Water-use in riparian cottonwood forests

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River floodplains: a nexus of regional ecological interactions & biodiversity

Hauer et al. (2016) Science Advances 2: e1600026
River floodplains: a nexus of regional ecological interactions & biodiversity

River flows and health of floodplain forests

Hauer et al. (2016) Science Advances 2: e1600026
The river floodplain as affected by human structures and disturbance

Hauer et al. (2016) Science Advances 2: e1600026
Dams, Environmental Flows and Floodplain Ecosystem Health: South Saskatchewan River Basin

Montana, USA
Effects of Dams on River Flows and Health of Floodplain Ecosystems

Oldman River  dramatic restoration with Functional Flows
Waterton River  recovery with Functional Flows
St. Mary River  irreversible impacts of dam
St. Mary River (Upstream of water diversions)

Photo: S.B. Rood
St. Mary River: Down-stream of water diversions

Photo: S.B. Rood

St. Mary River: Down-stream of water diversions

Photo: S.B. Rood
Flow requirements for healthy cottonwood ecosystems

River Discharge = Flow Rate (m$^3$/s)

1. High flows for river channel and point-bar development
2. Riparian recruitment: Post-peak ramping for cottonwood seedling survival
3. Sufficient flow for mature tree needs in late summer
Store as much as possible, for as long as possible.

Pre-winter draw-down
Store as much as possible, for as long as possible

Pre-winter draw-down
River flows and health of floodplain ecosystems

Questions: Oldman River Case Study

How much water is used by a cottonwood riparian ecosystem during evapo-transpiration (May-Sept)?

What proportion of evapo-transpiration is supplied by: (i) alluvial groundwater and (ii) precipitation sources?
Shallow roots absorb nutrient-rich soil moisture from precipitation.

Deep roots acquire water from the capillary fringe above the groundwater table, which rises and falls with the river stage.
River flows and health of floodplain ecosystems

Research Approaches:

• Tracing of water sources used in ET with stable isotope techniques

• Measuring ecosystem ET with the eddy covariance flux technique
Cottonwood Species:

- *Populus deltoides*
- *Populus angustifolia*
- *Populus trichocarpa*

Cottonwood Tree Size and Tree Density

- Height: $18 \pm 5 \text{ m}$
- DBH: $37 \pm 15 \text{ cm}$
- Density: $276 \pm 300 \text{ stems hectare}^{-1}$
- LAI: $1.8 \text{ m}^2 \text{ m}^{-2}$
Determining Water Sources: Stable Isotope Studies

Stable isotopes of hydrogen and oxygen in water:

\begin{align*}
\text{H}^1 & - 99.985\% \ (\text{H}_2\text{O}) \\
\text{H}^2 & - 0.015\% \ (\text{H}_2\text{O}) \\
\text{O}^{16} & - 99.759\% \ (\text{H}_2\text{O}^{16}) \\
\text{O}^{18} & - 0.204\% \ (\text{H}_2\text{O}^{18})
\end{align*}

\[ \delta = \left( \frac{R_{\text{sample}}}{R_{\text{standard}}} \right) - 1 \times 1000 \ (\text{‰}) \]

where \( R \) is \( ^2\text{H} / ^1\text{H} \) or \( ^{18}\text{O} / ^{16}\text{O} \)

Isotope composition of stem water reflects isotope composition of water sources available to the plant (no fractionation during plant water uptake)

Determine water sources used by comparing the stable isotope compositions of stem water and water sources (summer precipitation, groundwater)
Calgary Precipitation (1992-2001)

(a) $\delta^2$H (per mil)

(b) $\delta^{18}$O (per mil)

Time (day of year)

Calgary Meteoric Water Line

$y = 7.674x - 0.341$

$r^2 = 0.964$

Peng et al. (2004) Tellus 56B: 147-159
More Deuterium ($^2$H)

Less Deuterium ($^2$H)

Lethbridge (2014)
Lethbridge (2014-2016)

\[ y = 6.854x - 13.839 \]

\[ r^2 = 0.963 \]
Lethbridge (2014-2016)

\[ y = 6.854x - 13.839 \]
\[ r^2 = 0.963 \]

\[ y = \sim 4x \]
Diagram of hypothesized primary water sources. Deep roots of trees can access groundwater, while shallow-rooted understory plants are dependent on precipitation. (diagram from Scott et al. 2003).
**Symphoricarpos occidentalis**  
(snowberry)  
*Height = 0.8 ± 0.1 m  
Shallow-rooted*

**Sherpherdia argentea**  
(buffaloberry)  
*Height = 3.1 ± 0.4 m  
Deep-rooted*
Lethbridge (2016)

\[
y = 6.694x - 20.777 \\
\text{r}^2 = 0.978
\]

\[
y = 4.636x - 63.006 \\
\text{r}^2 = 0.826
\]
River flows and health of floodplain ecosystems

Conclusions: Tracing Water Sources

• Shallow-rooted *Symphoricarpos* used only precipitation

• Deep-rooted *Shepherdia* and cottonwoods used both groundwater and precipitation

• Quantitative estimates of proportional use of contrasting water sources are complicated by evaporative enrichment of precipitation after input to soils, the wide temporal variation in precipitation isotope signals, and mixing of precipitation with stored soil water
Lethbridge Growing Season Precipitation
(compared to average ±SD during 1971-2000 (Normal))

[Bar graph showing total precipitation (mm) over time (years).]
Lethbridge Growing Season Precipitation
(compared to average ±SD during 1971-2000 (Normal))

![Bar chart showing total precipitation (mm) from May to September for different years: Normal, 2014, 2015, and 2017. The chart indicates a significant increase in precipitation in 2014 compared to normal and subsequent years.]
Comparison of daily average (± SD) air temperature and vapour pressure difference in Lethbridge, Alberta during June and July.

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2015</th>
<th>2017</th>
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</thead>
<tbody>
<tr>
<td>Air Temperature (°C)</td>
<td>21.0 ± 4.9</td>
<td>23.3 ± 4.9</td>
<td>24.7 ± 5.0</td>
</tr>
<tr>
<td>Vapour Pressure Difference (kPa)</td>
<td>1.5 ± 0.7</td>
<td>2.2 ± 0.9</td>
<td>2.5 ± 1.0</td>
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</tbody>
</table>
Floodplain Soil Water Content Integrated over 0-2.5 m depth
Oldman River Discharge
Lethbridge Cottonwood Forest (May-September)

Ecosystem Photosynthesis

Evapo-transpiration

- **2014**
  - (a) Ecosystem Photosynthesis
  - (b) Evapo-transpiration

- **2015**
  - (c) Ecosystem Photosynthesis
  - (d) Evapo-transpiration

- **2017**
  - (e) Ecosystem Photosynthesis
  - (f) Evapo-transpiration

Time (day of year)
Lethbridge Cottonwood Forest

Ecosystem Photosynthesis

GEP (g C m\(^{-2}\) day\(^{-1}\))

Time (day of year)

2014

2017
Lethbridge Cottonwood Forest (May-September)
Lethbridge Cottonwood Forest (May-September)

Represents use of Groundwater or Stored Water
Lethbridge Native Grassland (May-September)
Lethbridge Cottonwood Forest (May-September)

Represents use of Groundwater or Stored Water
Ecosystem Photosynthesis

Ecosystem Evapo-transpiration

Ecosystem Water-use Efficiency
Scaled calculations of forest ET along the Oldman River corridor

- **2014**
  - (a) ET (mm day\(^{-1}\))
  - (b) ET (% of river flow)

- **2015**
  - (c)
  - (d)
Conclusions: ET eddy flux measurements

- Floodplain ecosystem ET remained similar across 3 growing seasons with widely different precipitation and river flows
- In dry years, precipitation input was less than 50% of floodplain ecosystem cumulative ET during May-Sept
- Large soil water storage capacity and groundwater access support the high and consistent ecosystem ET
- Scaled across the river corridor, floodplain ecosystem ET consumed 1-4% of river flow, with higher relative water use late in the growing season
These analyses of cottonwood water use will help to improve Functional Flow management procedures for regulating river flow rates in southern Alberta – in order to sustain healthy riparian cottonwood ecosystems.
2016


2017


2018


Project Publications

Submitted papers


Philipsen, L.J., D.W. Pearce, S.B. Rood* Hydroclimatic drivers of the growth of riparian cottonwoods at the prairie margin: River flows, river regulation and the Pacific Decadal Oscillation. *Dendrochronologia* (favorably reviewed, under revision) (AEP, AB Innovates, NSERC)


Yang, H., S.B. Rood, L.B. Flanagan* Controls on ecosystem water-use and water-use efficiency: Insights from a comparison between grassland and riparian forest in the northern Great Plains. *Agricultural and Forest Meteorology* (submitted) (AB Innovates, CPC, NSERC, CFI)