Ecohydrology of Vegetated Catchments Under Climate Change

Tim McVicar, Randall Donohue, Mike Roderick*, Tom Van Niel and Li Lingtao

26 June 2012 (* = ANU)
Catchment responses to climate change
($E_a =$ actual evaporation and $Q =$ stream flow)

<table>
<thead>
<tr>
<th></th>
<th>Energy-limited</th>
<th>Water-limited</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$E_a$</td>
<td>$Q$</td>
</tr>
<tr>
<td></td>
<td>Tropics</td>
<td>High latitudes/altitudes</td>
</tr>
<tr>
<td>$P$ ↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>$E_p$ ↓</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>(e.g., ↓wind, ↓$R_n$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$[CO_2]$ ↑</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Expect a differential response to based on catchment location
Use stream flow and remotely sensed vegetation cover (and $E$) to assess if expectations are matched by observations
Australia-wide trends in P and fPAR 1981-2006

Donohue, McVicar and Roderick (2009) Global Change Biology

Precipitation trend
+7%

Trend in total fPAR
+8%

Trend in persistent fPAR
+21%

Trend in recurrent fPAR
-7%
Budyko’s Framework: different locations, different responses

- The climatic Dryness Index (Φ) is the ratio of water demand to water supply; \( \Phi = \frac{E_p}{P} \)
- The climatic Evaporative Index (ε) is the ratio actual evaporation to precipitation; \( \epsilon = \frac{E_a}{P} \)
Where does the Murray-Darling Basin’s runoff originate?

Donohue, Roderick & McVicar (2011) J Hydrology – identify runoff producing areas

Annual Runoff

Runoff proportion by area

$R$ is modelled using Budyko’s curve and assumes no change in soil water storage

10% of the land area produces ~ 45% of total runoff

20% of the land area produces ~ 60% of total runoff
Runoff sensitivity to CC using Budyko framework

Roderick and Farquhar (2011) Water Resources Research - developed method & applied in a lumped manner for the MDB. An effective and transparent (+ repeatable) approach

Choudhury formulation

\[ R = P - \frac{PE_p}{P^n + E_p^n}^{1/n} \]

Essentially

\[ R = f(P, E_p, n) \]

Sensitivity of Runoff

\[ dR = \frac{\partial R}{\partial P} dP + \frac{\partial R}{\partial E_p} dE_p + \frac{\partial R}{\partial n} dn \]

Influence of 3 terms

\[ \frac{\partial R}{\partial P} = 1 - \frac{E}{P} \left( \frac{E_p^n}{P^n + E_p^n} \right) \]

\[ \frac{\partial R}{\partial E_p} = -E \left( \frac{P^n}{P^n + E_p^n} \right) \]

\[ \frac{\partial R}{\partial n} = -E \frac{n}{n} \left( \frac{\ln(P^n + E_p^n)}{n} - \frac{P^n \ln P + E_p^n \ln E_p}{P^n + E_p^n} \right) \]
Runoff sensitivity to CC using Budyko framework in the MDB

Donohue, Roderick & McVicar (2011) J Hydrology – spatially apply the sensitivity approach to Budyko framework the MDB

\[ \frac{\partial R}{\partial E_p} \text{ mm.y}^{-1}/\text{mm.y}^{-1} \]

\[ \frac{\partial R}{\partial P} \text{ mm.y}^{-1}/\text{mm.y}^{-1} \]

\[ \frac{\partial R}{\partial n} \text{ mm.y}^{-1} \]
Budyko’s Framework: different locations + different times, leads to different responses

- The climatic Dryness Index ($\Phi$) is the ratio of water demand to water supply; $\Phi = \frac{E_p}{P}$
- The climatic Evaporative Index ($\varepsilon$) is the ratio actual evaporation to precipitation; $\varepsilon = \frac{E_a}{P}$
Extending Budyko Framework: (Randall introduced BCP y/day)

Account for importance of seasonal dynamics:
1) Precip and ETp
2) Vegetation activity (roots and phenology)
3) Storage (both soil and GW)
Runoff sensitivity in the MDB using the BCP model

Donohue, Roderick & McVicar (2012) J Hydrology – developed BCP model (& inputs) and spatially assessed sensitivity of runoff to changes in inputs

\[ \frac{\partial R}{\partial P} \quad \text{mm.y}^{-1}/\text{mm.y}^{-1} \]

\[ \frac{\partial R}{\partial E_p} \quad \text{mm.y}^{-1}/\text{mm.y}^{-1} \]

\[ \frac{\partial R}{\partial Z_r} \quad \text{mm.y}^{-1}/\text{mm} \]

\[ \frac{\partial R}{\partial \alpha} \quad \text{mm.y}^{-1}/\text{mm} \]
• Penman (1948) combined the radiative and aerodynamic components
• To date CC related evaporative trends had strong focus on Ta, Rad and Precip
• From 148 regional studies average wind speed trend $= \sim -0.014 \text{ m s}^{-1} \text{ a}^{-1}$
• Assuming a linear trend this is a $-0.7 \text{ m s}^{-1}$ decline over the last 50 years
• Trend of $\text{ET}_a$ depends on limit to $\text{ET}_a$ ($\text{P}$ in WL areas, $\text{P}$ and $\text{ET}_p$ in EL areas)
Most plausible drivers of near-surface wind speed trends are:

i. increased roughness (Vautard et al., (2010) NGS);

ii. widening of the Hadley cell (Seidel et al., (2010) NGS); and

iii. increased aerosols (Jacobson and Kaufman (2006) GRL)

1982-1999 AVHRR NDVI trends
Beck et al (2011) RSE

GIMMS best able to track trends in 1424 Landsat pairs located worldwide
Observed Global Trends in $E_{\text{pan}}$


Globally 58 $E_{\text{pan}}$ studies reviewed with average trend = $-3.2$ mm a$^{-2}$

Only Class A pan studies = $-3.8$ mm a$^{-2}$ (n =37)

Studies using more than 10 Class A pans = $-2.6$ mm a$^{-2}$ (n =24)

Meteorological data forced modelled $E_{\text{pan}}$ trends in line with observed $E_{\text{pan}}$ trends in both N and S hemispheres; based on Roderick et al., (2007) GRL
Climate Non-Stationarity: $E_p$ Penman Trends (1981-2006)

Donohue, McVicar and Roderick (2010) J Hydrology

<table>
<thead>
<tr>
<th>Area</th>
<th>Total</th>
<th>Trends of Penman potential evapotranspiration (mm yr$^{-2}$)</th>
<th>Due to $R_n$</th>
<th>Due to $u$</th>
<th>Due to $e_a$</th>
<th>Due to $T_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(mm yr$^{-1}$)</td>
<td>Total</td>
<td>Due to $u$</td>
<td>Due to $R_n$</td>
<td>Due to $T_a$</td>
<td>Due to $e_a$</td>
</tr>
<tr>
<td>EHYZ</td>
<td>1248</td>
<td>-0.5</td>
<td>-0.3</td>
<td>-1.1</td>
<td>-0.5</td>
<td>+1.4</td>
</tr>
<tr>
<td>VHYZ</td>
<td>1379</td>
<td>-0.1</td>
<td>-0.5</td>
<td>-0.7</td>
<td>-0.5</td>
<td>+1.6</td>
</tr>
<tr>
<td>sHYZ</td>
<td>1502</td>
<td>-0.3</td>
<td>-0.6</td>
<td>-1.2</td>
<td>-0.4</td>
<td>+1.9</td>
</tr>
<tr>
<td>nHYZ</td>
<td>1739</td>
<td>+2.0</td>
<td>+0.9</td>
<td>-0.7</td>
<td>-0.1</td>
<td>+1.9</td>
</tr>
<tr>
<td>MDB</td>
<td>1977</td>
<td>+0.4</td>
<td>-1.7</td>
<td>-0.9</td>
<td>+0.7</td>
<td>+2.3</td>
</tr>
<tr>
<td>All Aus</td>
<td>2340</td>
<td>-0.8</td>
<td>-0.6</td>
<td>-1.3</td>
<td>-0.4</td>
<td>+1.5</td>
</tr>
</tbody>
</table>

These southern water yielding zones provide 50% of MDB Q

Different response to a changing climate depending on the location of the catchment / study area

There is not one rule for all locations for all time periods (responses change in space and time)

**Facing climate change not only global warming**
Class A pan Evaporation: Attribution of the trends


- **PenPan trends ($E_{pp}$)**
- **$E_{pp}$ due to Radiometric**
- **$E_{pp}$ due to Aerodynamic**
- **Aero due to Wind**
- **Aero due to VPD**
- **Aero due to $T_a$**
Ta \uparrow; \text{Relative Humidity} \sim \text{Constant}; \text{Specific Humidity} (q) \uparrow

\[ q = \frac{g \, H_2O}{\text{kg wet air}} \text{ and the mixing ratio } = \frac{g \, H_2O}{\text{kg dry air}} \]

With much of the land-surface being EL, where is the water the coming from?

Intensification of the global hydrological cycle (Huntington 2006 J Hydrology) and are there greater rates of evaporation over oceans due to increased heat storage and wind speeds over the oceans?

Wentz et al (2007) Science: 1987-2006, average trend + 0.008 m s\(^{-1}\) a\(^{-1}\)
Thank you