The effect of climate change on South West WA hydrology

Don McFarlane
Research Manager
Structure of the talk

1. Recent and projected climate change in South West WA
   i. Rainfall amount and intensity
   ii. Temperature

2. Wheatbelt
   i. Groundwater levels and dryland salinity
   ii. Streamflows and flooding

3. Darling Range
   i. Groundwater levels
   ii. Surface water yields

4. Perth Basin
   i. Groundwater levels
   ii. Surface water – groundwater interactions

5. Conclusions
Location of the areas discussed

Perth Basin
Darling Range streams
Wheatbelt

Blue + pink = South West Sustainable Yield project area

The effect of climate change on South West WA hydrology
South west WA annual rainfall has fallen since 1970
Bureau of Meteorology 2010

Trend in Annual Total Rainfall 1970-2009 (mm/10yrs)

>60 mm
>120 mm
South-west WA has had reduced rainfall since 1975

Change may have started in about 1965 and stabilised by 1975.
SWWA winter extreme rainfall has decreased since 1965
Li et al. 2005
Annual rainfalls have been even drier since 1997
CSIRO 2009

1997 to 2007 rainfall compared with 1975 to 1996 rainfall

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CSIRO 2009

14 of 15 GCMs project it will get drier

Global climate models

- Median future climate -7%
- Wet extreme future climate (90 percentile) -1%
- Dry extreme future climate (10 percentile) -14%

Change in annual rainfall

Mid warming
High warming
Low warming

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Temperatures have risen which increases potential evapotranspiration and reduces soil water.

Bureau of Meteorology 2010

Trend in Mean Temperature 1970-2009 (°C/10yrs)

- Up to 0.4°C
- Up to 0.6°C
- Up to 0.8°C
Projected changes in temperature by 2030
CSIRO and BoM 2007
Groundwater levels and salinity in the Wheatbelt
Examples of falling groundwater levels

5m fall since 2000 where WT is deeper

1m fall since 2000

Speed (2008)
Rising or stable trends prior to 2000

Declining trends irrespective of geology, WT depth or land use
Before 2000 most groundwater levels were rising in northern and central regions. Now most are falling.

Based on data in George et al. 2008
Land Monitor - dryland salinity spread 1989 to 1996 and hazard
Yellow = 1989       Red = 1996       Blue = salt hazard
## Shire salinity
McFarlane *et al.* 2004

<table>
<thead>
<tr>
<th>Shire</th>
<th>Percentage of shire with salinity in 1996</th>
<th>Percentage of shire with salinity in 1989</th>
<th>Change between 1989 salinity and 1996 salinity</th>
<th>Salinity Hazard (ha)</th>
<th>Hazard as a Percentage of Shire</th>
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<tbody>
<tr>
<td>Boddington</td>
<td>1.2%</td>
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<td>0.61%</td>
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<td>Jerramungup</td>
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<td>Katanning</td>
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<td>Kent</td>
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<td>0.78%</td>
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<td>Kulin</td>
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<td>3.8%</td>
<td>0.90%</td>
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<td>Lake Grace</td>
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<td>Moora</td>
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<td>6.2%</td>
<td>1.46%</td>
<td>81,158</td>
<td>21.6%</td>
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<td>Narrogin</td>
<td>4.9%</td>
<td>4.4%</td>
<td>0.55%</td>
<td>45,613</td>
<td>28.2%</td>
</tr>
<tr>
<td>Nungarin</td>
<td>11.1%</td>
<td>7.7%</td>
<td>3.40%</td>
<td>50,012</td>
<td>43.0%</td>
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<tr>
<td>Tambellup</td>
<td>8.6%</td>
<td>7.7%</td>
<td>0.92%</td>
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<td>Wagin</td>
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<td>5.8%</td>
<td>0.85%</td>
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<td>29.0%</td>
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<td>West Arthur</td>
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<td>0.69%</td>
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<td>Wongan-Ballidu</td>
<td>10.9%</td>
<td>10.2%</td>
<td>0.70%</td>
<td>94,822</td>
<td>28.1%</td>
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<tr>
<td>Woodanilling</td>
<td>5.5%</td>
<td>4.7%</td>
<td>0.83%</td>
<td>36,217</td>
<td>32.1%</td>
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<tr>
<td><strong>TOTALS</strong></td>
<td><strong>2.9%</strong></td>
<td><strong>2.6%</strong></td>
<td><strong>0.30%</strong></td>
<td><strong>5,464,834</strong></td>
<td><strong>16.8%</strong></td>
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</table>

17,000 ha per annum

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Comparison of salinity extent and hazard

<table>
<thead>
<tr>
<th>Method</th>
<th>Extrapolation from studies Ferdowsian et al. 1996</th>
<th>NLWRA 1998</th>
<th>Land Monitor McFarlane et al. 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt-affected in 1996 to 2000 period (ha)</td>
<td>1.8M</td>
<td>4.4M</td>
<td>0.96M</td>
</tr>
<tr>
<td>Annual rate of increase (ha)</td>
<td>75,000 2000 to 2020</td>
<td>55,000 2000 to 2020</td>
<td>14,000 1989 to 1996</td>
</tr>
<tr>
<td>Final hazard area (ha)</td>
<td>6.1M</td>
<td>8.8M</td>
<td>&lt;5.5M</td>
</tr>
</tbody>
</table>
Streamflow and flooding in the Wheatbelt
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Wet years defined as above 1-in-10 year
annual recurrence interval

Wet years for Narrogin in 25-year segments
(Hatton and Ruprecht 2001)
Annual floodflow for the Avon (Walyunga)
Hatton and Ruprecht 2001

NB: Modelled flows from 1910 to 1969 and gauged data after 1969

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Valley Hazard

Blackwood Catchment - Land Monitor Valley Hazard

Legend
- Subcatchments
- No Hazard
- Valley Hazard

Kilometers
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Predicted peak flows of the Blackwood at Darradup with January 1982 rainfall (Cyclone Bruno)
Hatton and Ruprecht (2001)

Calibration
Prediction: Scenario 1 - Salt-affected land area doubles
Prediction: Scenario 2 - Salt-affected land area trebles
Prediction: Scenario 3 - Salt-affected land area quadruples
Major catchments of the Avon River Basin

Ali et al. (2009)

Total area
~116,600 km²
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% reduction in annual flow if rainfall is 10 and 20% less

Based on data from Ali et al. (2009)

10% rainfall reduction compared with 1976 to 2003

20% rainfall reduction compared with 1976 to 2003

- 3 to 4 times reduction
- 3+ times reduction

Walyunga
Northam
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10% rainfall reduction compared with 1976 to 2003

20% rainfall reduction compared with 1976 to 2003

Based on data from Ali et al. (2009)
Groundwater levels and surface water yields in the Darling Range
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Annual rainfall and inflow into Perth dams
Runoff is affected by climate and other factors

Yearly rainfall at Jarrahdale

Annual Total
1911 to 1974 (1251mm)
1975 to 2009 (1047mm)
1997 to 2009 (1003mm)

16% reduction

Yearly streamflow for major surface water sources - IWSS

Annual Total
1911 to 1974 (338GL)
1975 to 2009 (151GL)
1997 to 2009 (107GL)

55% reduction

Note: A year is taken as May to April (Data courtesy of the Water Corporation)
Declining groundwater levels in Darling Range catchments
CSIRO 2009

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Groundwater trend
Petrone et al. 2010

- Increasing annual amplitude
- Decreasing groundwater depths
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**Table 1. Annual Rainfall and Inflow Statistics Since the 1950s for Major Perth Water Supply Reservoirs**

<table>
<thead>
<tr>
<th>Site</th>
<th>Change Point Year</th>
<th>Change Point P</th>
<th>Linear Slope (mm yr⁻¹)</th>
<th>Mann Kendall Slope P</th>
<th>Pre-Change Point Flow (mm)</th>
<th>Post-Change Point Flow (mm)</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Churchman (Armadale)</td>
<td>1969</td>
<td>&lt;0.0001</td>
<td>-8.9</td>
<td>&lt;0.0001</td>
<td>164</td>
<td>113</td>
<td>-42</td>
</tr>
<tr>
<td>Helena</td>
<td>1975</td>
<td>&lt;0.001</td>
<td>-3.4</td>
<td>&lt;0.0001</td>
<td>154</td>
<td>46</td>
<td>-52</td>
</tr>
<tr>
<td>Canning</td>
<td>1975</td>
<td>&lt;0.001</td>
<td>-4.9</td>
<td>&lt;0.0001</td>
<td>154</td>
<td>46</td>
<td>-52</td>
</tr>
<tr>
<td>Sorrentine</td>
<td>1975</td>
<td>&lt;0.01</td>
<td>-4.2</td>
<td>&lt;0.0001</td>
<td>154</td>
<td>46</td>
<td>-52</td>
</tr>
<tr>
<td>Stirling (Wokalup)</td>
<td>1975</td>
<td>&lt;0.0001</td>
<td>-3.8</td>
<td>&lt;0.0001</td>
<td>154</td>
<td>46</td>
<td>-52</td>
</tr>
<tr>
<td>Churchman</td>
<td>1969</td>
<td>&lt;0.0001</td>
<td>-1.6</td>
<td>&lt;0.0001</td>
<td>154</td>
<td>46</td>
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<tr>
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<td>-1.0</td>
<td>&lt;0.0001</td>
<td>154</td>
<td>46</td>
<td>-52</td>
</tr>
</tbody>
</table>

**Table 2. Inflow and Streamflow Trend Analysis From 1989 to 2008 for Perth Water Supply and Darling Plateau Catchments**

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Area (ha)</th>
<th>Map</th>
<th>Change Point Year</th>
<th>Change Point P</th>
<th>Linear Slope (mm yr⁻¹)</th>
<th>Mann Kendall Slope P</th>
<th>Pre-Change Flow (mm)</th>
<th>Post-Change Flow (mm)</th>
<th>Change (%)</th>
<th>No-Flow Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jane</td>
<td>73</td>
<td>C1</td>
<td>2001</td>
<td>&lt;0.01</td>
<td>-8.0</td>
<td>277</td>
<td>164</td>
<td>-135</td>
<td>168</td>
<td>0</td>
</tr>
<tr>
<td>Waterfall Gully</td>
<td>9</td>
<td>C7</td>
<td>1991</td>
<td>&lt;0.0001</td>
<td>-9.8</td>
<td>&lt;0.0001</td>
<td>239</td>
<td>108</td>
<td>-55</td>
<td>0</td>
</tr>
<tr>
<td>Seldom Seen</td>
<td>7</td>
<td>C7</td>
<td>1991</td>
<td>&lt;0.0001</td>
<td>-10.0</td>
<td>177</td>
<td>54</td>
<td>-70</td>
<td>55</td>
<td>0</td>
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<tr>
<td>Waihi River</td>
<td>81</td>
<td>C4</td>
<td>2001</td>
<td>&lt;0.05</td>
<td>-0.05</td>
<td>177</td>
<td>54</td>
<td>-70</td>
<td>55</td>
<td>0</td>
</tr>
<tr>
<td>Stirling (Wokalup)</td>
<td>34</td>
<td>C4</td>
<td>2001</td>
<td>&lt;0.0001</td>
<td>-0.05</td>
<td>177</td>
<td>54</td>
<td>-70</td>
<td>55</td>
<td>0</td>
</tr>
<tr>
<td>Red Park</td>
<td>22</td>
<td>C5</td>
<td>1998</td>
<td>&lt;0.001</td>
<td>-11.4</td>
<td>&lt;0.0001</td>
<td>243</td>
<td>106</td>
<td>-56</td>
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<td>Warrin</td>
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<td>C5</td>
<td>-</td>
<td>&lt;0.0001</td>
<td>-12.6</td>
<td>&lt;0.0001</td>
<td>243</td>
<td>106</td>
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<td>Canning West</td>
<td>2.1</td>
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<td>-</td>
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<td>-12.6</td>
<td>&lt;0.0001</td>
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<tr>
<td>Donna</td>
<td>0.9</td>
<td>C9</td>
<td>1991</td>
<td>&lt;0.01</td>
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<td>&lt;0.0001</td>
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<td>Carabou West</td>
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<td>Red Park</td>
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<td>1998</td>
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<td>&lt;0.0001</td>
<td>218</td>
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<td>Waterfall Gully</td>
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<td>-56</td>
<td>0</td>
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<td>Waihi River</td>
<td>17</td>
<td>C4</td>
<td>-</td>
<td>&lt;0.05</td>
<td>-11.5</td>
<td>&lt;0.0001</td>
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<td>&lt;0.0001</td>
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<td>106</td>
<td>-56</td>
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<td>Wooroloo</td>
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<td>-10.0</td>
<td>&lt;0.0001</td>
<td>240</td>
<td>106</td>
<td>-56</td>
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<td>Canning</td>
<td>4</td>
<td>C9</td>
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<td>&lt;0.0001</td>
<td>-10.0</td>
<td>&lt;0.0001</td>
<td>240</td>
<td>106</td>
<td>-56</td>
<td>0</td>
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<td>Canning</td>
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<td>C9</td>
<td>-</td>
<td>&lt;0.0001</td>
<td>-10.0</td>
<td>&lt;0.0001</td>
<td>240</td>
<td>106</td>
<td>-56</td>
<td>0</td>
</tr>
<tr>
<td>Stirling</td>
<td>251</td>
<td>C9</td>
<td>-</td>
<td>&lt;0.05</td>
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<td>&lt;0.0001</td>
<td>215</td>
<td>131</td>
<td>-59</td>
<td>0</td>
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</tbody>
</table>

**1950-2008 Rainfall and Runoff Change Point 1969/1975**

**1989-2008 Runoff Only Change Point 1997/2001**

Petrone KC, JD Hughes, TG Van Niel, RP Silberstein 2010

*Geophysical Research Letters*

The effect of climate change on South West WA hydrology
Equilibrium shift in Drying Climate?

- Reduction in saturated area (groundwater discharge zone) and “saturation excess overland flow”
- Reduction in groundwater baseflow
- Reduction in interflow

after Croton and Bari 2001

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Projected change in mean annual runoff relative to the historical climate (1976 – 2007)

- Runoff declines by 25% under median future climate and 42% under dry climate
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Percent decline in runoff in all basins

- Decline under a continuation of the recent climate (1997 to 2007) is greatest from Gingin to Collie
- Decline under a median future climate is more uniform indicating that southern basins may ‘catch up’ in the drying trend
Groundwater levels in the Perth Basin
Topography

- Short streams that arise in the Darling Ranges are fresh
- Darling Fault separates Perth Basin from Darling Plateau
- Coastal plains are flat and low lying – Swan Coastal Plain; Scott Coastal Plain; South Coast
- Perth Basin Plateaux are higher in elevation
Land cover

- Surface water catchments are mainly forested.
- About 60% of the Perth Basin is cleared about 56% of this being under dryland agriculture.
- The uncleared areas include coastal areas north of Perth, the Gnangara Mound and the Blackwood Plateau.
Land cover likely to affect recharge / discharge

Groundwater assessment areas
• 56% dryland agriculture
• 38% native vegetation
• 6% plantations, urban, irrigated, open water
Maximum depth of the watertable in the southern half of the Perth Basin in 2007

- Coloured areas are potential GDEs if not cleared
- Coastal plain soils have very shallow watertables except Gnangara and Spearwood Dunes
- Plateaux areas mainly have deep watertables

<table>
<thead>
<tr>
<th>Depth of Water Table from Soil Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3 m</td>
</tr>
<tr>
<td>3 - 6 m</td>
</tr>
<tr>
<td>6 - 10 m</td>
</tr>
<tr>
<td>&gt; 10 m</td>
</tr>
</tbody>
</table>

22%  14%  10%  46%
Change in groundwater levels between 2008 and 2030 under climate and development scenarios

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Surface water - groundwater interactions
Gaining and losing sections in Gingin Brook
CSIRO 2009
Amount and proportion of baseflow will change as both streamflow and groundwater levels reduce.

Current base flow is about two-thirds of streamflow. Under a dry future climate baseflow may reduce.
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Collie groundwater basin level changes between 2008 and 2030

Groundwater levels are less affected near rivers

The effect of climate change on South West WA hydrology
Conclusions 1

- The SW of WA experienced a climate shift in about 1975 with rainfall amounts and intensities reducing. The accompanying rise in temperatures may be contributing to drier soils.
- Groundwater levels in the northern and central Wheatbelt are mainly falling and the rate of salinisation has slowed.
- Flooding in the Wheatbelt was projected to increase because of salinisation and increased rainfall intensities.
- However runoff and flooding have decreased and are projected to decrease further as catchments dry and if intensities remain low or fall further.
- There have been major reductions in streamflows in northern jarrah forest streams – initially due to the reduced rainfall and more recently due to lower groundwater levels resulting in changes in runoff processes.
- This trend is projected to continue to more southerly streams.
Conclusions 2

• Groundwater levels under the Perth Basin are falling under perennial vegetation and in the north but rising under dryland agriculture in most areas
• Levels are expected to fall further in future or rise more slowly under dryland agriculture in the south and central parts
• Where streams cross the Perth and Collie Basins they currently gain fresh groundwater
• These trends may reverse and brackish or saline streamflow may contaminate nearby fresh aquifers
• Water dependent ecosystems have already been badly impacted by climate change and this is likely to worsen
• Hydrological processes need to be understood if future projections are to reflect these changes
Possible areas for post graduate study

• Surface water – groundwater interactions under climate change (hydrology, isotopes to separate flow components, modelling)

• Managing vegetation to influence recharge and runoff in a drier climate – e.g. Gnangara Mound post-pine areas

• The influence of lower rainfall, higher temperatures, higher potential evapotranspiration and more CO₂ on plants and hydrology (i.e. vegetation is also changing as a response to climate change so hydrological impacts are complex)

• Methods of reclaiming saline Wheatbelt valleys where groundwater levels have receded

• Ways of retaining important water dependent ecosystems in a drying climate (e.g. use of stormwater and treated wastewater to augment natural flows)
Questions?