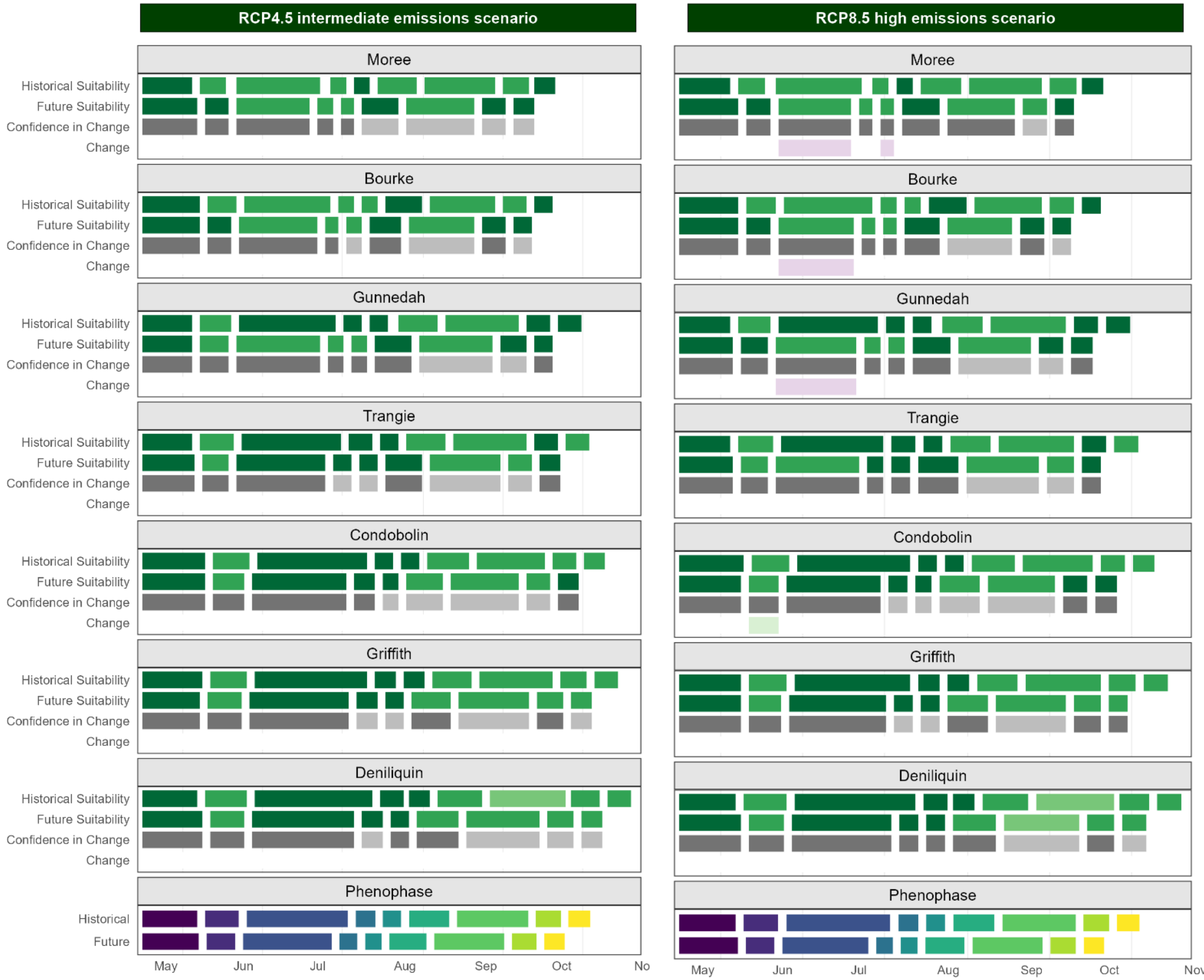
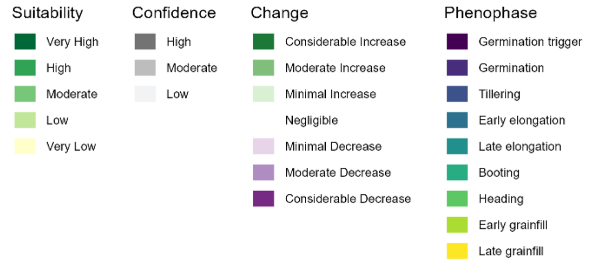
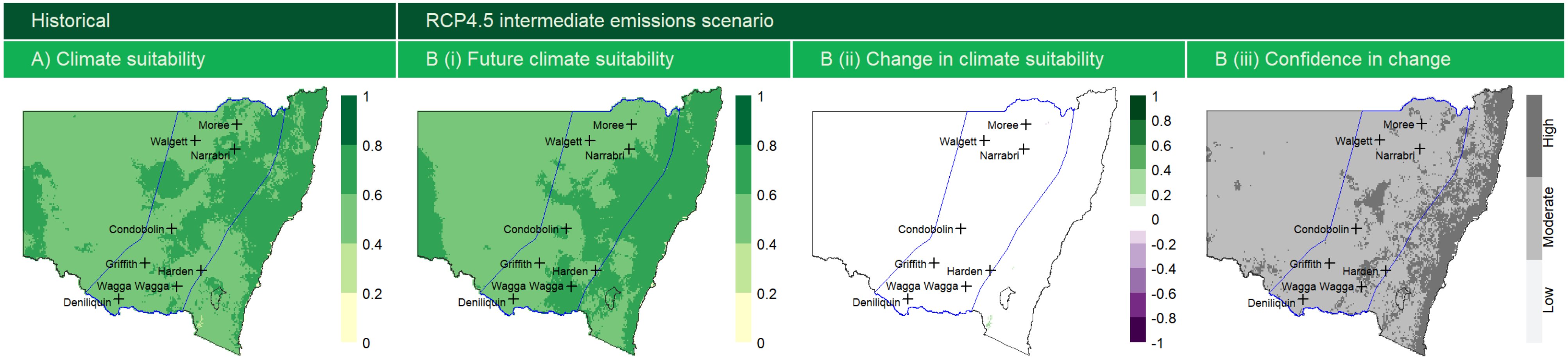



*Figure 18: Season length, in number of days, for irrigated wheat in NSW with the assumed May 1 sowing date. The figure is comprised of 7 maps: A) shows historical season length; B) and C) show future season length for the intermediate and high emissions scenarios, respectively; (i) shows future season length, (ii) shows the projected future change in season length as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). Sites indicating key regions where barley is grown are marked by black crosses.*




**Findings**: This figure supports the previous findings, that the growing season for wheat will be shorter at all sites by 2050 under both emissions scenarios. These sites are likely to maintain high to very high climate suitability across most phenophases.

# Irrigated wheat: overall climate suitability for completed crops




**Findings:** considering only years in which germination and crop completion both occur, negligible change in climate suitability for irrigated wheat is likely under both emissions scenarios. The historical levels of moderate to high climate suitability in the NSW wheat belt (*moderate confidence*).

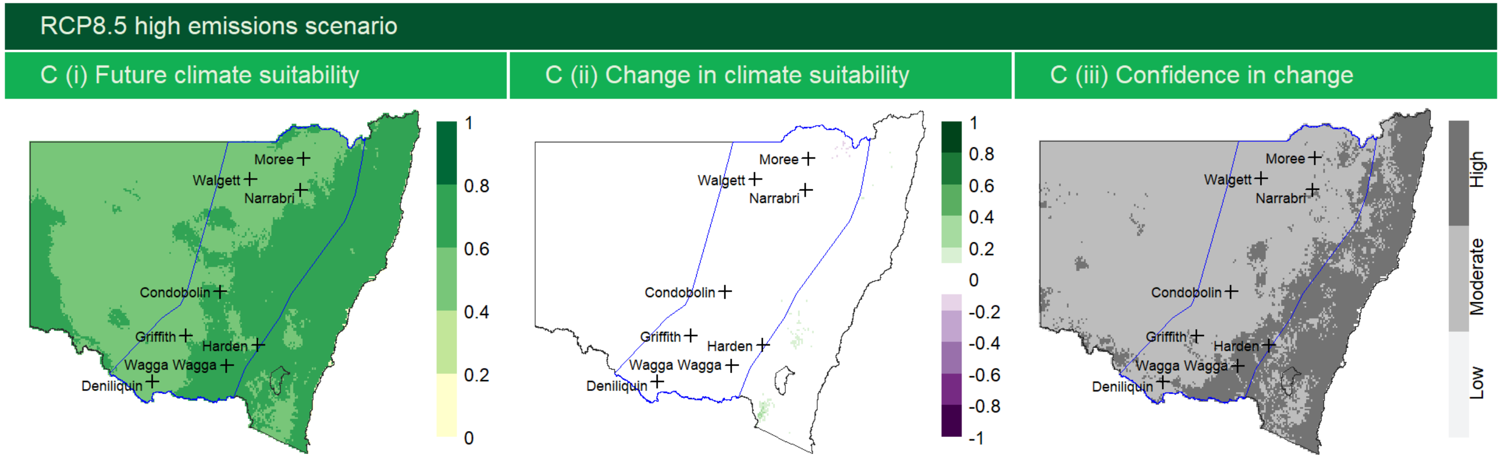



*Figure 19: Overall climate suitability for years when germination and completion are both achieved. The figure is comprised of 7 maps: A) shows historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). The NSW wheat belt is shown by the blue polygon, with representative sites shown by black crosses.*

## Climate impacts on phenophases

Climate change is likely to affect the phenophases of the annual cropping cycle of irrigated wheat in NSW in different ways:

### Temperature-driven phenophases

Overall temperature conditions are of high suitability across the entire NSW wheat belt (Figure 20) under both future emissions scenarios (*moderate to high confidence*).

Vegetative phenophases are likely to maintain high to very high climate suitability across the wheat belt. Shifts in mean temperatures may reduce climate suitability north of Moree during this phase (*high confidence*). Mean temperatures during tillering may reduce climate suitability around Walgett and Narrabri under the high emissions scenario (*high confidence*).

Reproductive phenophases are likely to maintain high climate suitability (*high confidence*). Heat and frost are likely to have a minimal impact on this phase (*moderate to high confidence*).

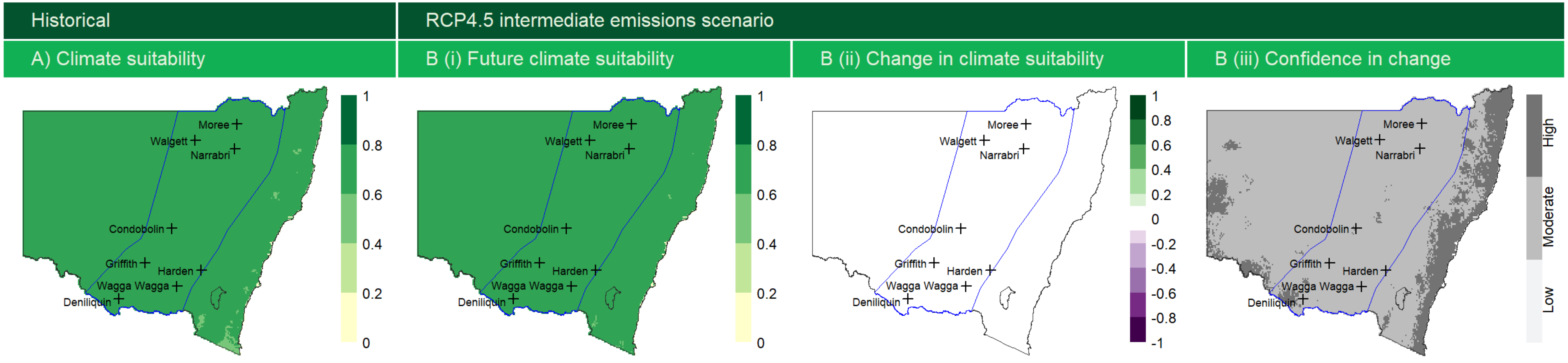
### Frost damage

Frost damage has historically had little impact on wheat and this is likely to remain the same under both emissions scenarios (*moderate to high confidence*).

### Heat damage

Heat damage has not historically impacted wheat and this is likely to remain the same under both emissions scenarios, except for in some areas in the west of the wheat belt and near Walgett (*moderate confidence*).

# Irrigated wheat: climate suitability due to temperature




**Findings:** climate suitability for wheat due to temperature is expected to remain high throughout the NSW wheat belt, with negligible change likely to occur in both emissions scenarios (*moderate to high confidence*).

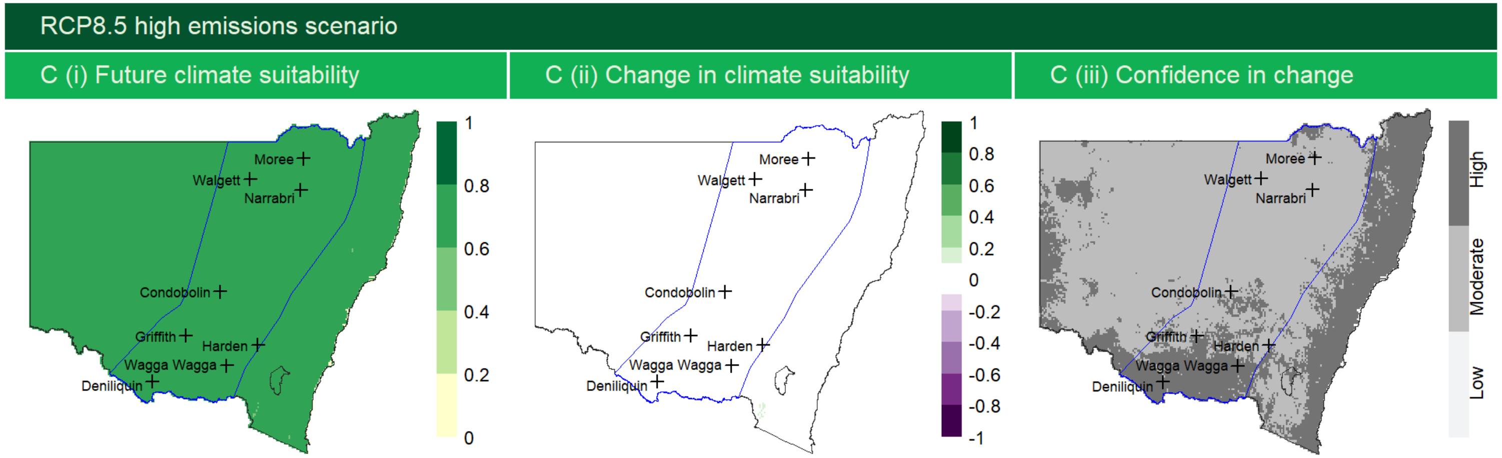
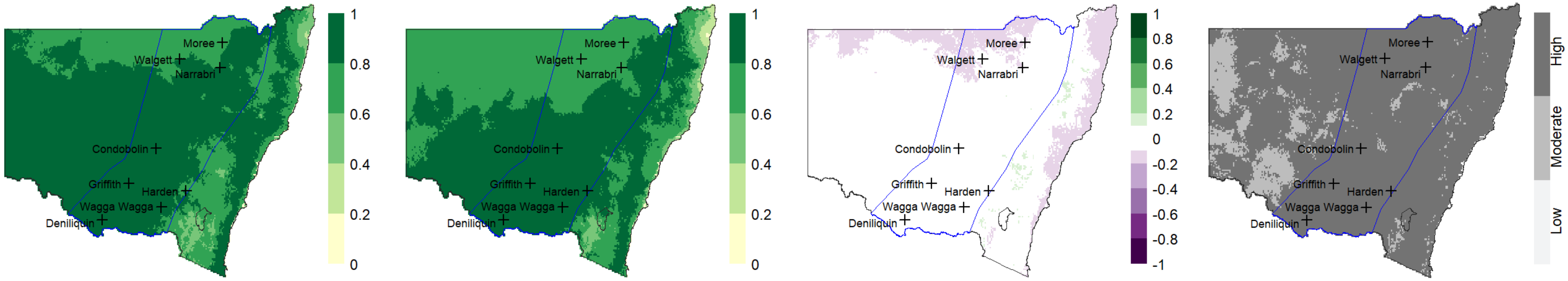



*Figure 20: Climate suitability for the temperature component of the irrigated wheat temperature model. The figure is comprised of 7 maps: A) shows historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). The NSW wheat belt is shown by the blue polygon, with representative sites shown by black crosses.*

# Irrigated wheat: climate suitability due to mean temperatures during tillering

**Historical** — A) Climate suitability

**RCP4.5 intermediate emissions scenario** — B (i) Future climate suitability | B (ii) Change in climate suitability | B (iii) Confidence in change




**Findings:** climate suitability for wheat during the tillering phenophase is likely to remain high to very high across the NSW wheat belt (*high confidence*). An area between Moree, Walgett and Narrabri is likely to experience a minimal decrease in both emissions scenarios *(high confidence)*.

**RCP8.5 high emissions scenario** — C (i) Future climate suitability | C (ii) Change in climate suitability | C (iii) Confidence in change

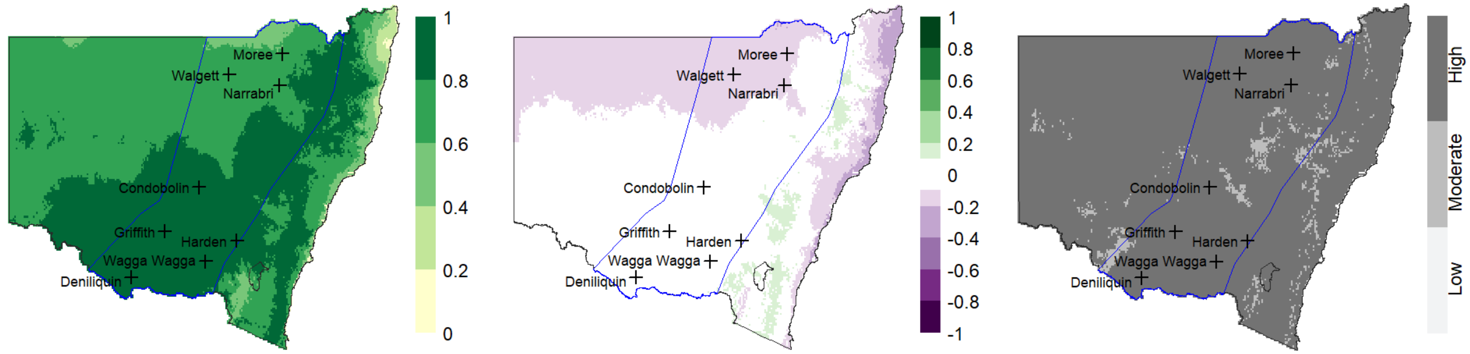



*Figure 21: Climate suitability for the mean temperature component of the irrigated wheat model during the tillering phenophase. The figure is comprised of 7 maps: A) shows historical climate suitability; B) and C) show future climate suitability for the intermediate and high emissions scenarios, respectively; (i) shows future climate suitability, (ii) shows the projected future change in climate suitability as negligible (white), positive (green) or negative (purple) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). The NSW wheat belt is shown by the blue polygon, with representative sites shown by black crosses.*

# Irrigation water requirements of wheat

## Determining irrigation water requirements

The climate suitability model assumes that sufficient irrigation water is available to meet the requirements of plant growth and crop production. However, it is important to understand how future water requirements may change to assess the industry's vulnerability to climate change and explore potential adaptations to reduce water usage. To gain insights into future irrigation water requirements, separate irrigation water requirement maps were produced using the method outlined below.

Assessment of the future availability of irrigation water is outside the scope of this assessment. See the Regional Water Strategies (page 33) which provides more information and links to estimates of future water availability.

## Calculation of irrigation water requirements

The globally accepted FAO56[7] crop coefficient method has been used to assess changes in irrigation water requirements by 2050. The approach uses crop coefficient values (Kc), to calculate crop evapotranspiration (ETc) which represents the amount of water used by a crop at a given growth stage. The Kc value varies across a plant's phenophases (Table 2), reflecting their changing water requirements. Each phenophase is defined by either start and end dates or development stages defined by growing degree days (see page 10).

Irrigation water requirements were calculated as the difference between crop evapotranspiration and total effective rainfall across the growing season. These results can then be used to estimate the change between historical and future irrigation water requirements for an entire growing season (one annual crop cycle).

## Climate variables used to calculate irrigation water requirement

- **Effective rainfall** is the amount of rainfall (mm per day) that enters the soil after considering interception by the crop/plant canopy[8] and the capacity of the soil to hold water.
- **Potential evapotranspiration** (ETo) refers to the transfer of water vapour (mm per day) to the atmosphere from vegetated and unvegetated land surfaces across the planted area (that is, crop transpiration plus soil evaporation). A model which predicts ETo from solar radiation and mean daily temperature has been used[9].
- **Crop evapotranspiration** (ETc) is calculated as ETo * Kc for a phenophase of interest.

For further details, refer to the Climate Vulnerability Assessment Methodology Report.

*Table 2: Crop coefficient (Kc) values for wheat*

| Phenophase | Kc Start Value | Kc End Value |
|---|---|---|
| Germination | 0.3 | 0.3 |
| Tillering | 0.3 | 0.7 |
| Early Elongation | 0.7 | 1.15 |
| Late Elongation | 1.15 | 1.15 |
| Booting | 1.15 | 1.15 |
| Heading | 1.15 | 1.15 |
| Early Grain Fill | 1.15 | 0.6 |
| Late Grain Fill | 0.6 | 0.25 |

[7] Allen, Richard G., Luis S. Pereira, Dirk Raes, and Martin Smith. "FAO Irrigation and drainage paper No. 56." *Rome: Food and Agriculture Organization of the United Nations* 56, no. 97 (1998).
[8] Brutsaert, W. (2010) Hydrology: An Introduction, 5th ed., Cambridge University Press

[9] Hargreaves, G.H. and Samani, Z.A. (1982) Estimating Potential Evapotranspiration, Journal of the Irrigation and Drainage Division, 108(3). https://doi.org/10.1061/JRCEA4.0001390

## Interpreting the irrigation water requirements maps

The results are presented as panels of 7 maps comparing historical irrigation water requirements in megalitres per hectare (ML ha$^{-1}$) with irrigation water requirements under two future emissions scenarios. Maps showing the change and the confidence in that change are also presented. Key wheat-growing regions in NSW are displayed on each map.

The historical climate suitability map shows the mean suitability for 30 years (1981 to 2010). For future projections, the mean suitability for 30 years (2036 to 2065) was calculated for 8 global climate models[10] (GCMs), and the median of these models was used to produce future projection climate suitability maps.

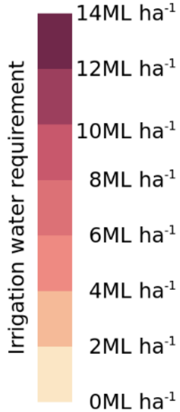



*Figure 22: Colour scheme for the irrigation water requirement maps; the range varies by commodity*

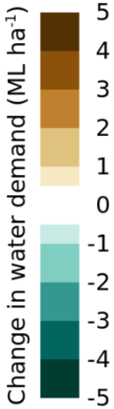



*Figure 23: Colour scheme for the change in irrigation water requirements maps*

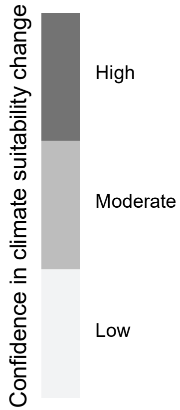



*Figure 24: Colour scheme for the confidence in the change in the irrigation water requirements maps*

### *Irrigation water requirements maps*

The ‘irrigation water requirements' maps show the water requirements for wheat on a scale of 0 to 6 ML h$^{-1}$. Pale yellow corresponds to very low irrigation water requirements, and dark burgundy corresponds to very high irrigation water requirements. The maximum value shown on the map varies for each commodity.

### *Change in irrigation water requirements maps*

The 'change in irrigation water requirements' maps use a turquoise-white-brown colour scheme with 11 categories: positive change, where the future irrigation water requirements become higher, is shown in shades of brown; negative change is shown in shades of turquoise. Negligible change is represented by white and occurs for values between –5 and 5; in these areas, the future irrigation water requirements are expected to be very similar to the historical.

### *Confidence in the change in irrigation water requirements maps*

The 'confidence in change in irrigation water requirements' maps represent the level of agreement on the direction and magnitude of change in irrigation water requirements across the ensemble of 8 GCMs. These maps use a grey colour scheme with three categories: the lightest grey represents low confidence, and the darkest grey represents high confidence.

[10] Data was sourced from Climate Change in Australia: Application Ready Data

## Climate impacts on irrigation water requirements

*Irrigation water requirements across the NSW wheat belt are likely to experience negligible change in the future.*

While plants are likely to use more water due to warmer temperatures, the growing season is also likely to be shorter. However, changes in growing season length also affect total water usage. The irrigation water requirements of wheat (Figure 25) are expected to remain similar to historical levels in 2050 under both emissions scenarios (*moderate to high confidence*).

Modelling confidence varies substantially across the state, as indicated by the range of confidence from low to high (Figure 26). This varying level of confidence indicates disagreement between projections made by the individual GCMs. The confidence maps and resulting uncertainty should be considered along with consultation of individual GCM projections.

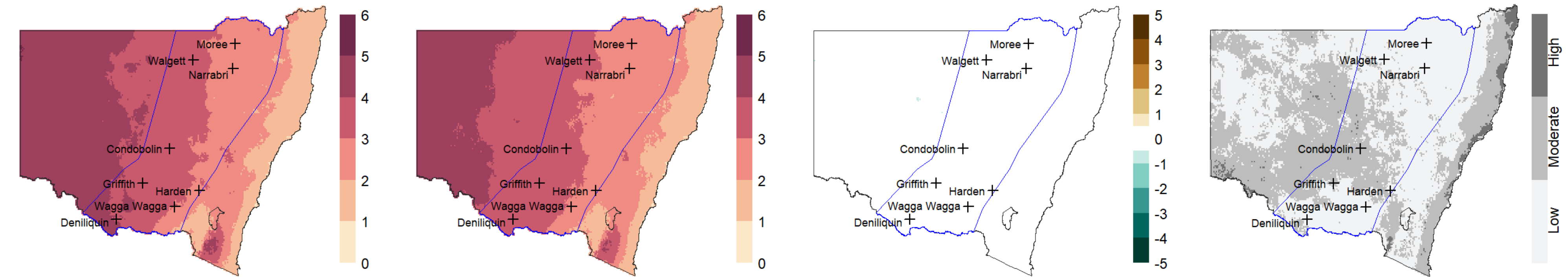
**Note that changes in irrigation water requirements presented here are based on a 30-year average. Year on year climatic variability could mean that even greater amounts of water are required for irrigation during hot and or dry years in the future.**

### Adapting to changing irrigation water requirements

The irrigated wheat producers may need to be more efficient with water storage and water use by changing irrigation practices or adopting new technologies, especially if reduced season lengths under future climate are restored through the development of slower-maturing varieties.

## Irrigated wheat: irrigation water requirements

| Historical | RCP4.5 intermediate emissions scenario | | |
|---|---|---|---|
| A) Irrigation water requirements | B (i) Future irrigation water requirements | B (ii) Change in irrigation water requirements | B (iii) Confidence in change |




**Findings:** negligible change in irrigation water requirements is likely across the NSW wheat belt, in both emissions scenarios, remaining close to their historical range of 2 to 6ML ha$^{-1}$ under both emissions scenarios (*low to moderate confidence*). However, GCM uncertainty about projected rainfall leads to low confidence in these results across much of the state.

| RCP8.5 high emissions scenario | | |
|---|---|---|
| C (i) Future irrigation water requirements | C (ii) Change in irrigation water requirements | C (iii) Confidence in change |

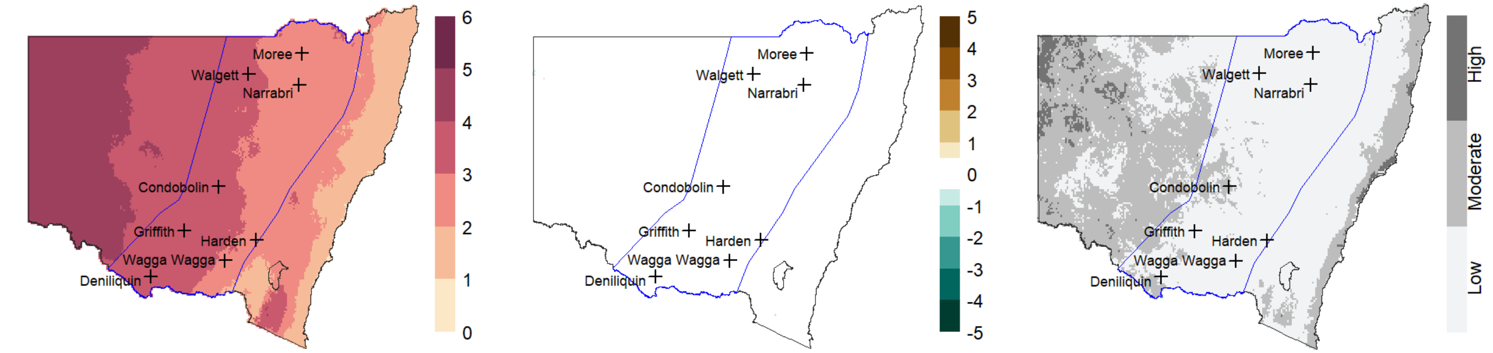
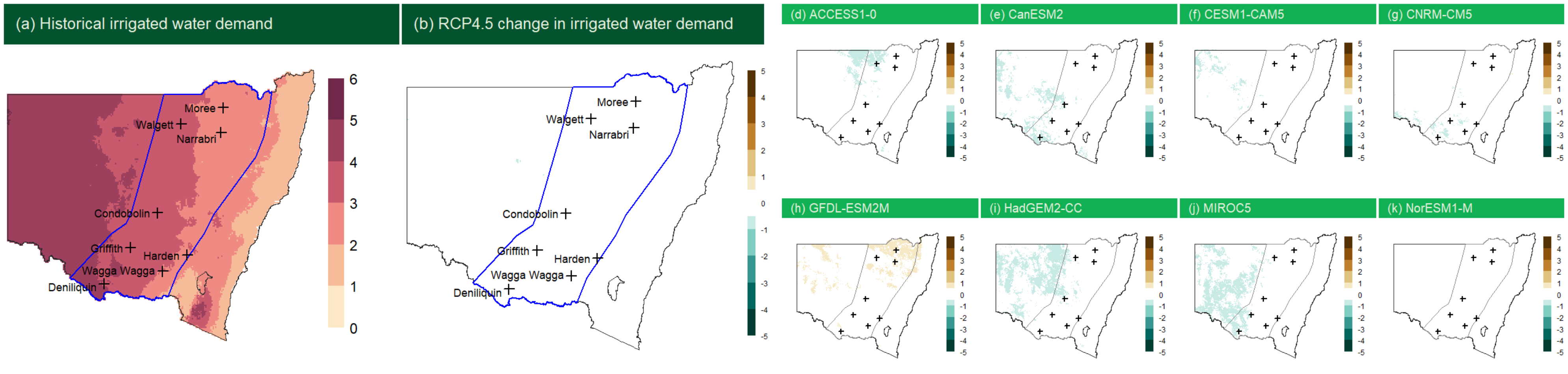



*Figure 25: Overall irrigation water requirements for irrigated wheat. The figure is comprised of 7 maps: A) shows historical irrigation water requirements; B) and C) show future irrigation water requirements for the intermediate and high emissions scenarios, respectively; (i) shows future irrigation water requirements, (ii) shows projected future change in irrigation water requirements as negligible (white), positive (brown) or negative (teal) change, and (iii) shows the level of model confidence associated with this change (low, moderate or high). The NSW wheat belt is shown by the blue polygon, with representative sites shown by black crosses (see Figure 13).*

# Irrigated wheat: change in irrigation water requirements for all GCMs




**Findings:** individual GCMs show a range of projected changes in irrigation water requirements by 2050. While the median change is negligible across the state for both emissions scenarios (b, c), some individual GCMs project areas with increases of to 1-2ML ha$^{-1}$ (h, o, p) while others show decreases of up to 1ML ha$^{-1}$ (d, e, g, i, k) in some areas. This disagreement reduces confidence in the estimates of future change, and it is important to consider the full range of change across all GCMs.

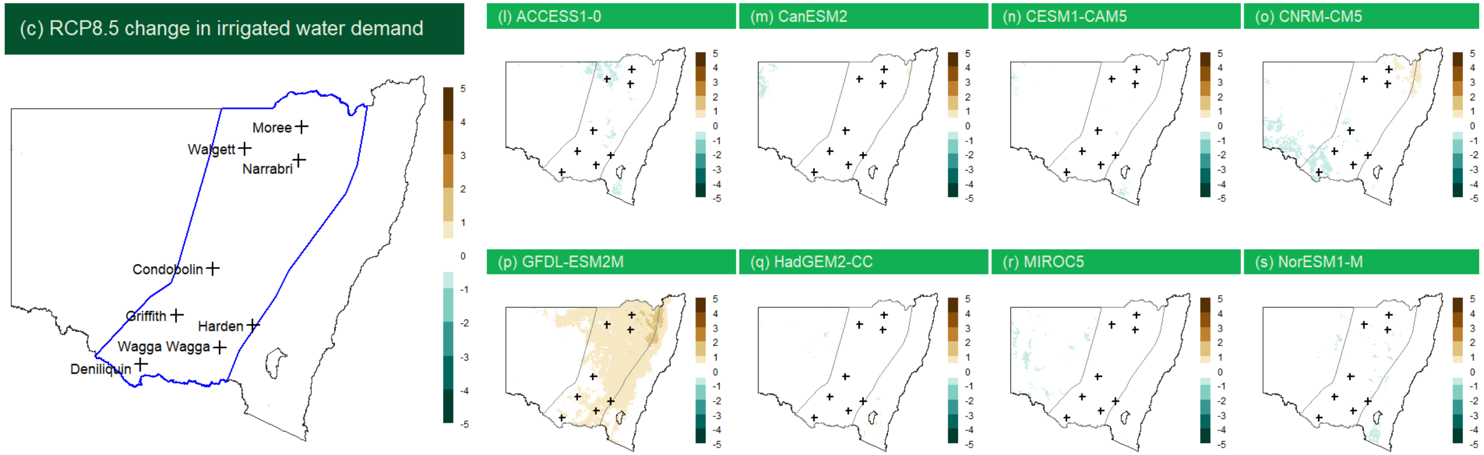



*Figure 26: Irrigation water requirement for irrigated wheat, for all GCMs. (a) historical irrigation water requirements; (b) and (c) median projected future change in irrigation water requirements for the intermediate and high emissions scenario, respectively; (d) to (k) projected future change in irrigation water requirements for each GCM under the intermediate scenario; (l) to (s) projected future change in irrigation water requirements for each GCM under the high emissions scenario. The NSW wheat belt is shown by the blue polygon, with representative sites shown by black crosses (see Figure 13).*

# Regional water strategies

The assessment of future water availability for irrigation is not within the scope of the Climate Vulnerability Assessments. However, insights into changing water availability can be gained from the work of the NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW).

A new approach that aims to improve understanding of past and future climate risk is informing 12 regional water strategies across NSW. Undertaken by the NSW DCCEEW, these strategies form a roadmap for the next 20 years for a more water-secure future.

The regional water strategies look at how much water each region will need to meet future demand, and reflect the challenges and choices involved in meeting those demands. Regional water strategies determine the actions we need to take to manage risks around water availability from our surface water and groundwater systems.

Each strategy is an evidence-based integrated package that balances diverse water objectives. They aim to deliver the right amount of water at the right time to people and businesses across NSW.

### The regional water strategies modelling helps us to understand water security for regional NSW

The regional water strategies are underpinned by new climate data and modelling that improve our understanding of past climate conditions and plausible climate futures.

This improved climate data has informed river system models, enabling a better understanding of the water security and reliability risks faced by water users and the environment in each region. Regional water strategies use the data to investigate the potential benefits and impacts of regional water strategy options. The data will also be used by WaterNSW and other agencies to assess the merits of new projects, plans and programs.

If you are interested in learning more about the regional water strategies modelling approach, please refer to the Regional Water Strategies Guide.

### NSW's water supply is likely to be less secure in the future

Modelling undertaken for Regional Water Strategies[11] found that winter and spring rains are likely to decrease for southern inland NSW. Along the south coast, changes in the patterns of east coast lows are likely, with a potential increase in the intensity of rainfall but with rain falling in fewer events. There is a lower possibility of significant changes in the average annual rainfall in the northern part of the state. All models in the ensemble predict increases in evaporation rates across the state, leading to drier conditions, and the modelling has shown us that NSW's surface water supplies are likely to be less secure in the future. More work is required to apply this new climate data to our understanding of groundwater systems and the security of groundwater supplies in the future.

Find out more about projected changes for your region on DCCEEW's Regional Water Strategies Website:

- Border Rivers
- Far North Coast
- Greater Hunter
- Gwydir
- Macquarie-Castlereagh
- Namoi
- North Coast
- South Coast
- Western
- Lachlan
- Murrumbidgee*
- NSW Murray*
- Fish River–Wywandy*

*under development at the time of writing (June 2025)

[11]Regional Water Strategies, 2020. Fact Sheet - New climate analysis informs New South Wales regional water strategies. Department of Planning, Industry and Environment.

# Wheat stripe rust snapshot: projected changes for NSW?

Wheat stripe rust is a fungal crop disease caused by the pathogen *Puccinia striiformis* f.sp. *tritici*. The wheat stripe rust pathogen requires cool and wet conditions to infect crops. Once infected, the fungus grows in the leaf tissue, then erupts onto the surface producing the rust-like orange-yellow pustules. When these pustules rupture, they release spores that become wind-borne and can then attack healthy plants.

The life stages of wheat stripe rust are impacted by climate in different ways, and this model is designed to be considered alongside the irrigated wheat model.

## Wheat stripe rust | *Puccinia striiformis f. sp. tritici*

Changes in climate suitability for wheat stripe rust are likely to create challenges for wheat production. Increases in climate suitability are likely for all life stages in the wheat belt of NSW by 2050 under both emissions scenarios.

## Impact on broadacre cropping

The historical climate suitability for wheat stripe rust in NSW has been high, and this will likely continue through to 2050. The increased climate suitability for the pathogen will likely be counteracted by planting rust-resistant wheat varieties.

Current strategies to manage the disease are likely to remain effective, but grain growing industries may need to adapt by adopting earlier-maturing varieties to minimise or avoid the wheat stripe rust window. Another strategy may be to increase late-season fungicide applications, which carries an enhanced risk of exceeding maximum residue limits in grains prior to harvest.

## For more information

The full reports for wheat stripe rust and other biosecurity risks are available on the Climate Vulnerability Assessment Summary Report or on the website.

# Key findings and insights from a changing climate

The results of this study provide valuable insights into the historical and potential future climate suitability of irrigated wheat, with implications for broadacre growers.

## Historical and future trends

The NSW wheat belt (Figure 14) is expected to maintain moderate climate suitability for growing wheat by 2050 under both emissions scenarios (*moderate to high confidence*).

## Future climate vulnerabilities

Germination reliability could also be impacted due to reduced cool season rainfall in the north of the NSW wheat belt (*moderate confidence*).

The length of the growing season is likely to become shorter across the state due to higher temperatures (*high confidence*).

## Future climate opportunities

No clear new opportunities for growing irrigated wheat in NSW under future climate scenarios have been identified.

# Adapting to the changing climate

Assessing future climate suitability is a prerequisite to making effective decisions around planning for primary industries and developing effective adaptation strategies for addressing future climate change.

The next stage of work is to conduct a detailed assessment of adaptation strategies for broadacre cropping to provide industries with insights into the value of adaptation for reducing the impacts of climate change in NSW.

## Adapting to a shorter growing season

Increasing temperatures across the state may reduce the length of the growing season. Selecting or breeding ‘shorter season’ varieties could represent an adaptation action for the projected shorter seasons.

The shorter growing season is also expected to negate the higher plant water use associated with warmer mean temperatures.

# Irrigated Wheat: where to from here?

## Future priorities

We have assessed the future climate suitability for wheat as a prerequisite for effective planning decisions and for developing adaptation strategies to address future climate change impacts.

The results presented in this report have identified changes in climate suitability for wheat and considered how these changes are likely to impact the industry in NSW. More research and development is needed to best advise the industry on managing these changes to support the industry's productivity going in the future under climate change.

The next stage of work is to conduct a detailed assessment of adaptation strategies to provide industries with insights into the value of adaptation for reducing the impacts of climate change. Work on these issues is underway within the wheat industry: see the GRDC's 'Research, Development & Extension Plan 2023-28'[12] for further information.

Effective management approaches must be carefully planned, evaluated, and deployed to minimise disruptions and costs. The following options merit consideration:

- Consider using shorter-season varieties.
- Monitor soil moisture.
- Partial irrigation or full irrigation depending on water availability, cost and return on investment.

## Addressing the gaps, barriers and challenges

The information generated by this project has helped to identify future climate vulnerabilities of wheat. However, knowledge gaps were identified during the development of the MCA model.

A lack of knowledge about a particular organism and its optimal climate conditions leads to a risk of important climate factors being left out of the model. Additional research may lead to results which improve the irrigated wheat model used here. The following area is deemed a key knowledge gap in need of further research:

- Rainfall remains a critical variable for the irrigated wheat model as it is used to determine germination. Given the differences in rainfall projections between GCMs used in this project, we could not provide clear insights with high confidence into the impacts that changes in future rainfall might have on germination reliability or on irrigation water requirements for irrigated production.

This report aims to highlight these gaps to assist in directing future research and project development. It was not possible to cover all varieties or broadacre crops important to NSW. Consideration should be given to modelling other significant or emerging broadacre crops such as hemp, sorghum, sugar cane, and cover cropping varieties. Expanding the range of the current modelling extent to Australia-wide to inform future industry planning nationally.

[12] https://rdeplan.grdc.com.au/

# Conclusion

The Climate Vulnerability Assessment provides important baseline information to support state, regional and strategic industry-level planning for future climate change, highlighting where adaptation and investment should be prioritised to sustain and enhance broadacre cropping and limit the impacts of climate change on wheat.

The results presented in this report provide a comprehensive assessment of how climate suitability is likely to shift under climate change for this key commodity in NSW. This research also sets out the challenges ahead, which will require investment in adaptation strategies and education to underpin the broadacre cropping industry's future growth and sustainability.

NSW DPIRD will use these findings in partnership with industry to prioritise future efforts, strategic partnerships, and networks across the state to support effective policies and programs that keep primary industries resilient and productive in a changing climate.

## For more information

For detailed information on the methodology and data used in this project please see the Climate Vulnerability Assessment Methodology Report.

Results from other commodities and biosecurity risk assessments can be found in the Climate Vulnerability Assessment Summary Report or on the website.

An accompanying report on NSW Drought in a Changing Climate provides a comprehensive understanding of how drought frequency and duration will change as a result of climate change and it is recommended to read this report alongside the results presented for wheat.

## Contact us

For further information, please get in touch with vulnerability.assessment@dpird.nsw.gov.au

# Acknowledgements

We thank the experts who participated in the focus groups. These experts ensured that the model contents reflected published knowledge and lived experiences and determined the relative influence or importance of different climate variables in the model.

Thanks to all the NSW Department of Primary Industries staff who participated in the NSW DPI Broadacre Cropping Team: Danny Norris, Daowei Sun, David Burch, Iain Hume, Jasim Uddin, Malem McLeod, Michelle Miller, Peter Regan and Sarah Sullivan.

We thank the Climate Vulnerability Assessment team for driving this project from inception to completion over the last five years, individually acknowledging each team member: Bethany Ellis, Jane Kelley, David Allingham, James Lawson, Rachael Young, Chris Nunn, Joanna Pardoe, Rebecca Darbyshire, Gary Allan, Mary Timms, Lachlan Philips, Samantha Currie and Paris Capell.

Image credits: cover, p. 6, 15 NSW DPI © State of New South Wales; p. 7, 38 photographs by G. Johnson, NSW DPI © State of New South Wales.

NSW
GOVERNMENT

# Appendix

The complete MCA model structure for wheat. Due to the size of the model, each phenophase is shown on a separate page.

*Figure A1: MCA model structure for irrigated wheat vegetative growth phenophases, all temperatures are mean temperatures.*

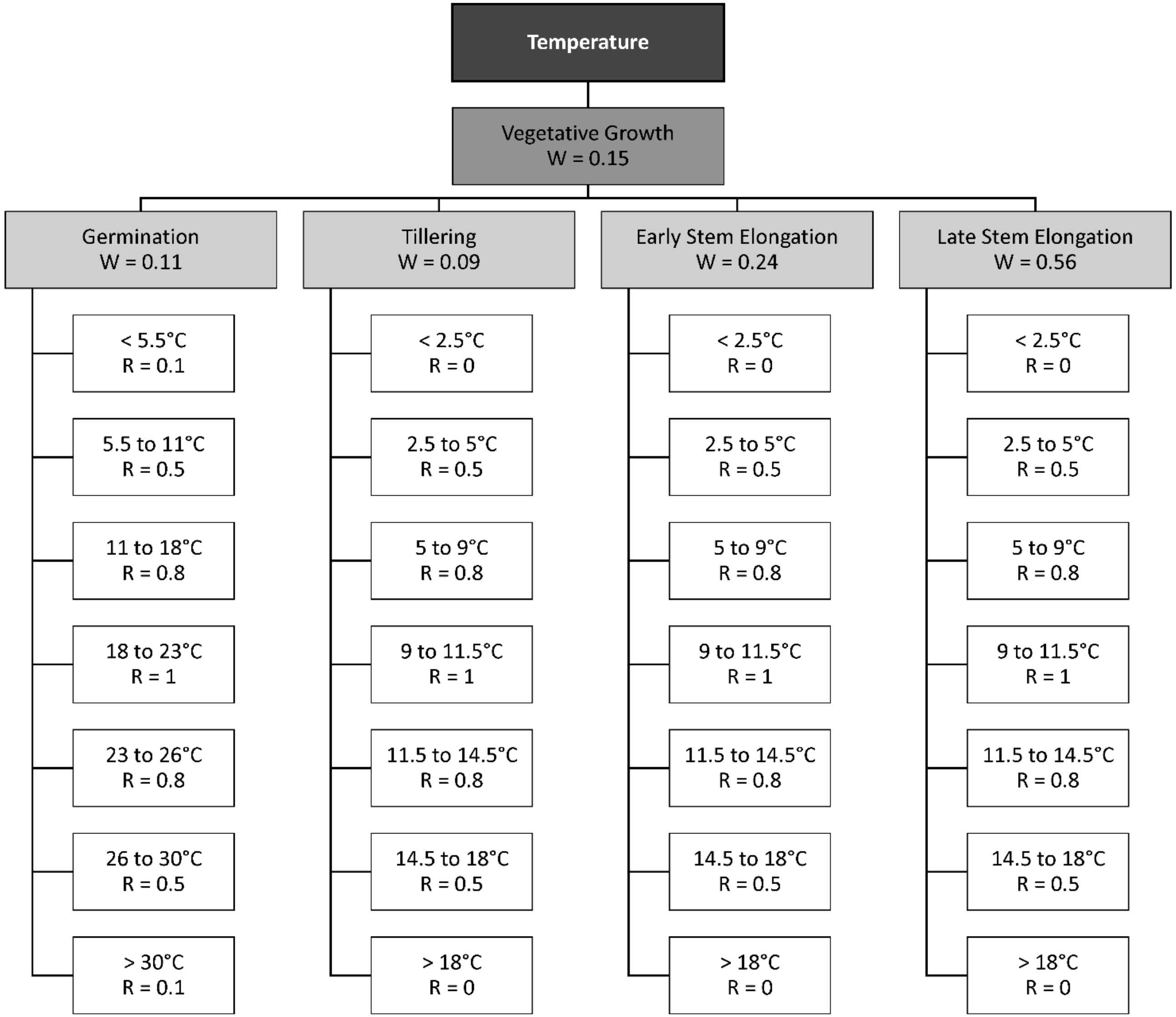
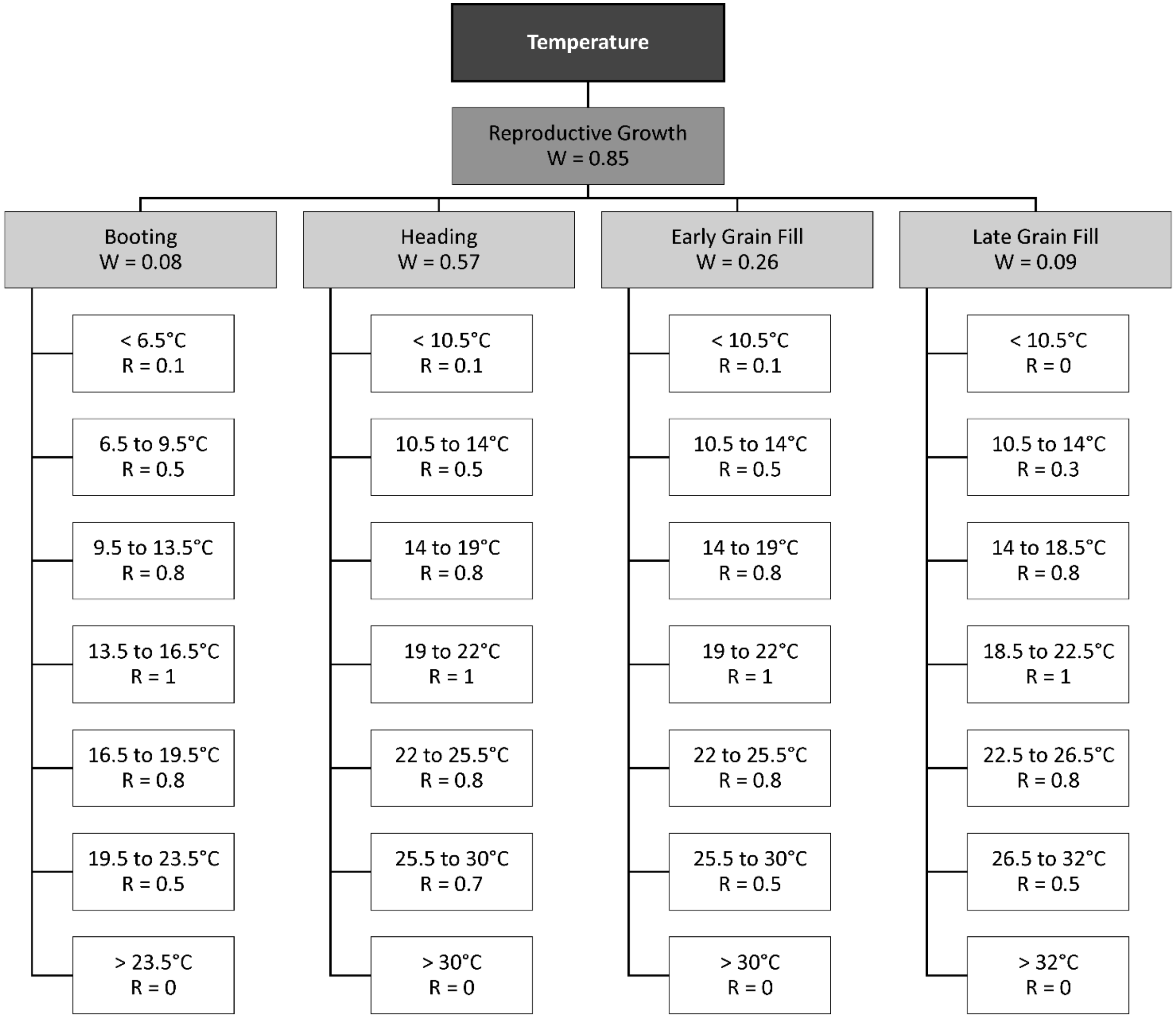


***Figure A2: MCA model structure for irrigated wheat reproductive growth phenophases, all temperatures are mean temperatures.***



Primary Industries Climate Change Research Strategy

# Climate Vulnerability Assessment

Irrigated Wheat Results Report

NSW GOVERNMENT