

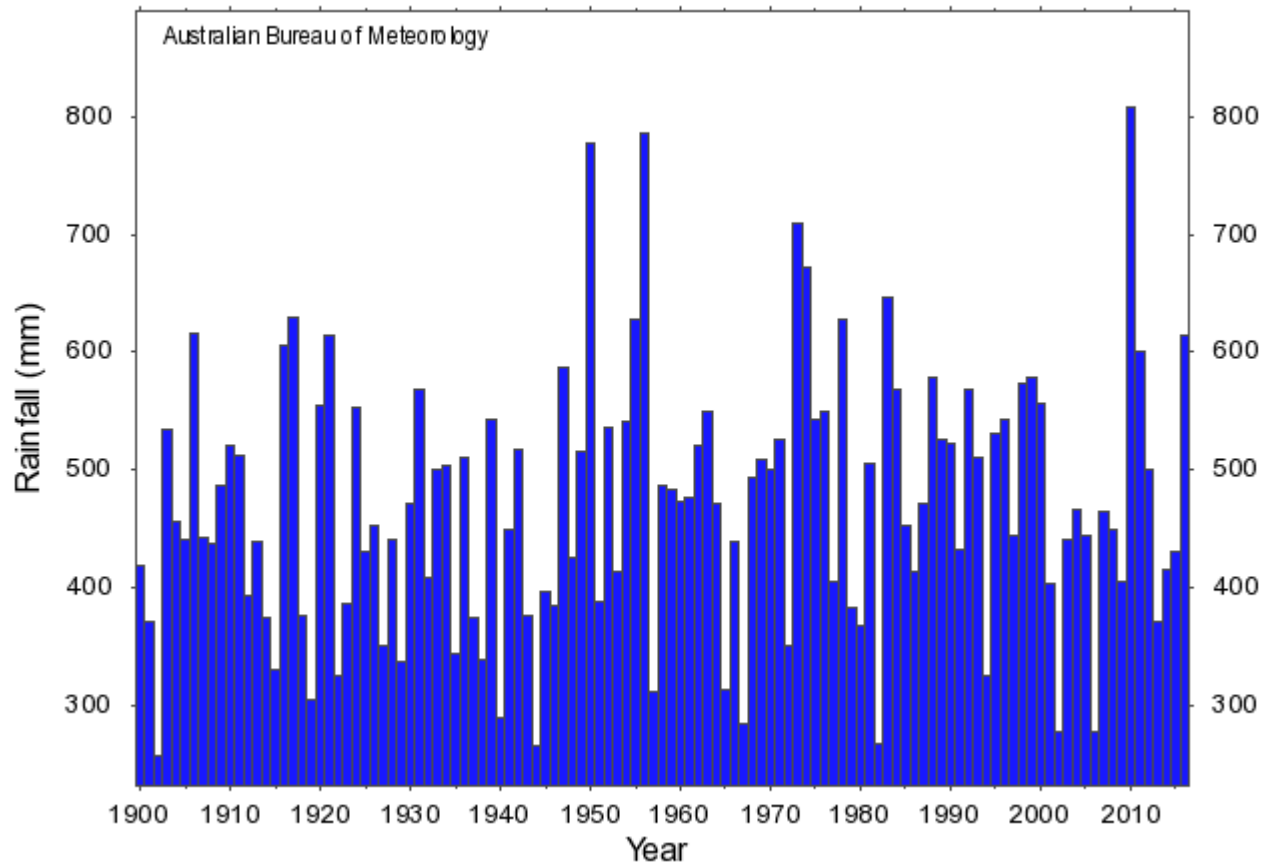
Drought

Michael L. Roderick

Australian National University, Canberra, Australia

CLeX Winter School, ANU, 26 June 2018

Annual rainfall - Murray Darling Basin (1900-2016)



**Federation
Drought**



**WW2
Drought**



**Millenium
Drought**

Australia even has a drought page on WIKI

Contents [\[hide\]](#)

- 1 [Droughts in the 19th century](#)
- 2 [Drought in the 20th century](#)
 - 2.1 [Federation drought](#)
 - 2.2 [Other 20th century droughts](#)
 - 2.2.1 [1937-1947 drought](#)
 - 2.2.2 [1960s](#)
 - 2.2.3 [1980s](#)
 - 2.2.4 [1990s Queensland drought](#)
- 3 [Drought in the 21st century](#)
 - 3.1 [2000s or 'Millennium' drought in south-eastern Australia](#)
 - 3.1.1 [1996 to 2000: patchy rainfall in the south-east](#)
 - 3.1.2 [2001 to 2009: the peak of the drought](#)
 - 3.1.3 [2010 and 2011: La Niña finally breaks the drought](#)
 - 3.1.4 [Effects on agricultural production](#)
 - 3.2 [2013–2015](#)
- 4 [See also](#)
- 5 [References](#)
- 6 [External links](#)

Drought is a way of life in Australia
So much that we even get a WIKI page

Defining Drought can we ?

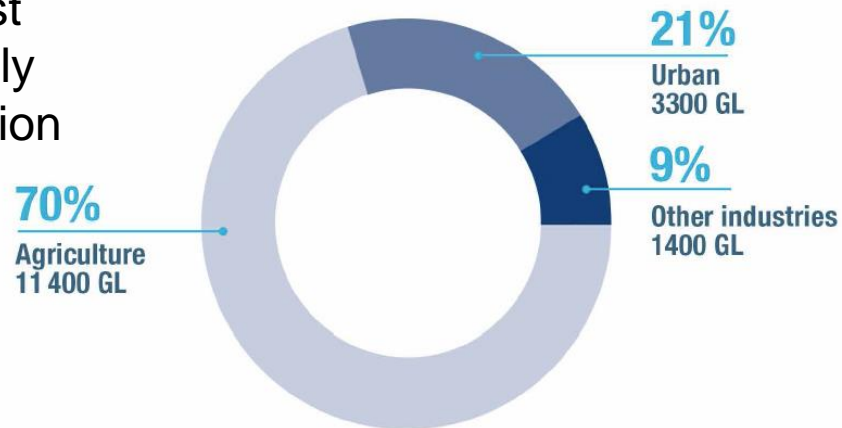
Seems simple

Everyone knows drought when
they see it



Water Use in Australia

Almost
Entirely
Irrigation



Defining Drought can we ?

Seems simple

Everyone knows drought when they see it



Some things that matter:

Dryland & Irrigation Farmers

Futures Trader

Manufacturing

City Residents

Rural Residents

Profit in a market economy

Production [= yield * area] in a non-market economy

National/Global Production (supply vs demand)

Water for industrial use

Clean drinking water, water for gardens, recreation

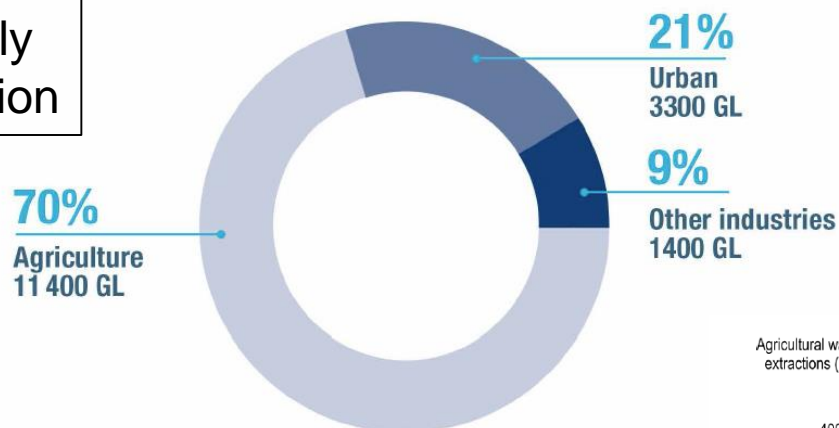
Clean drinking water, water for gardens, recreation

} Money
Drought

} Water
Drought

Water Use in Australia

Almost
Entirely
Irrigation



More than
90% of
Agricultural
Water Use
is irrigation
in MDB

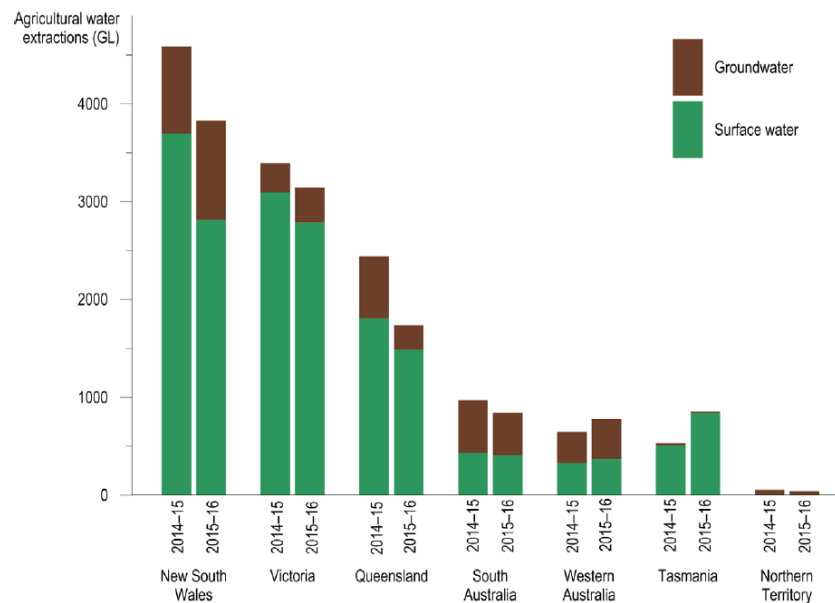


Figure 21. Volume of agricultural water extractions from surface water and groundwater in each State and Territory, 2014–15 and 2015–16

Getting a feel for the MDB

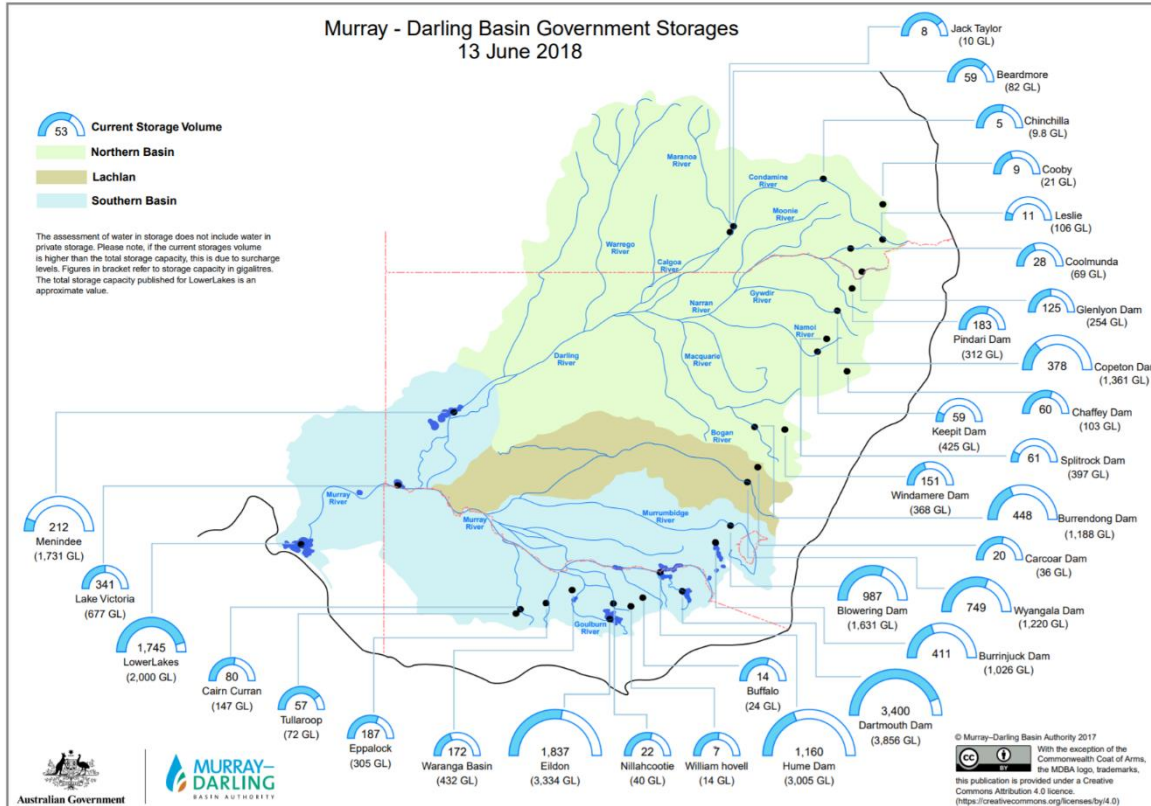
Water in storages

As at 13 Jun 2018

The information on water in storage in the Murray-Darling Basin is updated fortnightly.

Whole of Basin total

51%
(11,242 of 22,256 GL)



Dominance of Agricultural Water Use:

When Dartmouth Dam is full (~3856 GL) it has the same capacity as the Australian annual urban water use

JUST 1 DAM !

Defining Drought can we ?

Seems simple

Everyone knows drought when
they see it



BUT

DROUGHT turns out to be incredibly difficult to define

There is NO UNIVERSALLY ACCEPTED DEFINITION

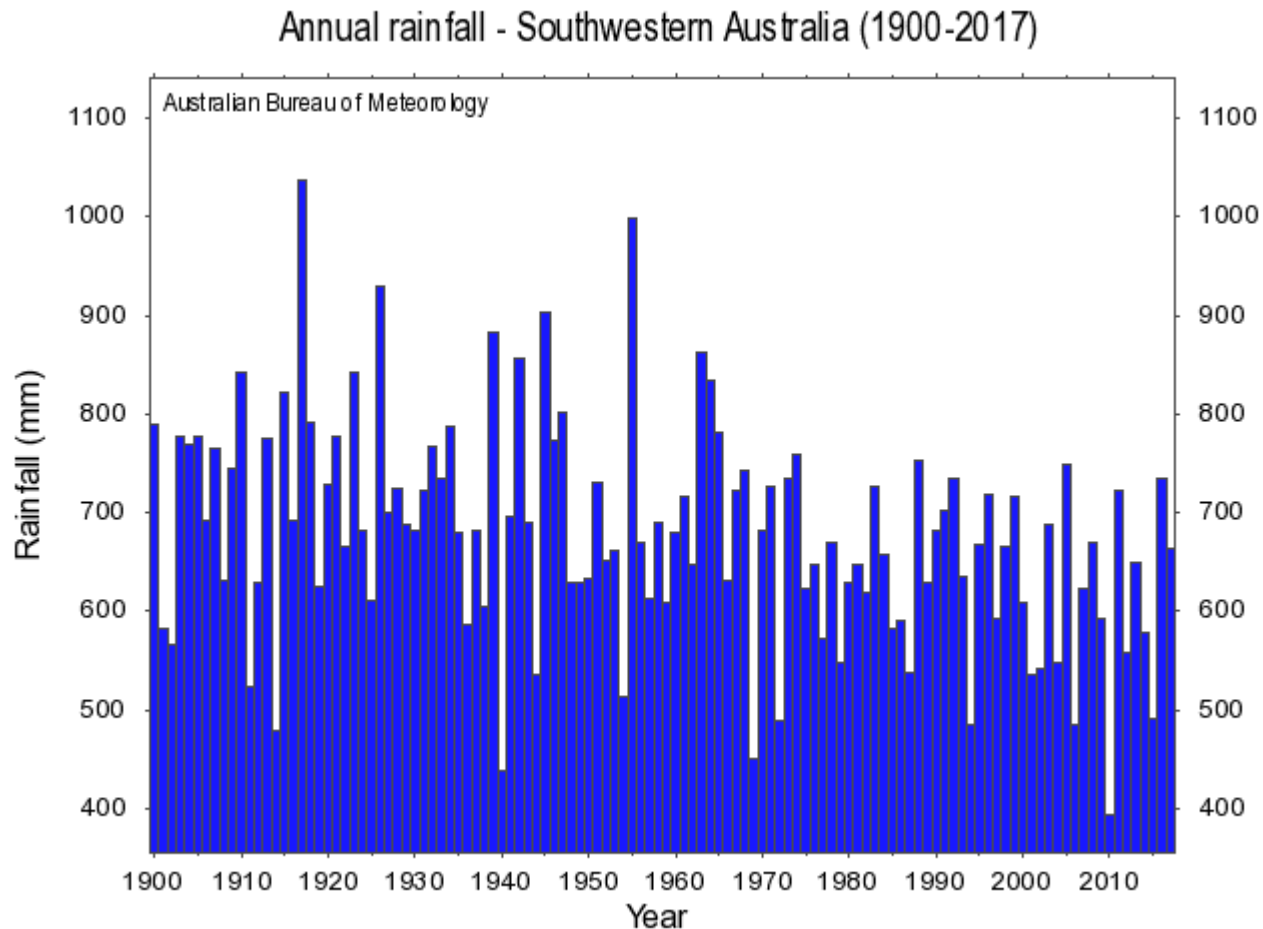
probably because

IMPACTS ARE MOSTLY **CONTEXT DEPENDENT**

Lesson/s

1. Drought is complex and context dependent

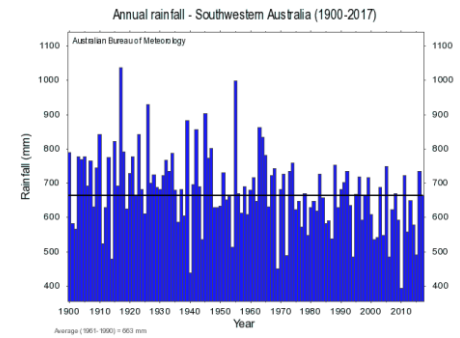
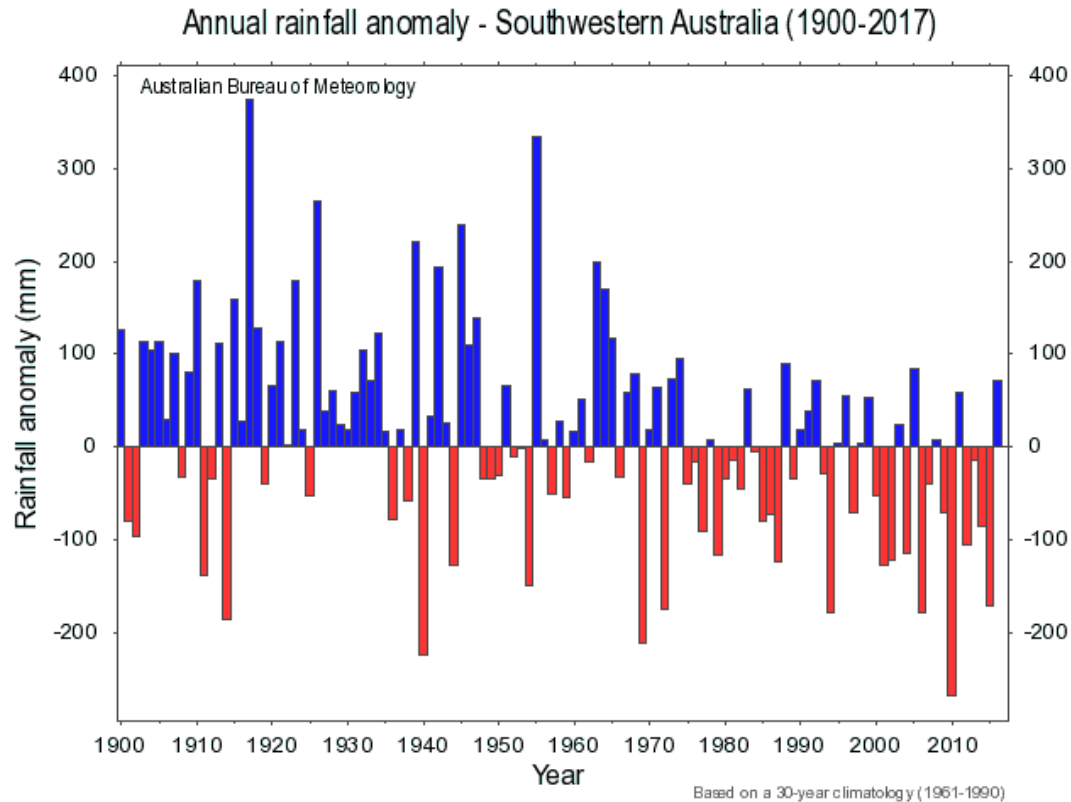
Case Study: SW of WA



Dry Years about the same.

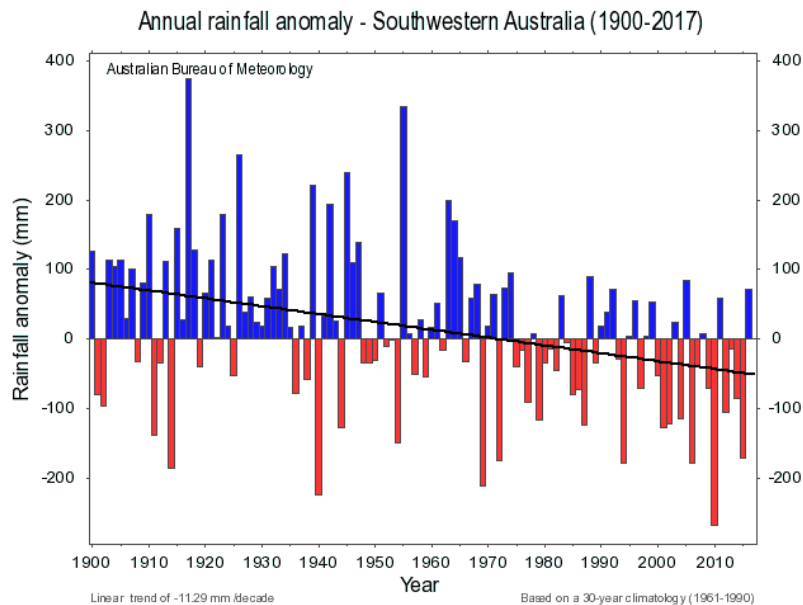
Recent drop in rainfall caused by: lack of wet years since mid-1960s

Case Study: SW of WA

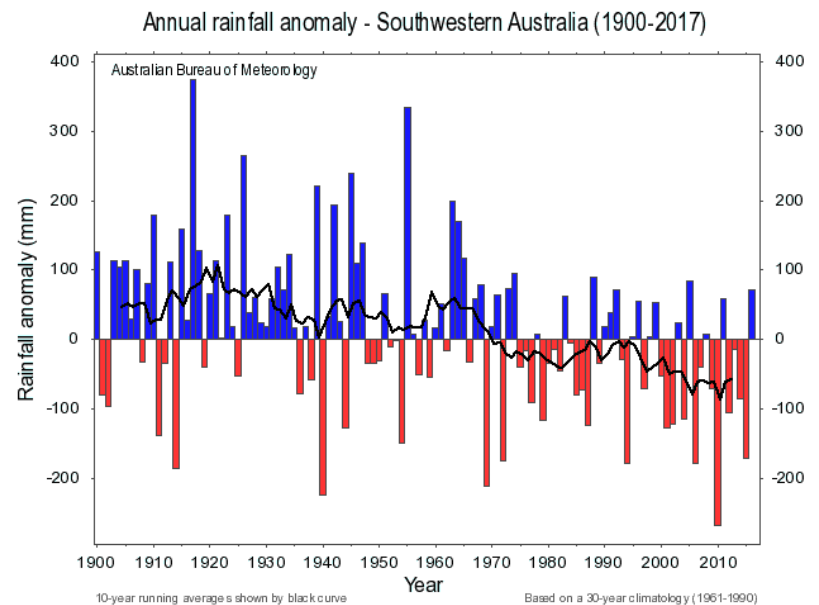


If we calculate anomaly from long term mean then it will show increasing drought with time

Case Study: SW of WA



Anomaly relative to long term (linear) trend



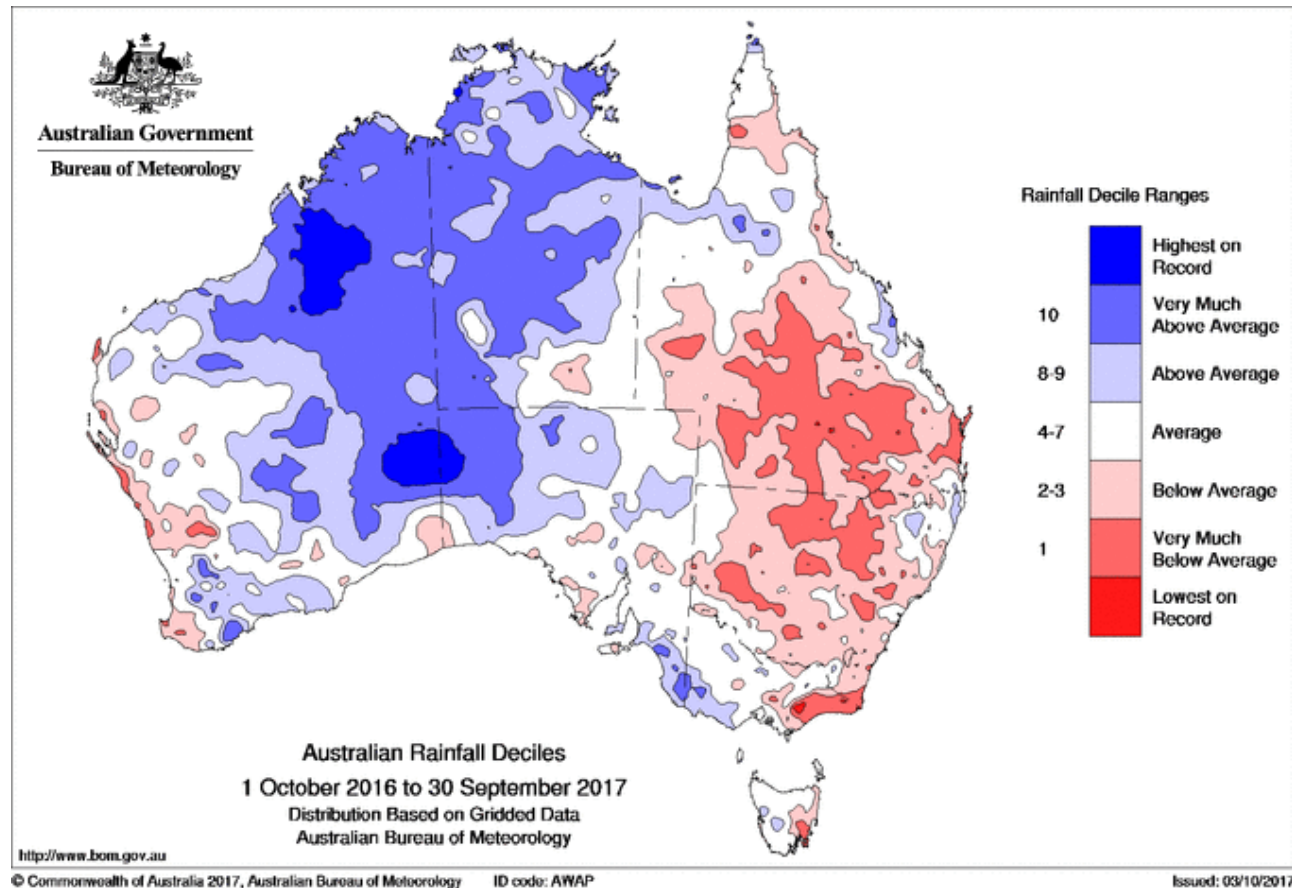
Anomaly relative to 10 year moving average

Lesson/s

1. Drought is complex and context dependent
2. Extremes always relative to some (local) baseline

Meteorological Drought

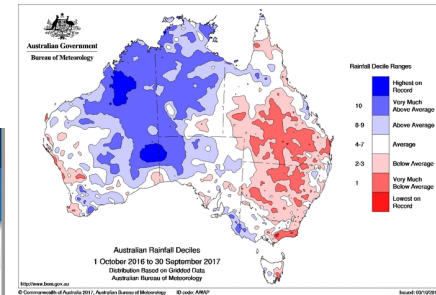
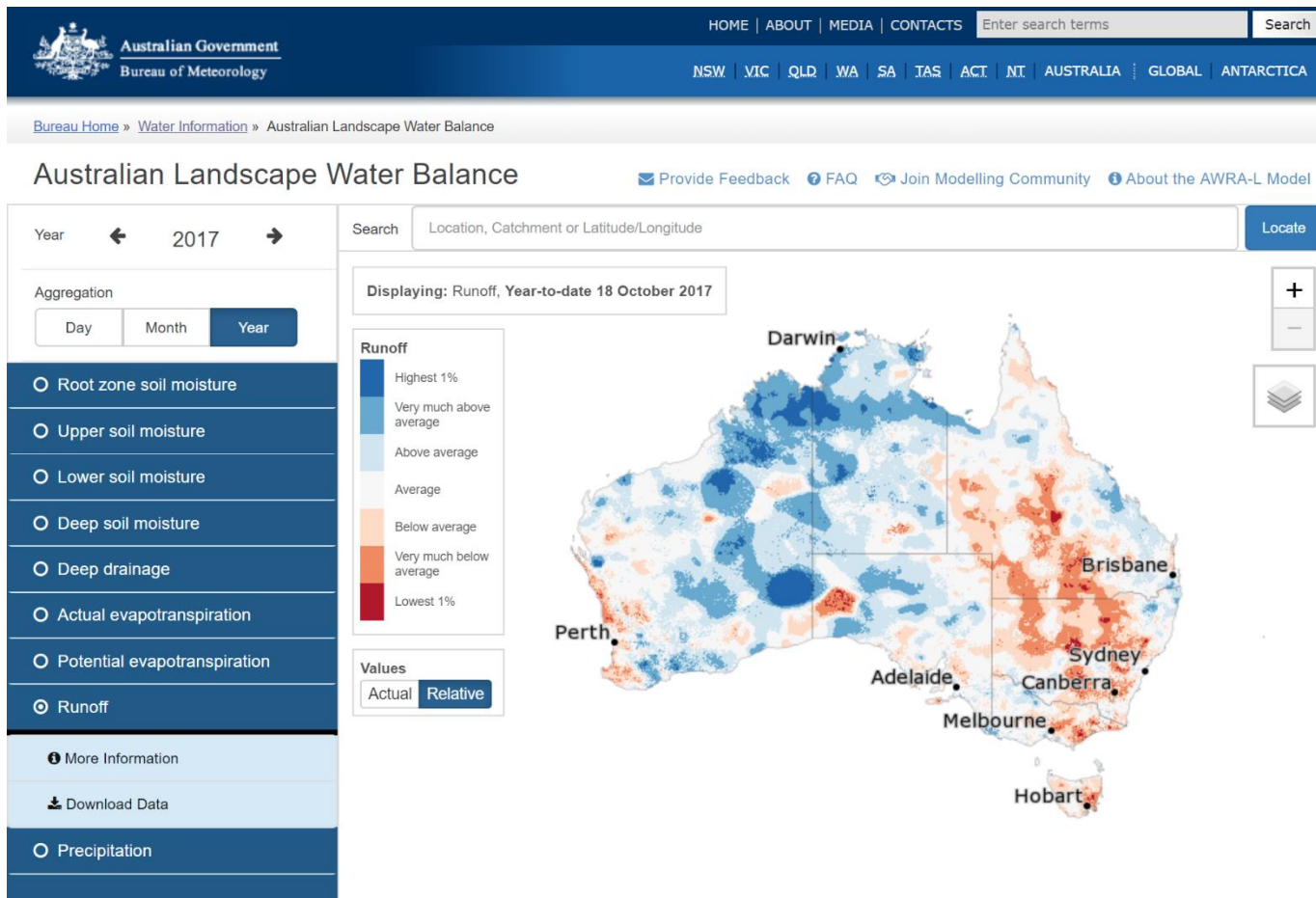
(Metric: Precipitation)



e.g. Much of INLAND SW Qld and NW NSW have received DECILE 1 (i.e. lowest 10% of years) in 12 months to Sept 2017

Hydrologic Drought

(Metric: Streamflow)



Spatial patterns of Precipitation and Streamflow roughly similar but they are not identical

Hydrologic Drought

(Metric: Streamflow)

CONTEXT:

INDUSTRIAL WATER SUPPLY

rural
regional
metropolitan

DOMESTIC WATER SUPPLY

rural
regional

metropolitan

DESALINISATION PLANTS

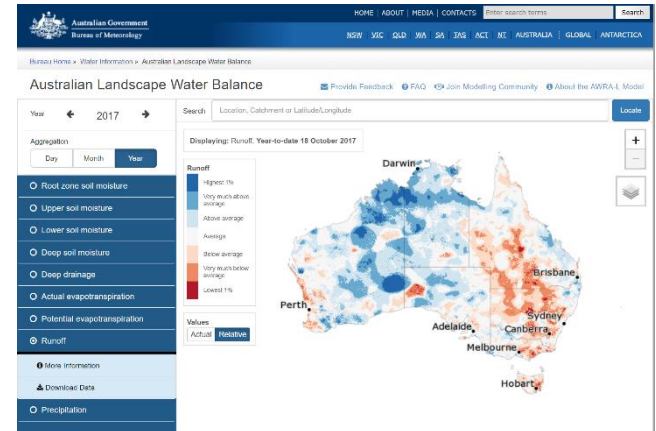
(Q: how often do we need to run the desalinisation plants?)

AGRICULTURAL WATER SUPPLY

stock

irrigation

LARGEST USER OF WATER GLOBALLY (and in Australia)

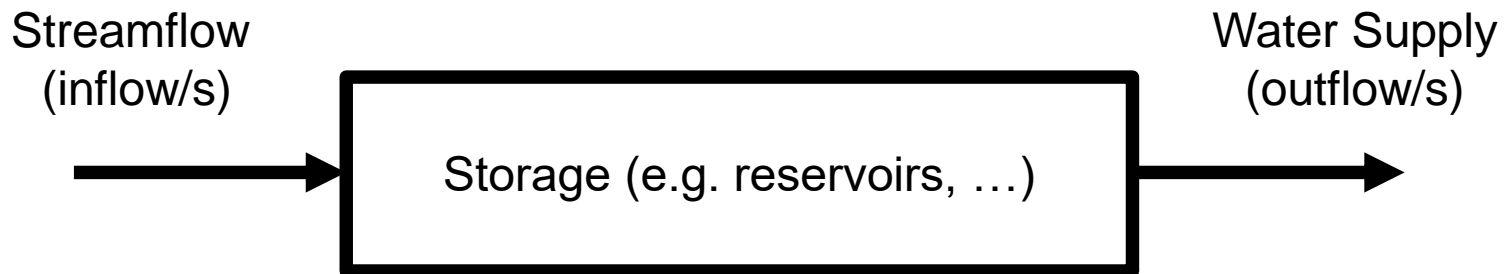


Engineering problem of balancing supply against demand.

In practice this involves interaction between streamflow (flux) and storage (stock)

Hydrologic Drought

Engineering problem of balancing supply against demand.
In practice this involves interaction between streamflow (flux) and storage (stock)



Commonly Used Options for Managing Drought

Surface management

e.g. roaded catchments,
vegetation management

Use different sources

(groundwater, desalination)

Change size of storage

Designated Uses

(security)

Restrictions on Use

Agricultural Drought

Dryland: often the focus is on variables such as:
soil moisture, evaporative demand, etc..

Irrigated: often the focus is on irrigation allocation

BUT

Underlying biophysical metric is:



Image Source: theaustralian.com.au

CROP PRODUCTION (= YIELD x AREA) {not continuous}

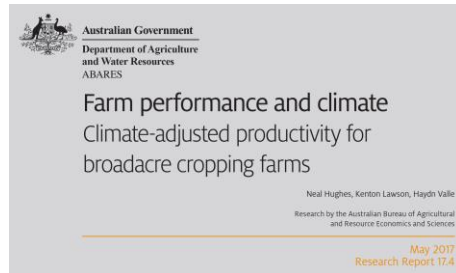
Underlying socio-economic metric (in a market-based economy) is:

FARM NET INCOME (and return on capital and)

Underlying socio-economic metric (in a non-market-based economy) is:

SOMETHING QUITE DIFFERENT

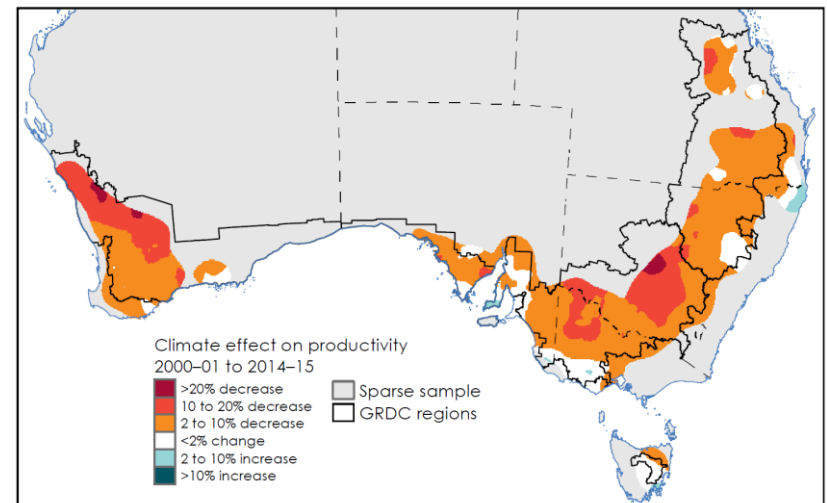
Relation between Drought and Agricultural Productivity is complex



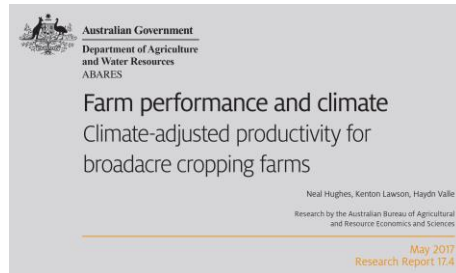
May 2017 ABARES report highlighted:

Drop in crop production in last 15 years of around 10-20% due to succession of low rainfalls (i.e., Millennium Drought)

FIGURE 14 Average climate effect on productivity levels since 2000–01, relative to the 1914–15 to 2014–15 average



Relation between Drought and Agricultural Productivity is complex



BUT:

Overall farm profitability increased around 20-30% in last 15 years – especially after 2006 (i.e., after ~ 5 years of drought).

May 2017 ABARES report highlighted:

Drop in crop productivity in last 15 years of around 10-20% due to succession of low rainfalls (i.e., Millenium Drought)

Evidence of ADAPTATION (Drought drives agricultural innovation?)

FIGURE 1 Average climate-adjusted productivity for cropping specialist farms, 1977-78 to 2014-15

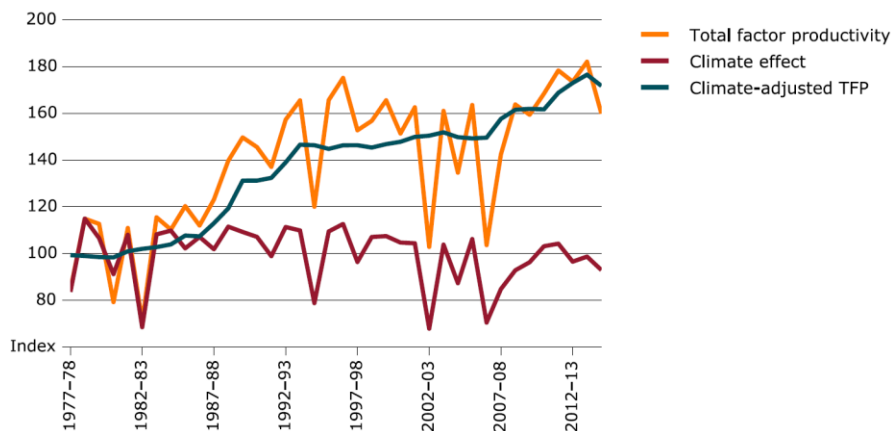
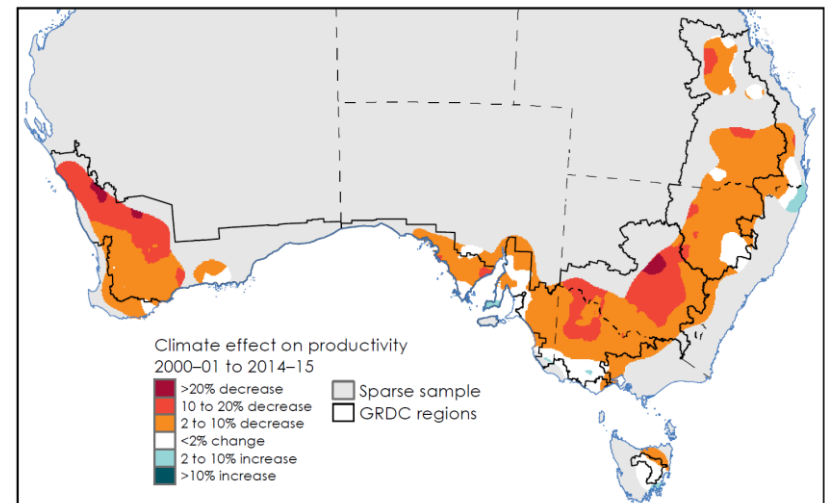


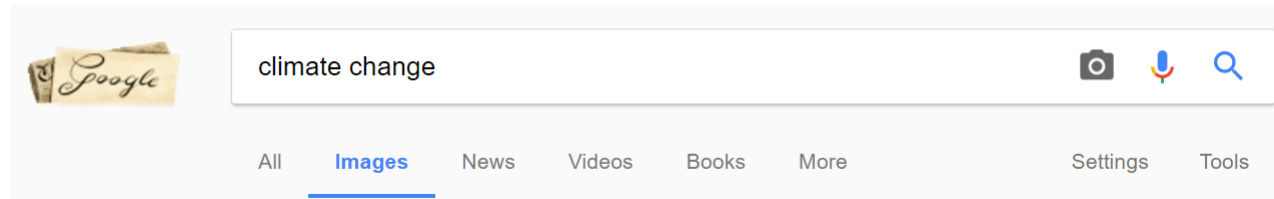
FIGURE 14 Average climate effect on productivity levels since 2000-01, relative to the 1914-15 to 2014-15 average



Lesson/s

1. Drought is complex and context dependent
2. Extremes always relative to some (local) baseline
3. Drought has a socio-economic context as well as a biophysical setting
4. Humans can and do adapt to changing circumstances

EXPERIMENT:



Type “climate change” into Google and pick the first image



Problem: Which side (of the image) represents climate change ???

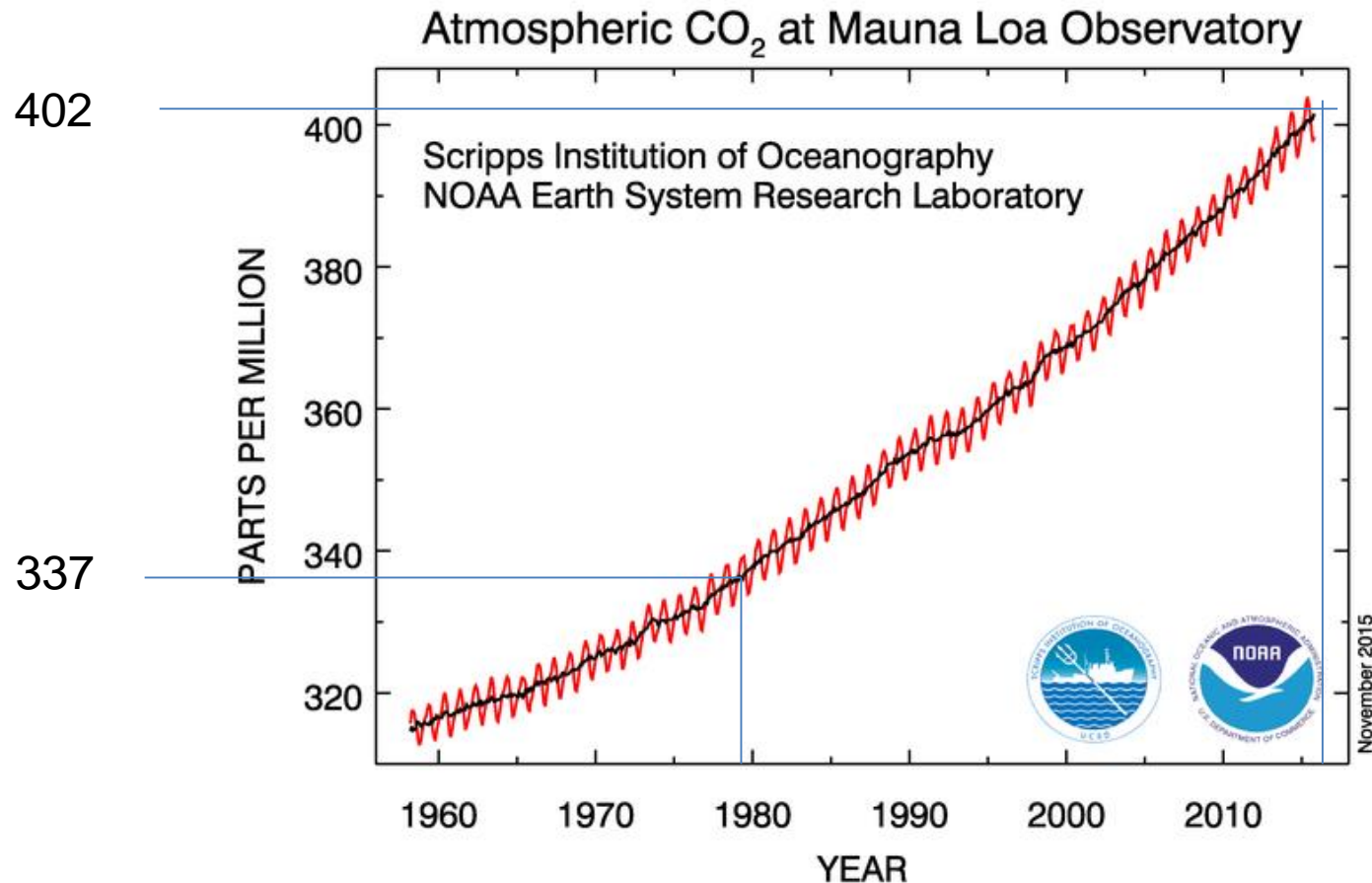
Public Perception

NOW → FUTURE



NOW → FUTURE

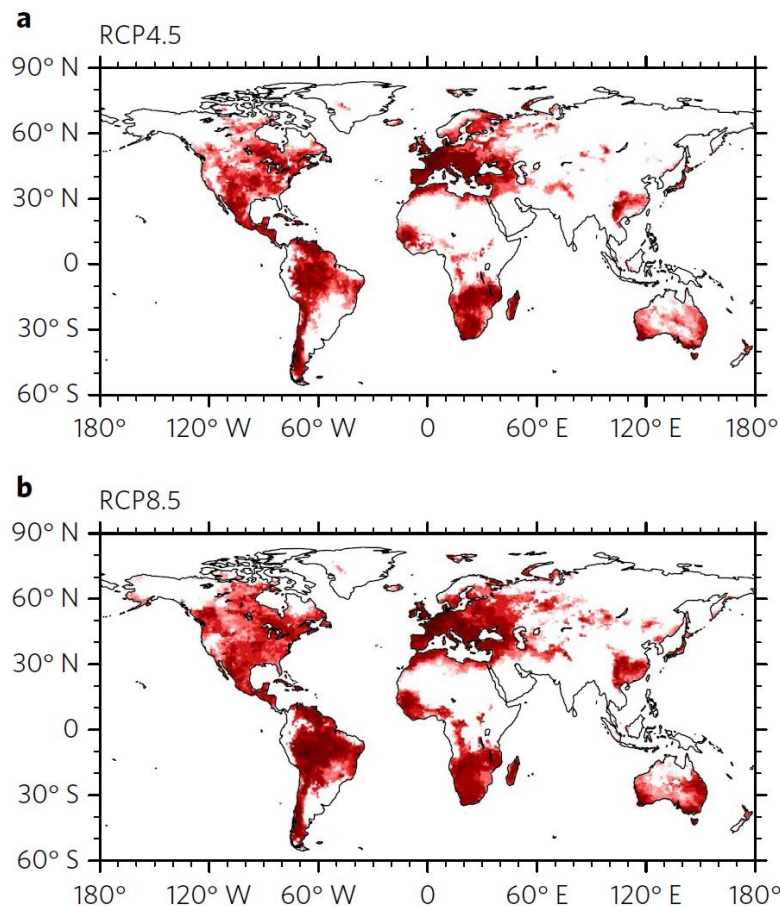
[CO₂] is increasing very quickly



1979 337 ppmV

2016 402 ppmV

$$\Delta = (402 - 337) / 337 = +19\%$$



LETTERS

<https://doi.org/10.1038/s41558-017-0034-4>

nature
climate change

Keeping global warming within 1.5 °C constrains emergence of aridification

Chang-Eui Park¹, Su-Jong Jeong^{1*}, Manoj Joshi², Timothy J. Osborn², Chang-Hoi Ho³, Shilong Piao^{4,5,6}, Deliang Chen⁷, Junguo Liu¹, Hong Yang^{8,9}, Hoonyoung Park³, Baek-Min Kim¹⁰ and Song Feng¹¹

Aridity increases with CO₂-induced Warming

Only a matter of time ...

Problem with the Offline Methodology

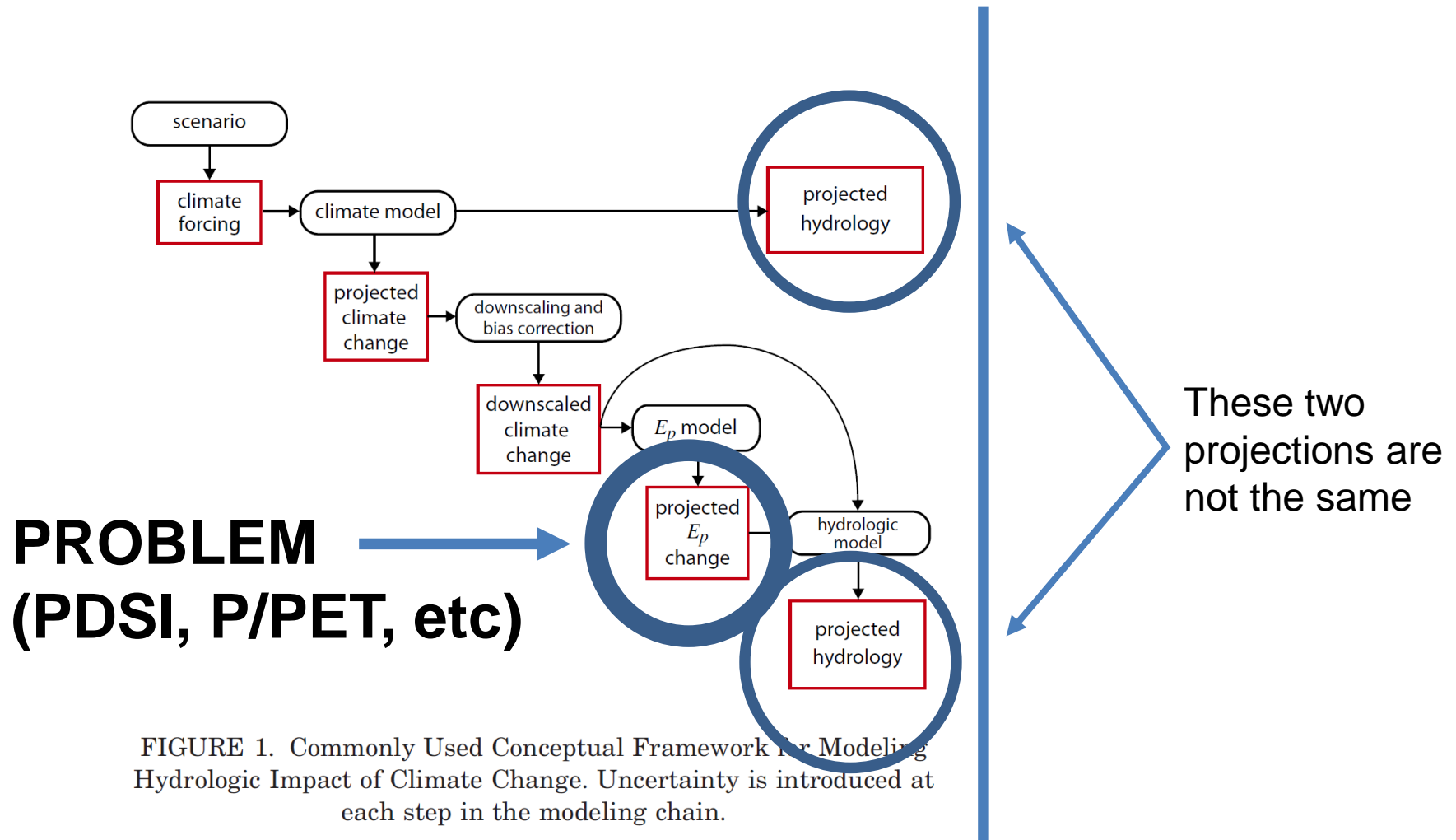
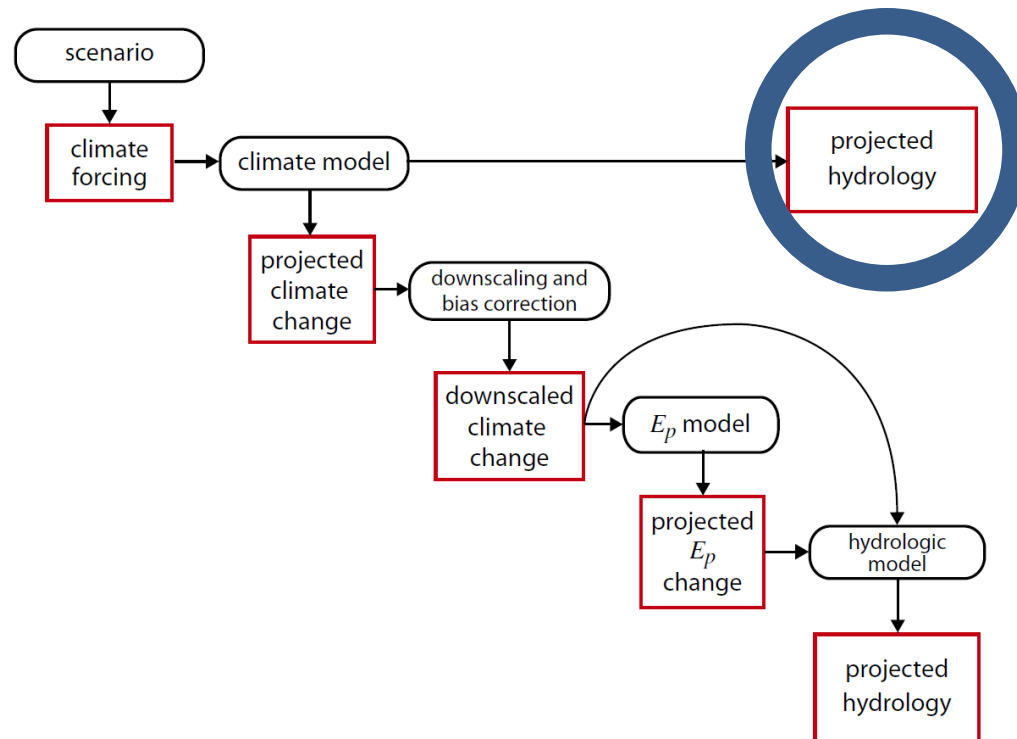


FIGURE 1. Commonly Used Conceptual Framework for Modeling Hydrologic Impact of Climate Change. Uncertainty is introduced at each step in the modeling chain.

From Milly & Dunne 2017

Journal of the American Water Resources Association

Problem with the Offline Methodology



Use model projections
to assess aridity
and drought

FIGURE 1. Commonly Used Conceptual Framework for Modeling Hydrologic Impact of Climate Change. Uncertainty is introduced at each step in the modeling chain.

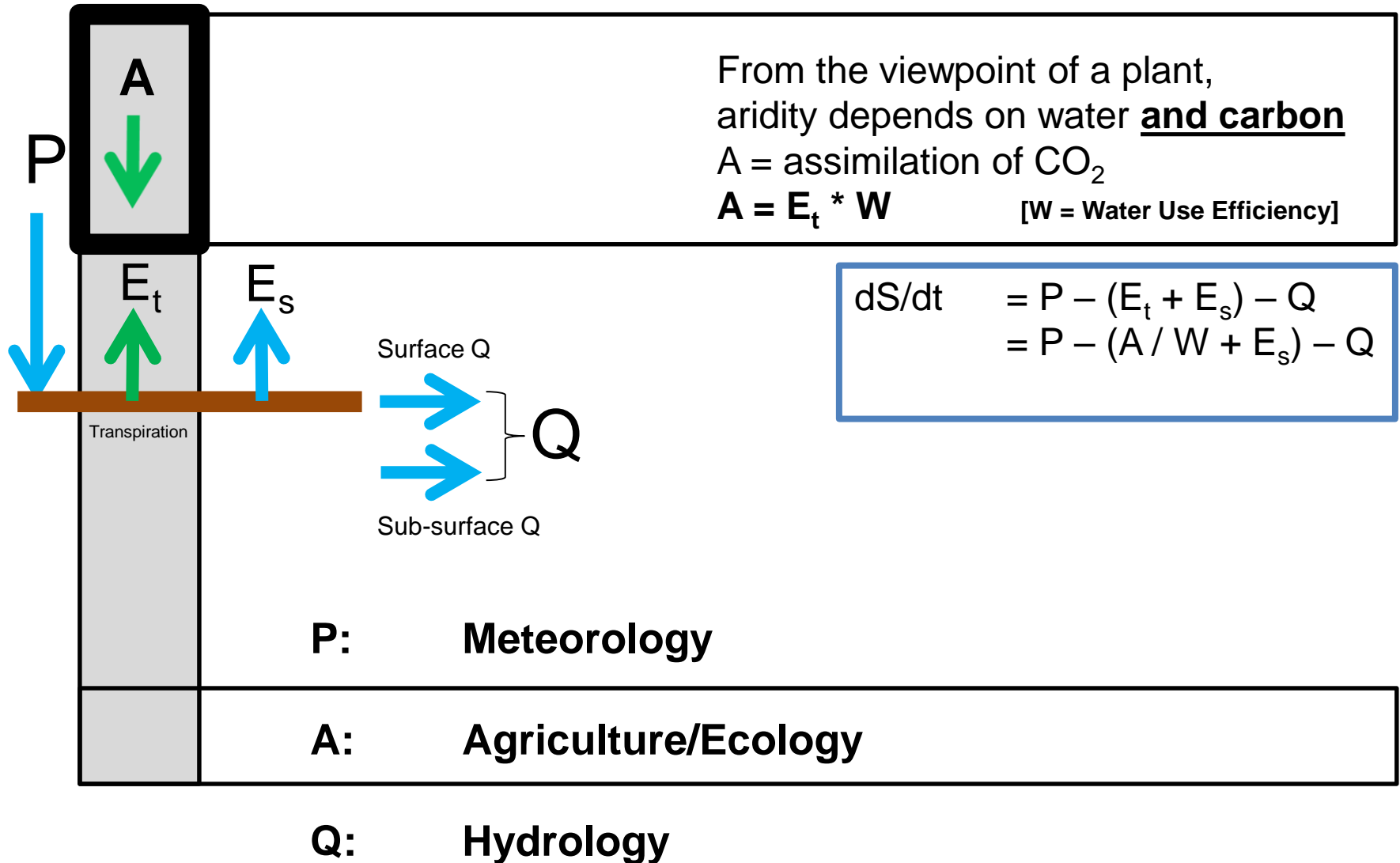
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Journal of the American Water Resources Association

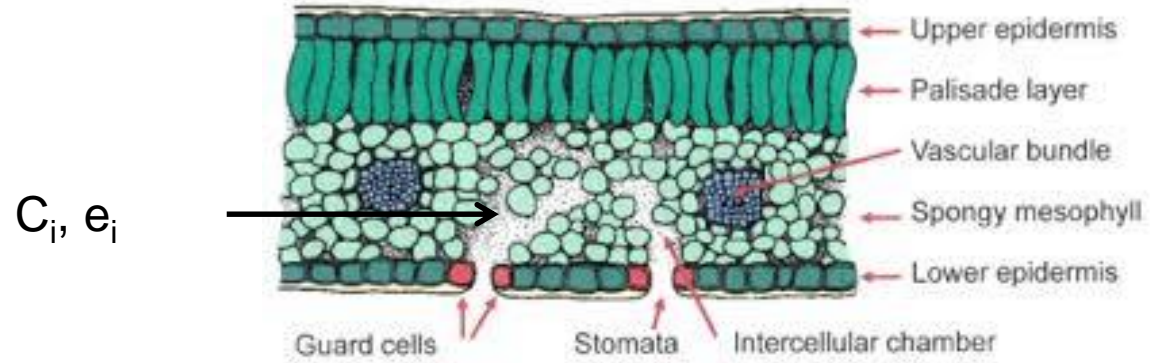
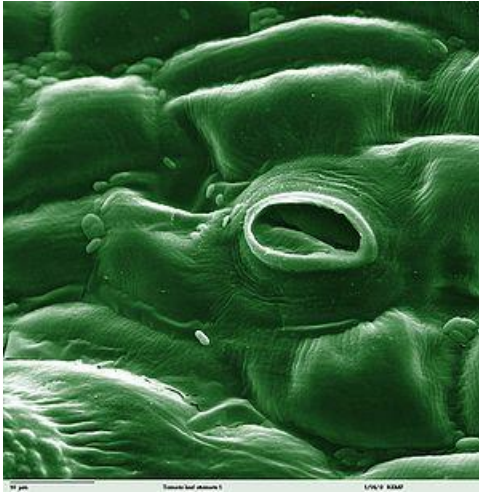
Lesson/s

1. Drought is complex and context dependent
2. Extremes always relative to some (local) baseline
3. Drought has a socio-economic context as well as a biophysical setting
4. Humans can and do adapt to changing circumstances
5. To make projections using climate models use the climate model output

Water & Carbon - Coupled



CO₂ uptake and Water loss



C_i, e_i

C_a, e_a

C - CO₂ concentration
e - Vapour pressure
Inside the leaf: $C_i, e_i = e_s(T_L)$
In the atmosphere: $C_a, e_a(T_a)$

$$W = A_L / E_L = g_c (C_a - C_i) / \{g_w (e_s(T_L) - e_a(T_a))\}$$

&

$$g_w = 1.6 g_c \quad \{\text{diffusivity in air}\}$$

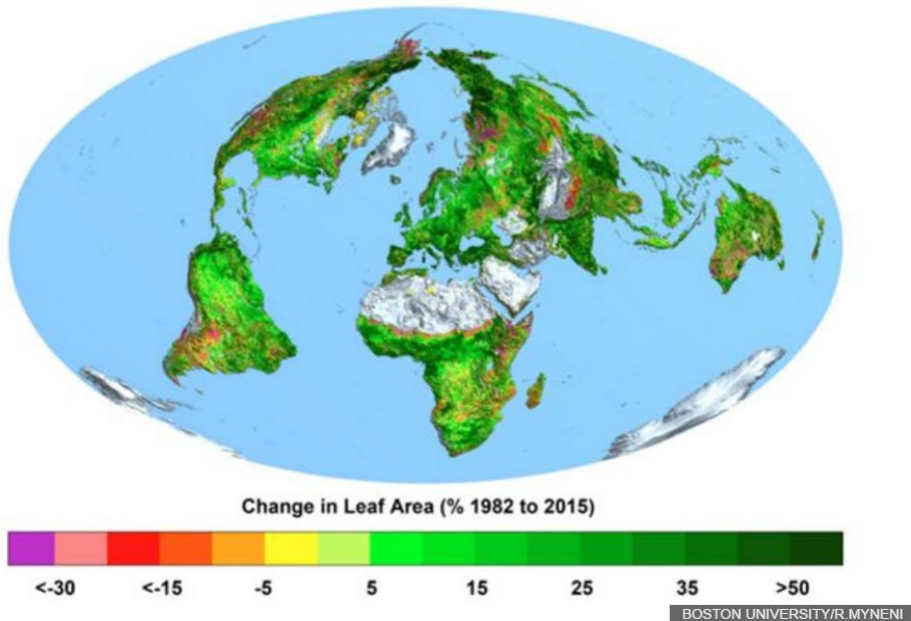
$$W = (C_a - C_i) / (1.6 v)$$

$$W \approx C_a (1 - C_i / C_a) / (1.6 D) \quad \{\text{assuming } D \approx v, \text{ assumes leaf } T \sim \text{air } T\}$$

Rise in CO₂ has 'greened Planet Earth'

By Roger Harrabin
BBC environment analyst

🕒 25 April 2016 | [Science & Environment](#)



Carbon dioxide emissions from industrial society have driven a huge growth in trees and other plants.

NOT A SURPRISE

Increasing CO₂ causes global greening

- INDIRECT
 - Warmer
 - colder regions have longer growing seasons
- DIRECT
 - increased water use efficiency of photosynthesis

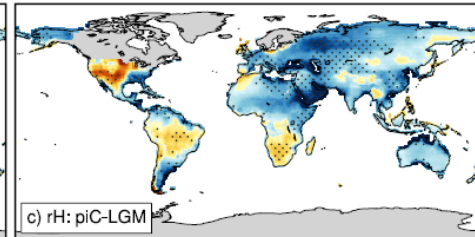
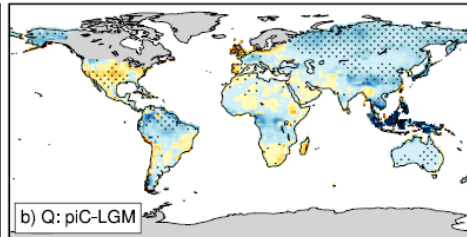
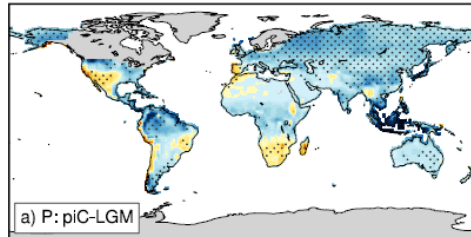
Regional Hydrology: Australia

Now-LGM

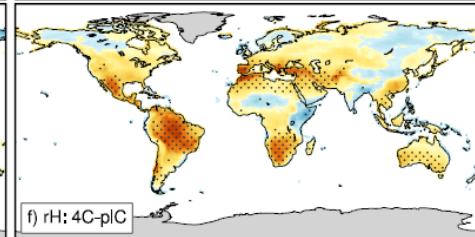
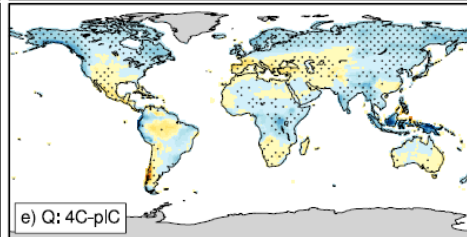
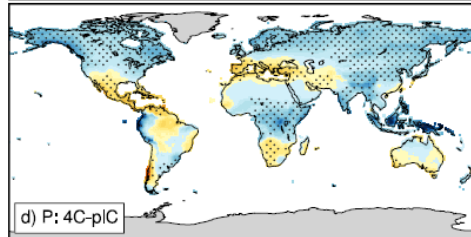
More P now

More Q now

Now
-
LGM



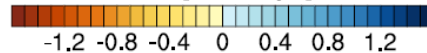
Future
-
Now



ΔP [mm day⁻¹]



ΔQ [mm day⁻¹]



ΔrH [%]



Future – Now

More P north

Less P south

More Q north

Less Q south

Regional Carbon/Water: Australia

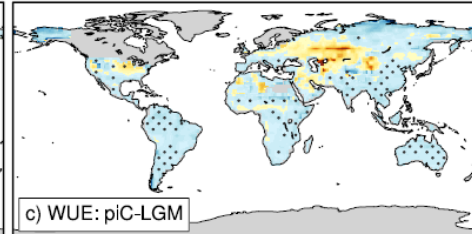
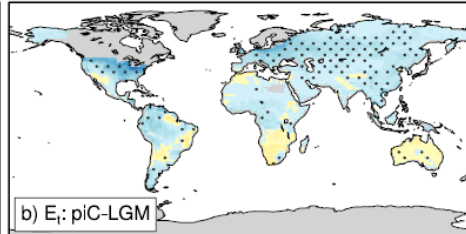
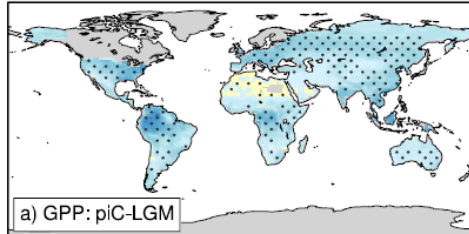
Now-LGM

Higher GPP now

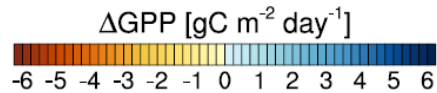
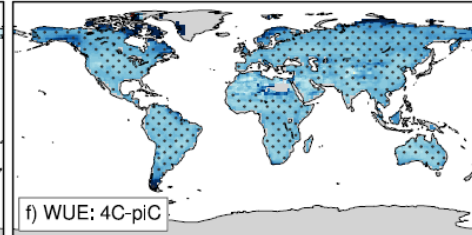
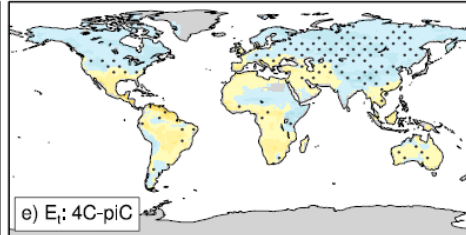
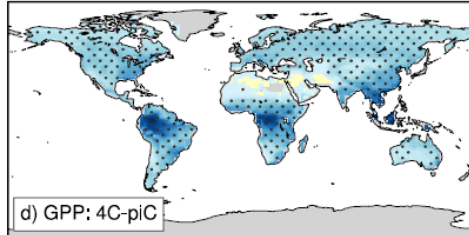
Lower E_t now

Higher WUE now

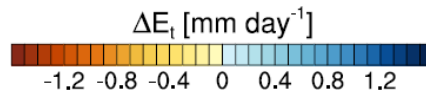
Now
-
LGM



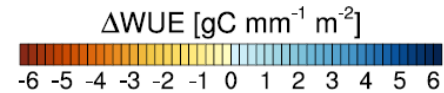
Future
-
Now



GPP



Transpiration



WUE

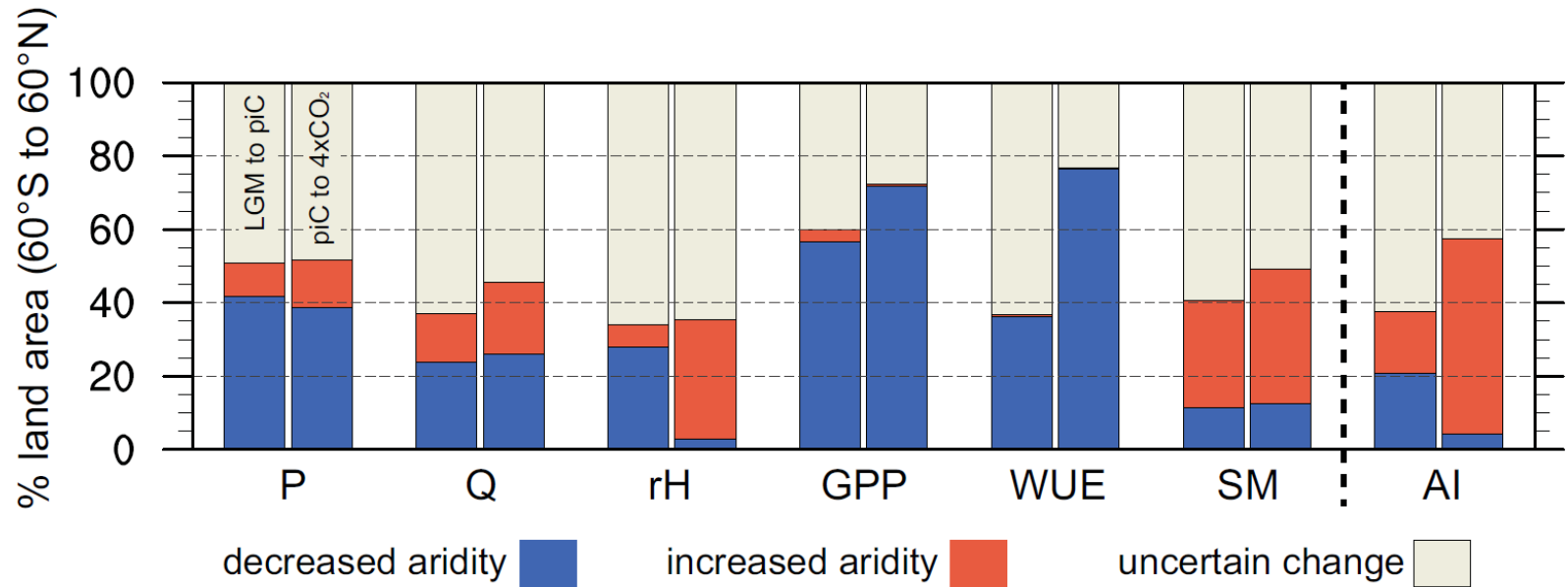
Future – Now

Higher GPP future

Lower E_t future

High WUE future

Global Summary



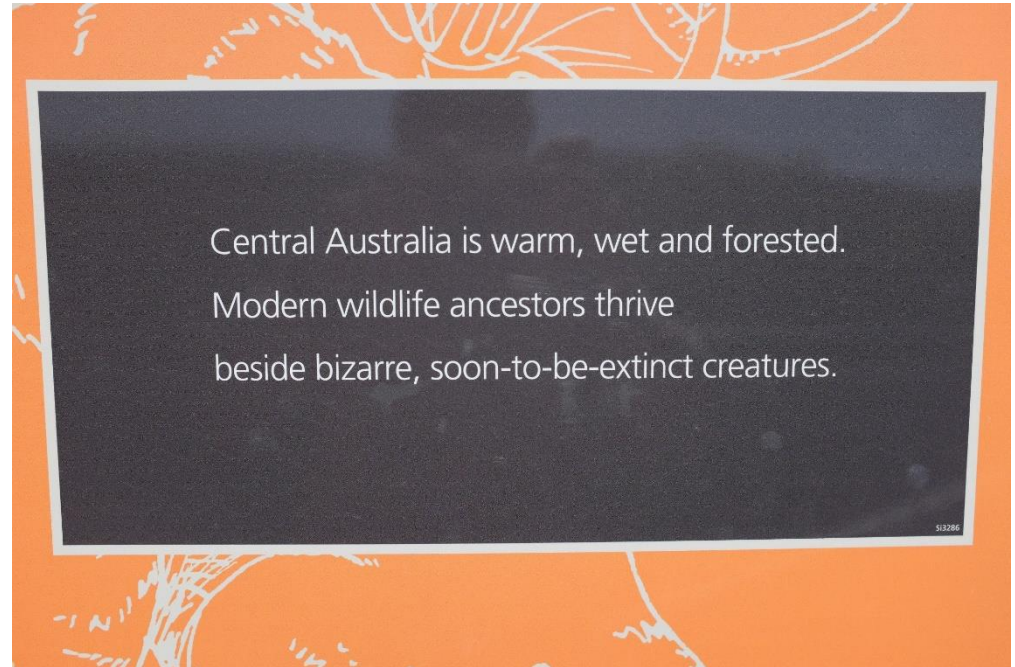
Last Glacial Maximum



Low atmospheric CO₂: cool and dry



High atmospheric CO₂: warm and wet



Example of Accessible Long Term Ecological Records

Koonamore Vegetation (Arid Zone in South Australia)

Youtube search term: Koonamore

University of Adelaide Photographic (and other) Monitoring since 1920s

Images recently put on Youtube by Dr Dean Graetz (retired CSIRO Ecologist)

Example: <https://www.youtube.com/watch?v=LaP7SSciW2I>

Aridity vs Drought

Aridity gives the baseline (background state)

Drought is an extreme
extreme relative to background state

Lesson/s

1. Drought is complex and context dependent
2. Extremes always relative to some (local) baseline
3. Drought has a socio-economic context as well as a biophysical setting
4. Humans can and do adapt to changing circumstances
5. To make projections using climate models use the climate model output
6. GCMs project a generally warmer and wetter world (less aridity)
(These are projections not facts)
7. Vegetation behaviour is central to the aridity/drought projections
(These are projections not facts – they make assumptions that may be incorrect)
9. Research only just beginning on hydro-climatic extremes

Finally, Drought is serious business

Think about the consequences of an off-hand statement like:

“Expect an increase in drought in XXX in coming years”

The Australian context:

Australian Agriculture

First Management Response:

How much capital is needed?

Australian Metropolitan Water

First Management Response:

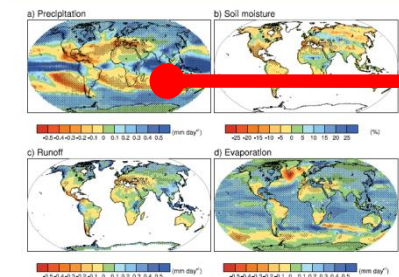
How often will we need to run the desalinisation plant?

SPARES

The Question:

- How does a projected change (e.g. 5 or 10%) in P compare to the typical year to year variability ?

Chapter 10 Global Climate Projections

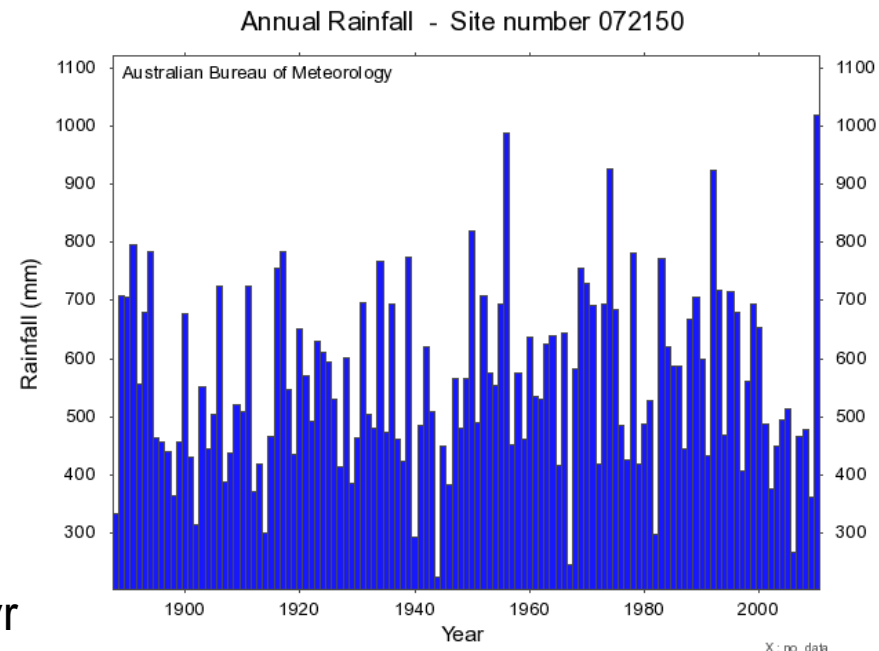


Projected Change
2080-2099 less 1980-1999

- ~ - 0.1 mm/day
- ~ - 36 mm per yr
- ~ - 6% ($= -36/550$)



Site: Wagga Wagga
Data: BoM
Range in P:
~ 225 to 1000 mm per yr
Mean P ~ 550 mm per yr



Crop Yields

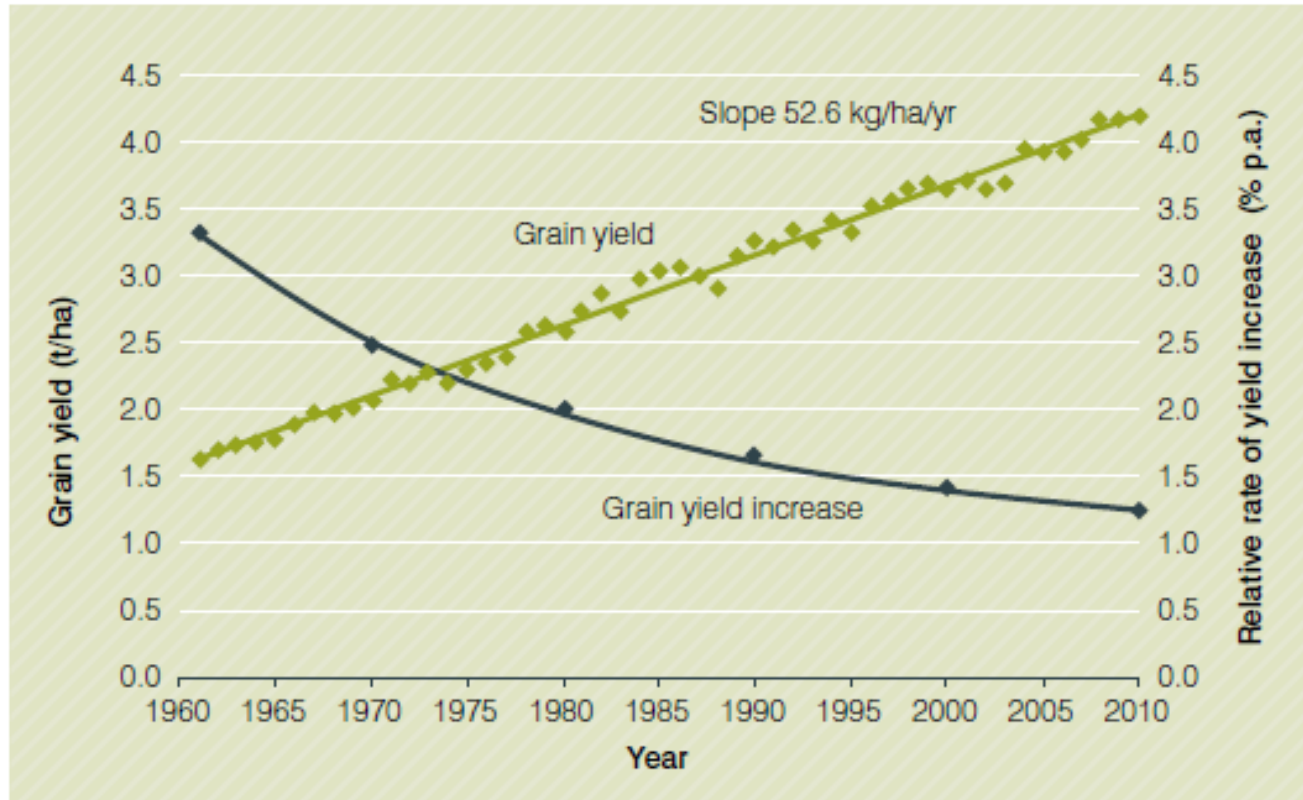


Figure 1.1 World yield of wheat, rice and maize (arithmetic average) and the annual relative rate of yield increase between 1960 and 2010. Standard error of slope = 0.7 kg/ha/yr, $R_{sq} = 0.992$. Source: FAOSTAT (2013)

Ecological Drought

Droughts can have long-term ecological consequences

Metric depends on viewpoint & context

Viewpoint Metric

FLORA:

Biodiversity	Species
Veg. Structure	Vegetation Cover, Annual vs Perennial
Biome
.....

- Australian vegetation is drought adapted
 - BUT - there are species-level differences in drought adaptation

FAUNA:

.....



Image Source: www.abc.net.au/news

Ecological Drought



Example:

Mulga tree in Western Australia dated to 200 years old

Since it is still alive, this means it has survived the driest hours/days/months/years/decades/centuries in the last 200 years

Ecological Drought



Example:

Mulga tree in Western Australia dated to 200 years old

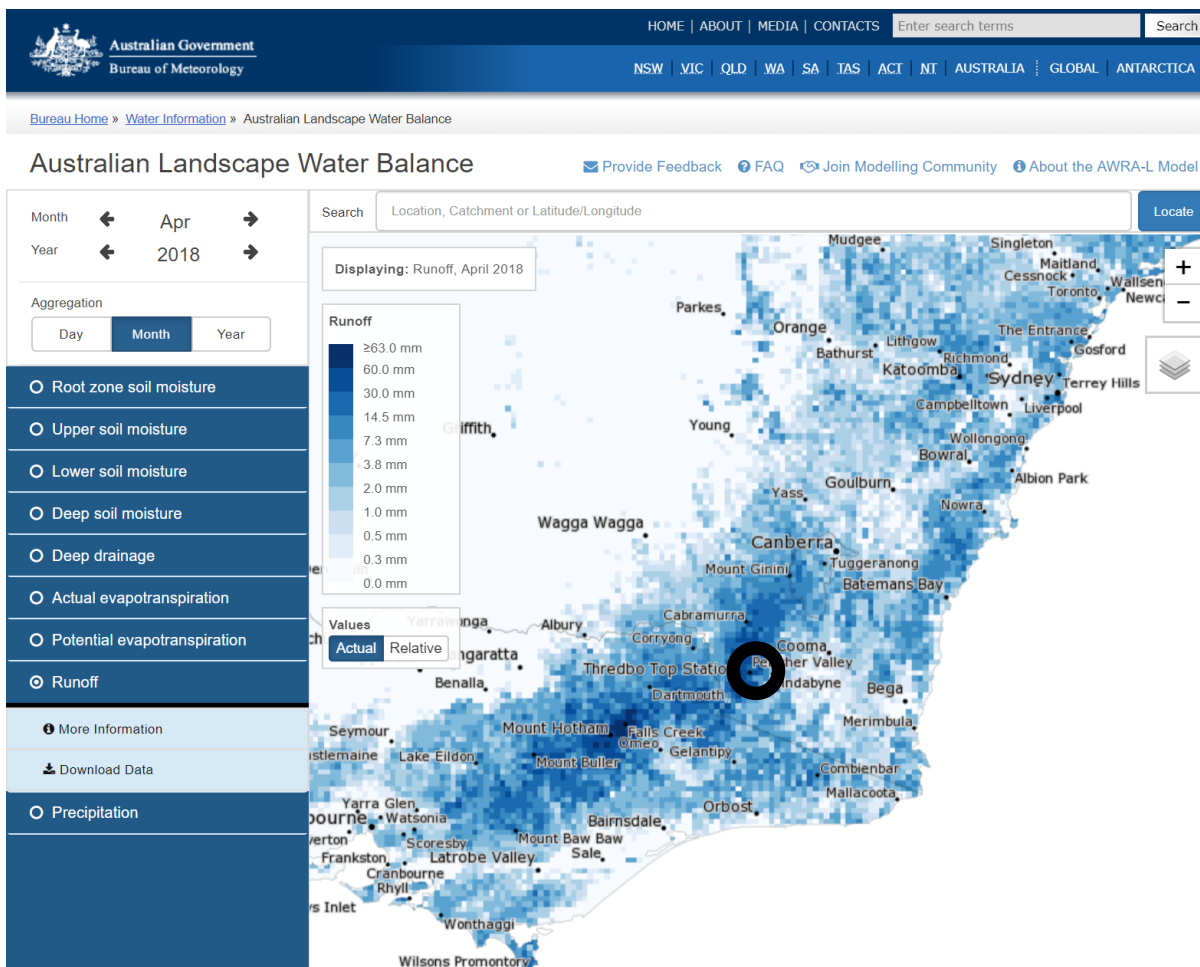
Since it is still alive, this means it has survived the driest days/months/years/decades/centuries in the last 200 years

Actually, I made that up – I have no idea if that particular tree is 200 years old. It could be

Thredbo River, 6 May 2018

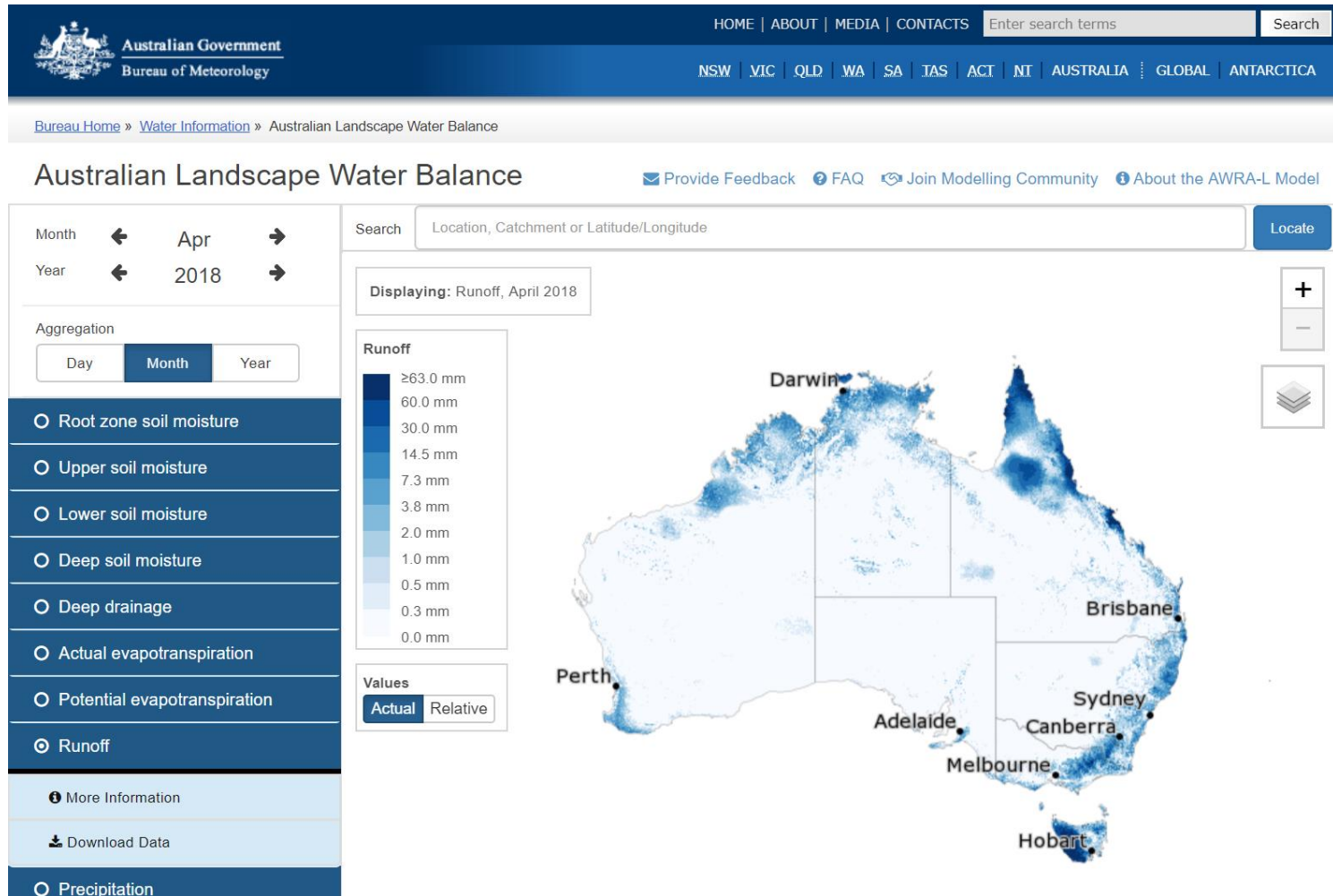


Thredbo River, 6 May 2018

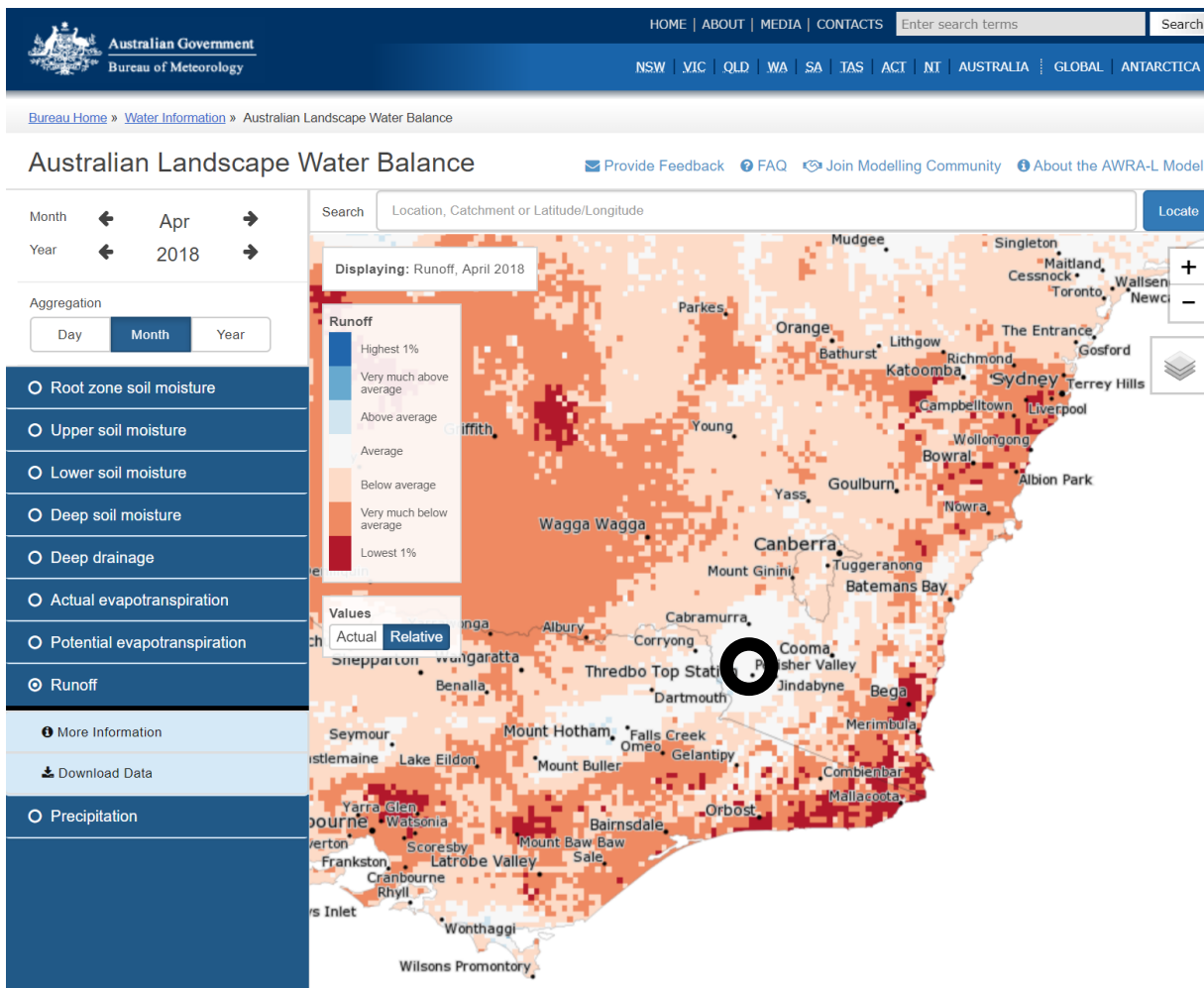


Seems wet
compared to
other places

Runoff, April 2018

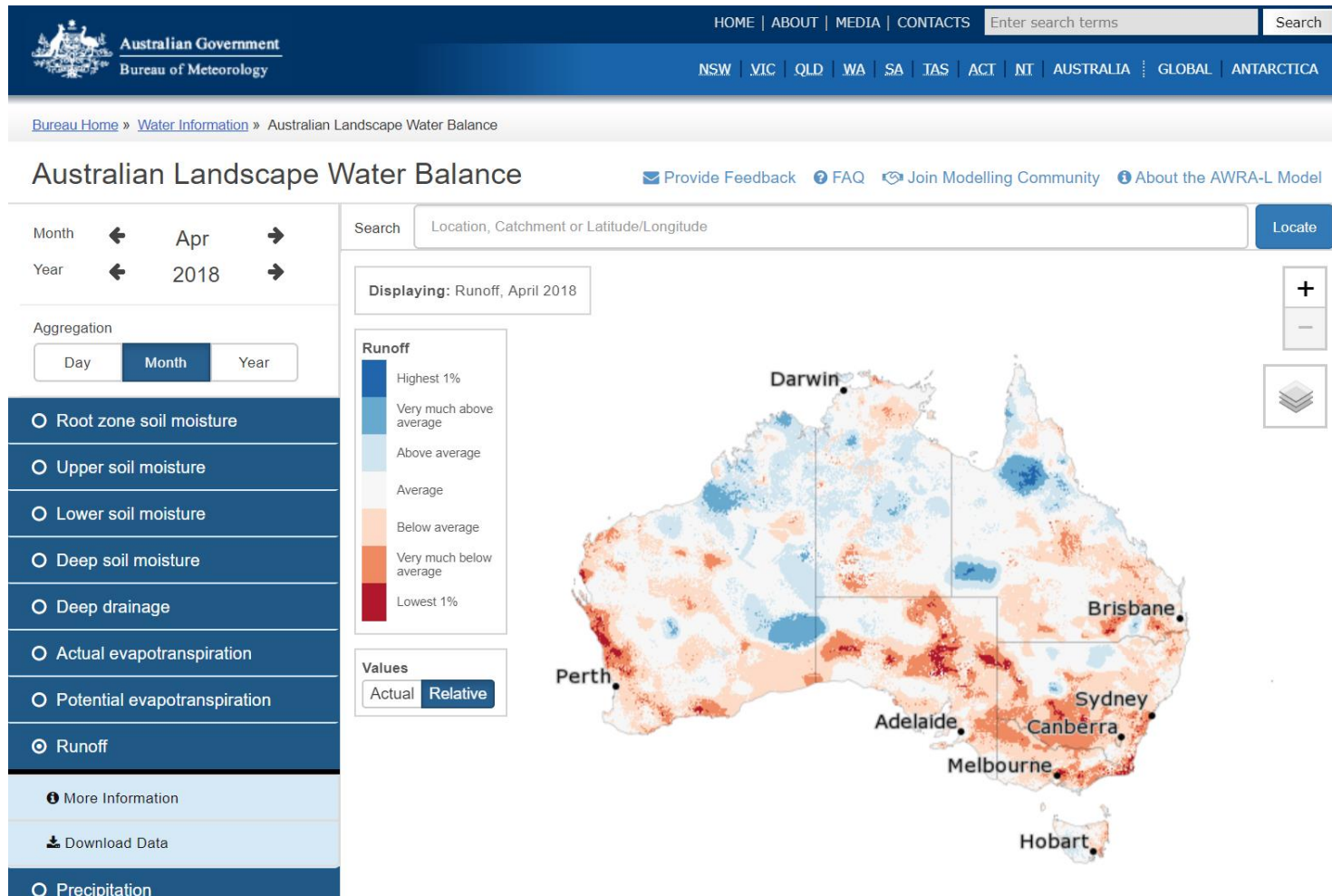


Thredbo River, 6 May 2018



Actually BoM
says average
runoff.

Relative Runoff, April 2018

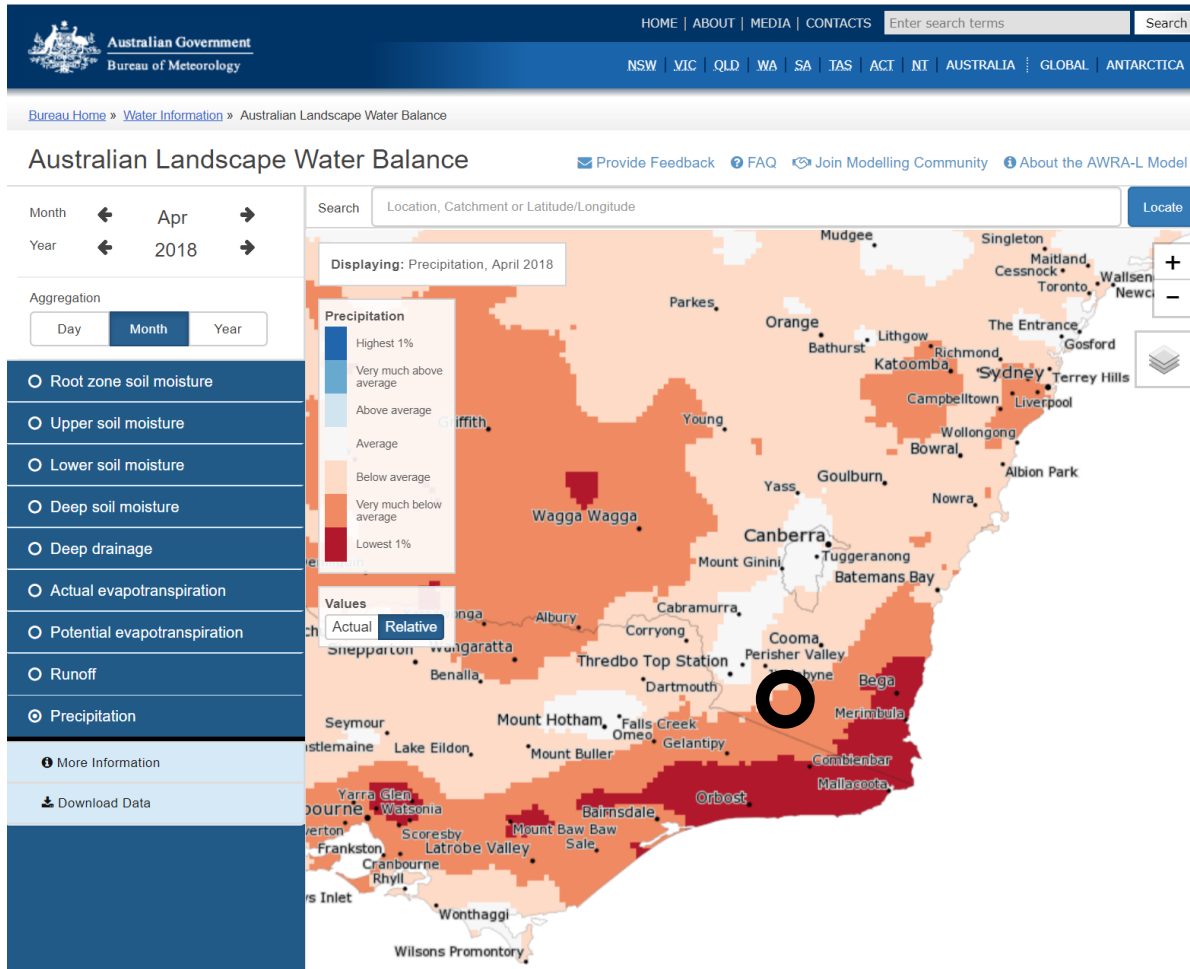


Monaro Plains, 6 May 2018

(~ 30 km southeast of Thredbo River)



Monaro Plains, 6 May 2018



Only 30 kms from Thredbo River and yet rainfall is “very much below average”

Presumably why ground appears bare

Monaro Plains, 6 May 2018

(~ 30 km southeast of Thredbo River)



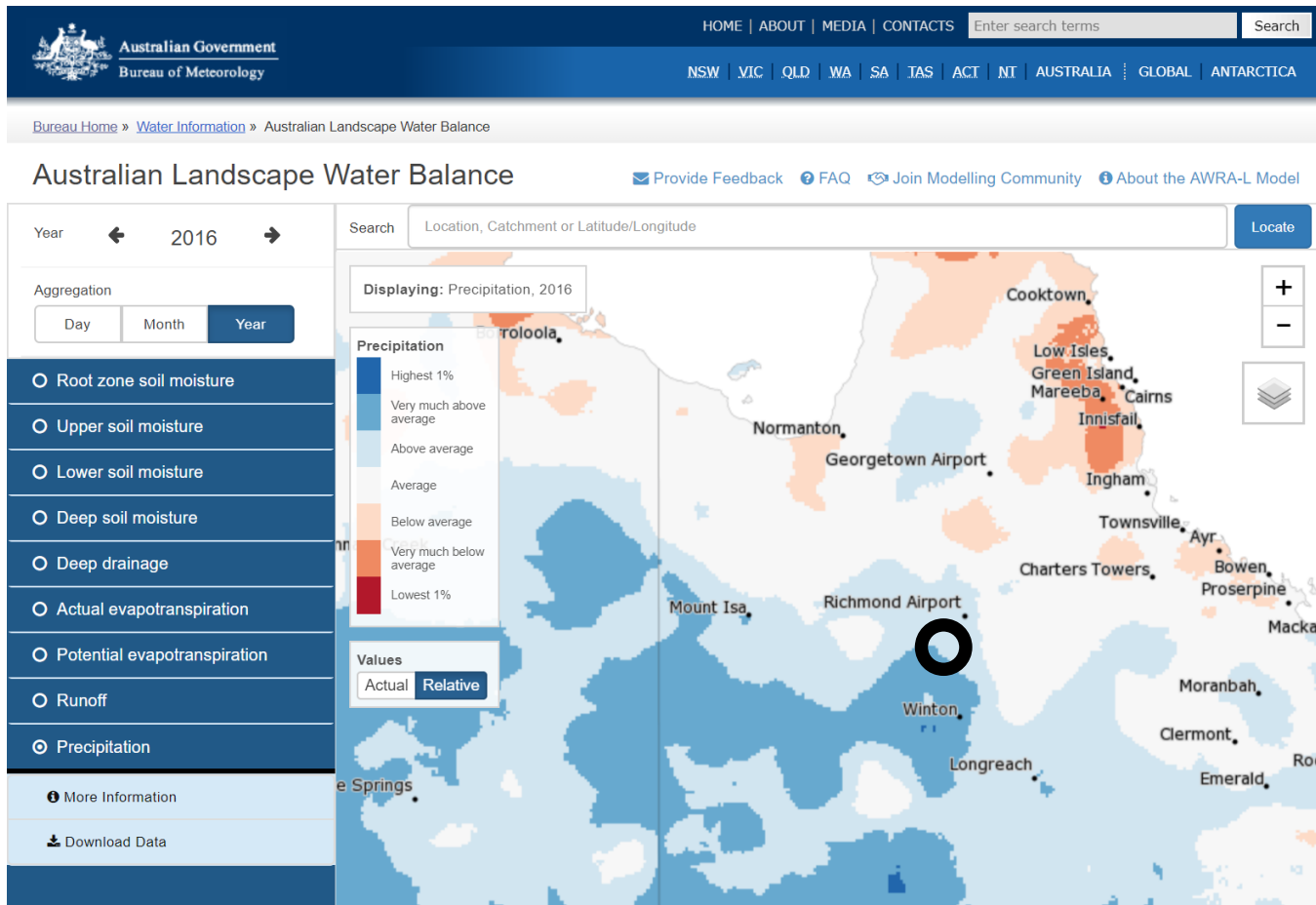
Presumably why ground appears bare

Is this the only possibility?

Richmond, NW Qld, June 2016



Richmond, NW Qld, June 2016



2016 was not
actually that dry ?

Richmond, NW Qld, June 2016



What does
fenceline effect
mean?

Richmond, NW Qld, June 2016



What does
fenceline effect
mean?

The presence of a fenceline effect means that land management (in this example, the stocking rate of cattle) plays an important role in determining drought impacts.

Human decisions matter!!