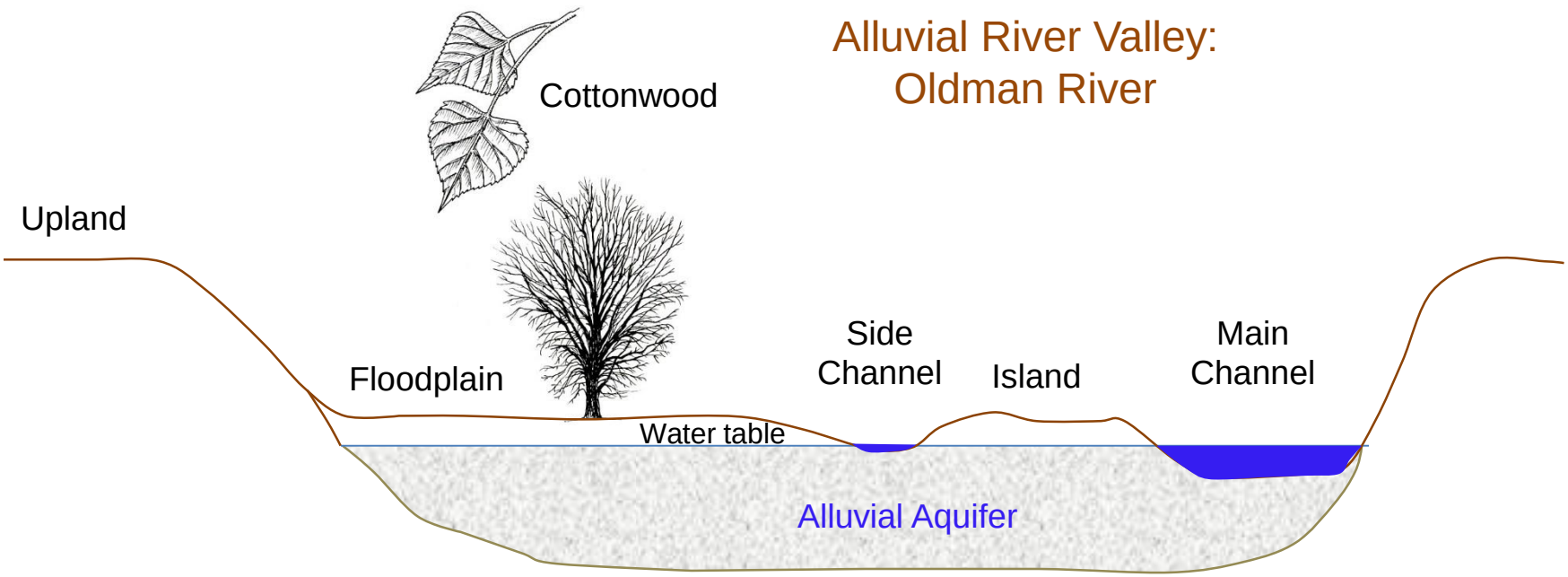
Water-use in riparian cottonwood forests

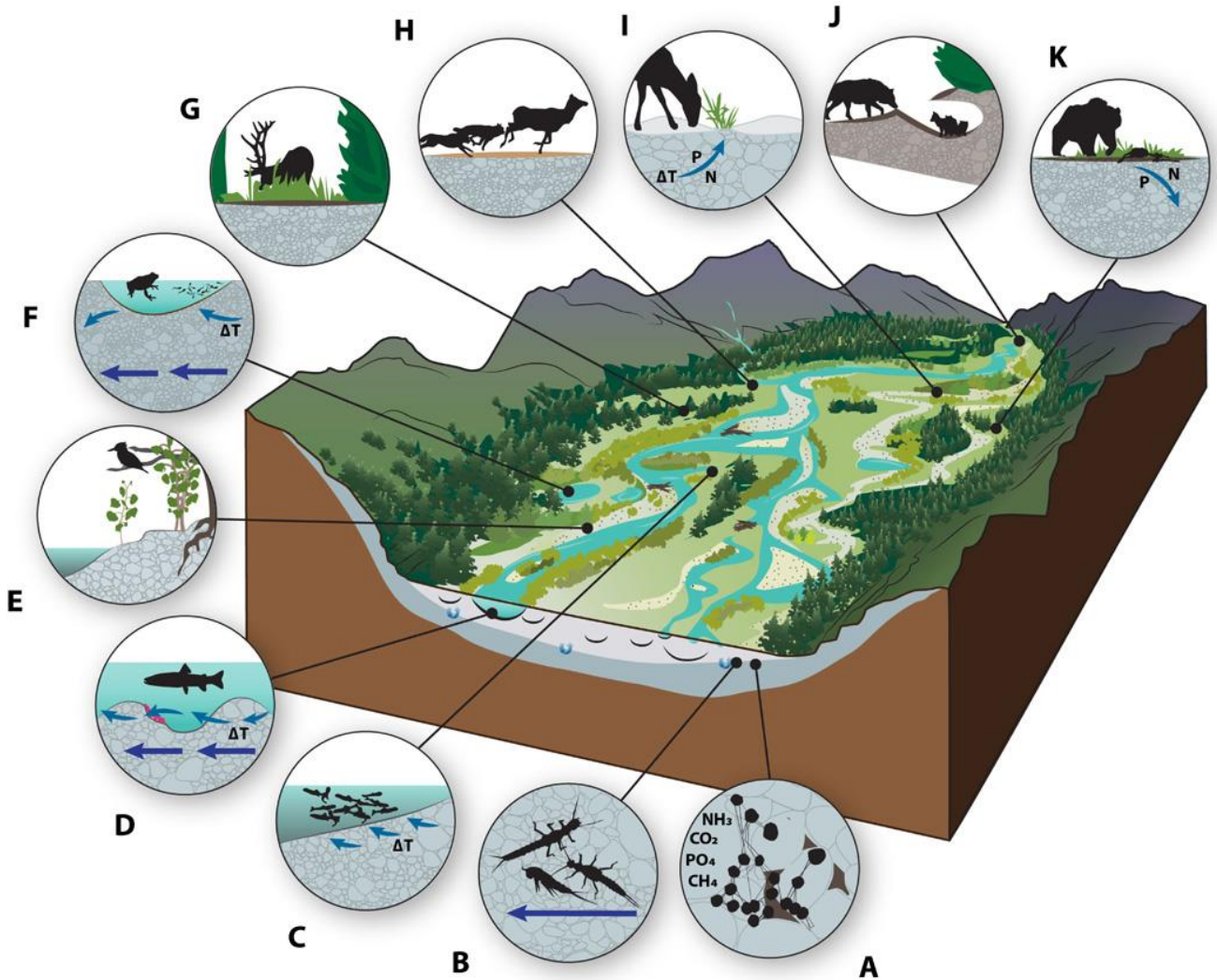
L.B. Flanagan and S.B. Rood
Department of Biological Sciences
University of Lethbridge

ALBERTA INNOVATES
Expanding Functional Flows: Floods, Floodplains and Groundwater use
NSERC CRSNG
INNOVATION.CA
CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION
ConocoPhillips Canada


Photo: S.B. Rood

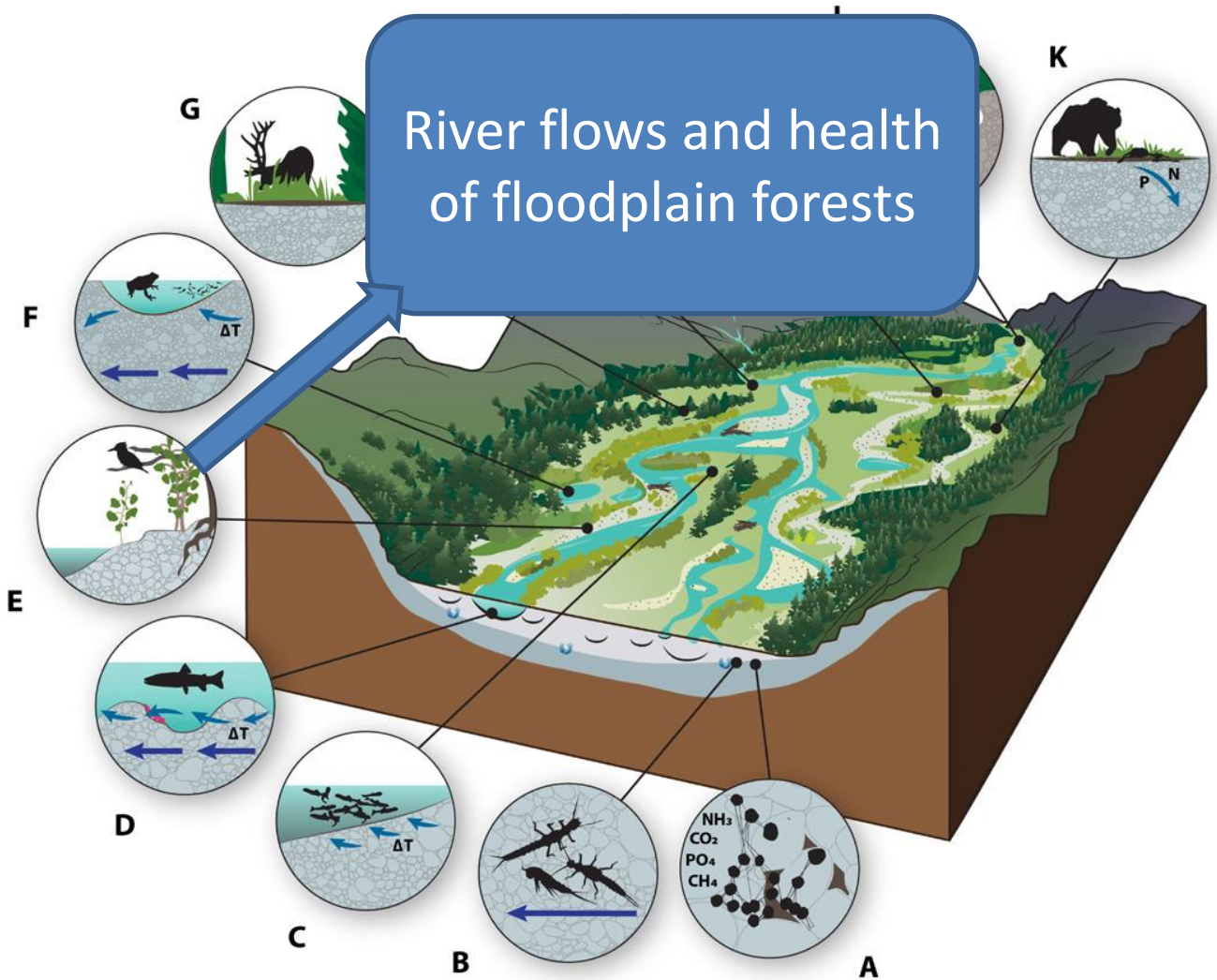

Alluvial River Valley:
Oldman River
Cottonwood
Upland
Floodplain
Side
Channel
Island
Main
Channel
Water table
Alluvial Aquifer

River floodplains: a nexus of regional ecological interactions & biodiversity



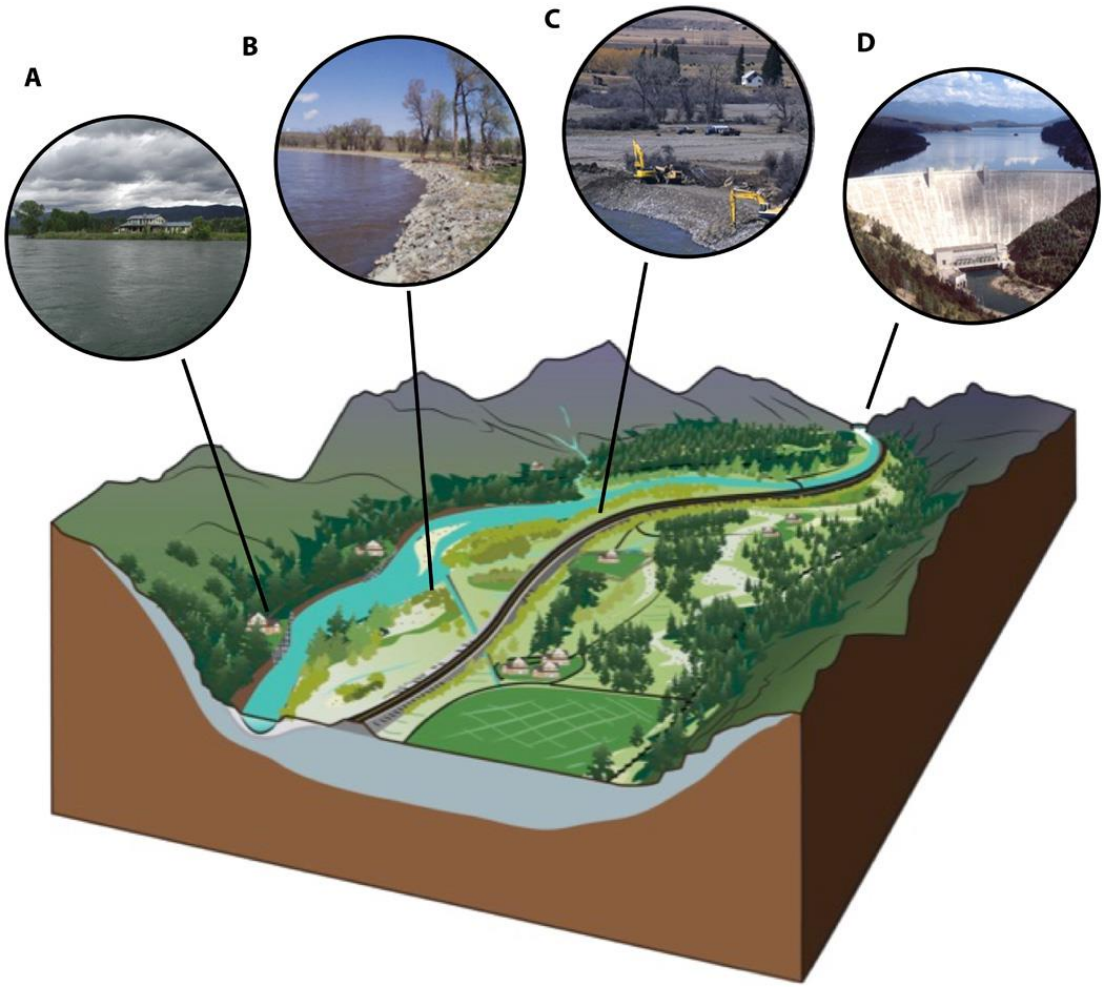
Hauer et al. (2016) Science Advances 2: e1600026

River floodplains: a nexus of regional ecological interactions & biodiversity



Hauer et al. (2016) Science Advances 2: e1600026

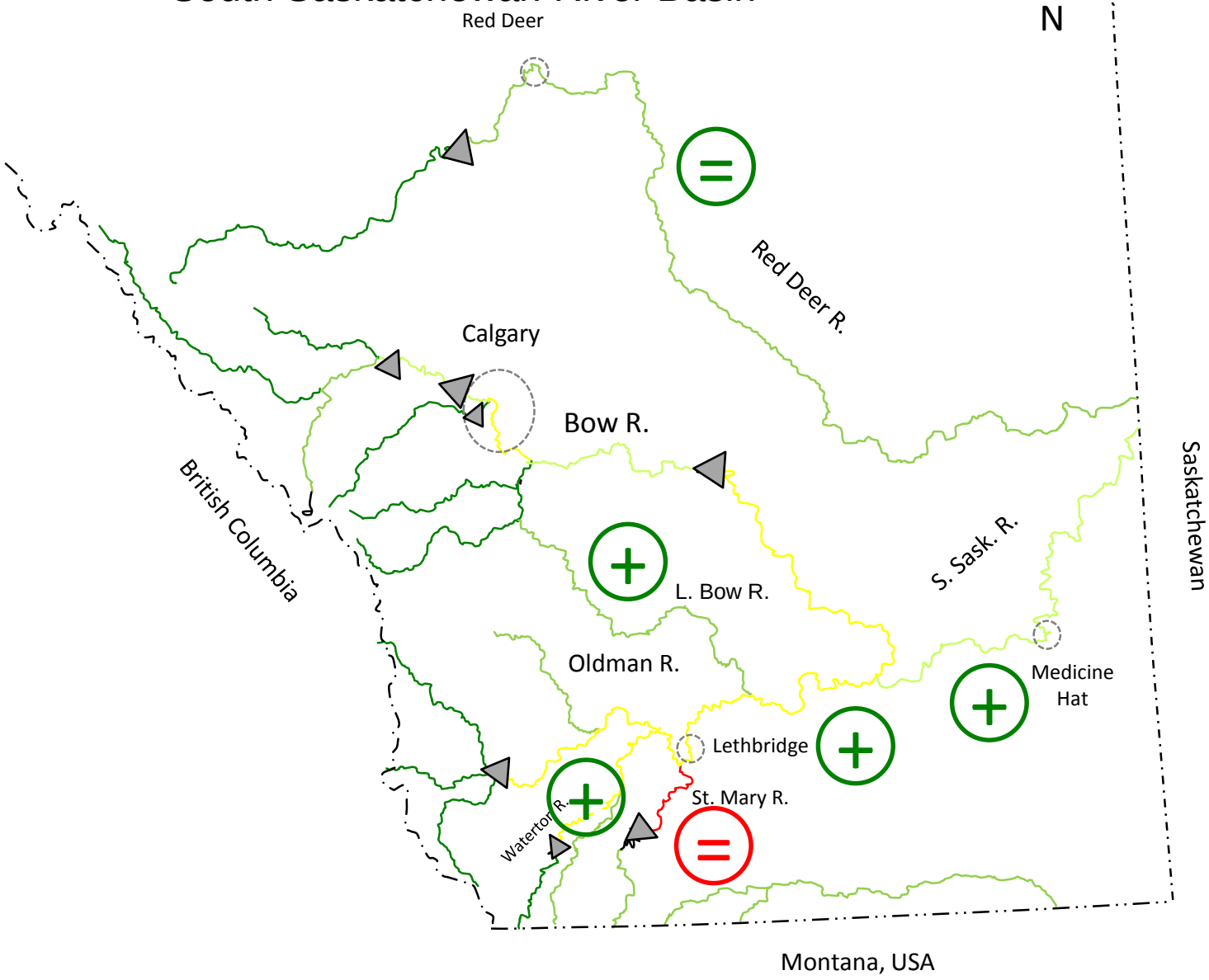
The river floodplain as affected by human structures and disturbance



Hauer et al. (2016) Science Advances 2: e1600026


Oldman River Dam
June 21, 2013

Dams, Environmental Flows and Floodplain Ecosystem Health: South Saskatchewan River Basin



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

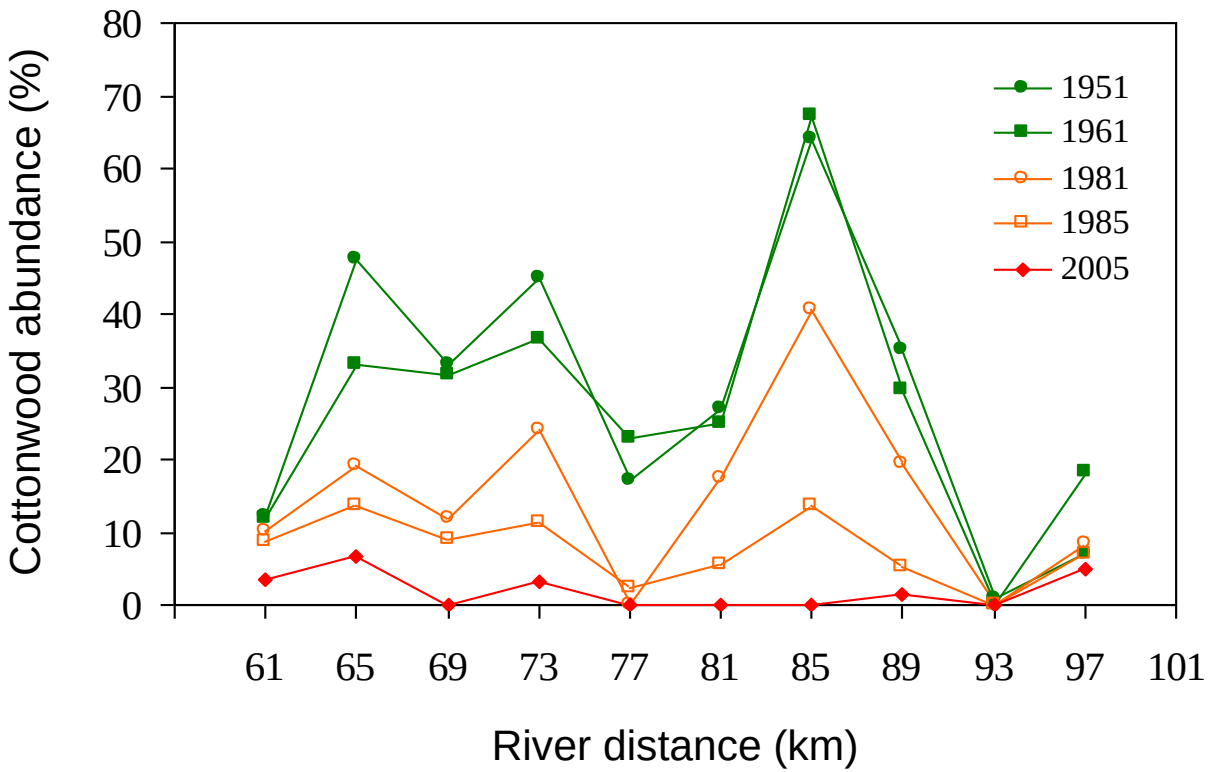
St. Mary River (Upstream of water diversions)

Photo: S.B. Rood

St. Mary River: Down-stream of water diversions

Photo: S.B. Rood

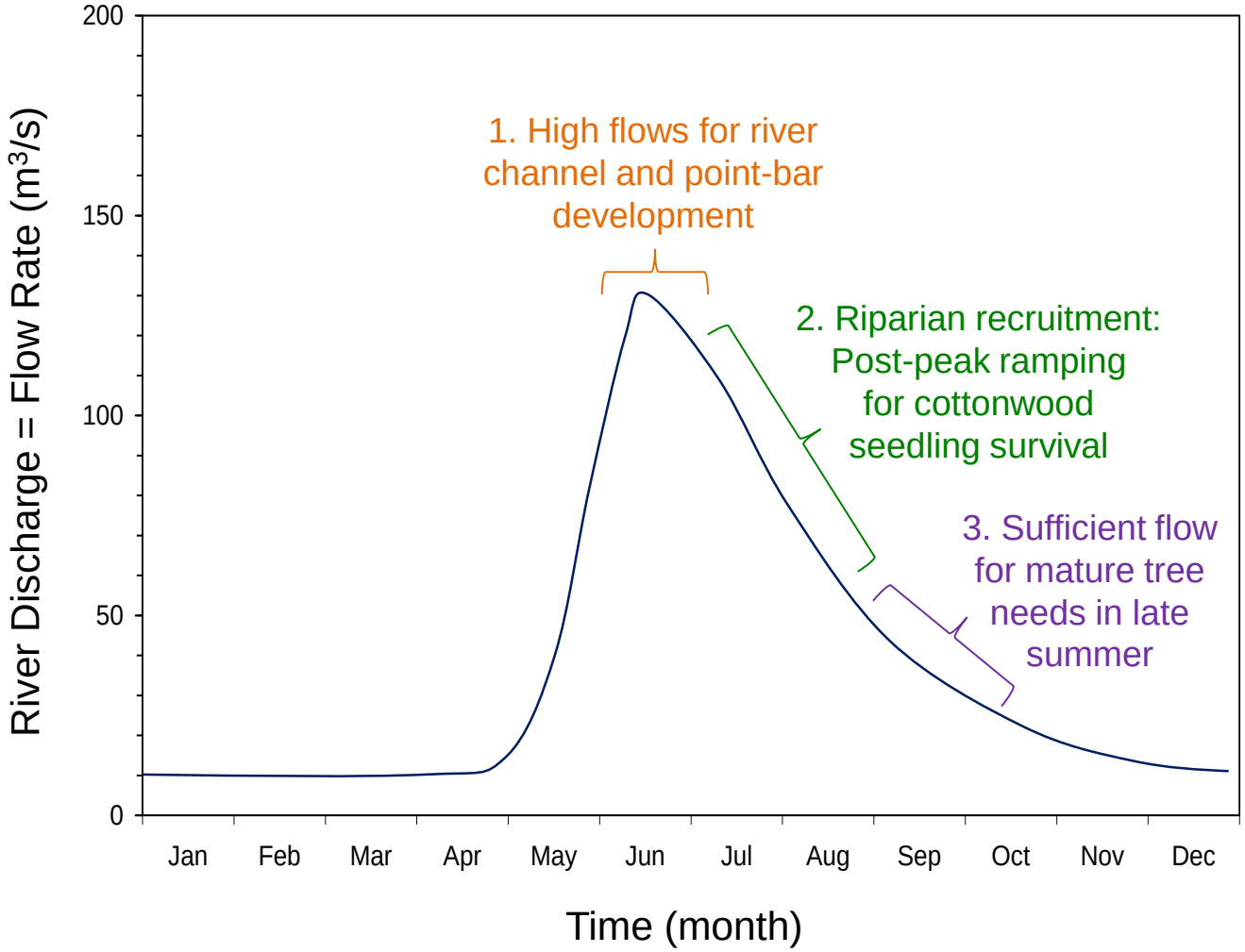
S.B. Rood et al. (1995) Instream flows and the decline of riparian cottonwoods along the St. Mary River, Alberta. Can. J. Bot. 73: 1250-1260

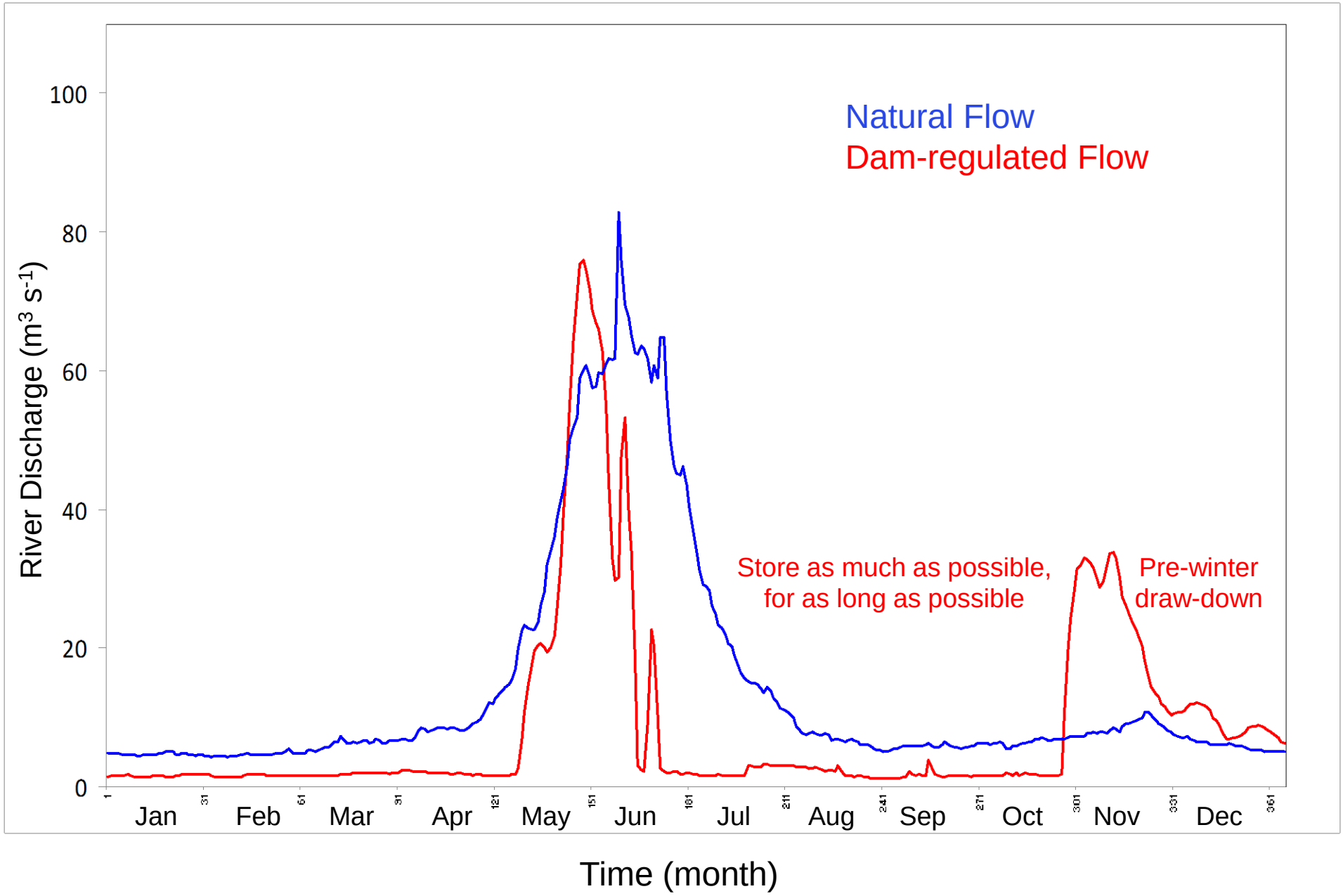


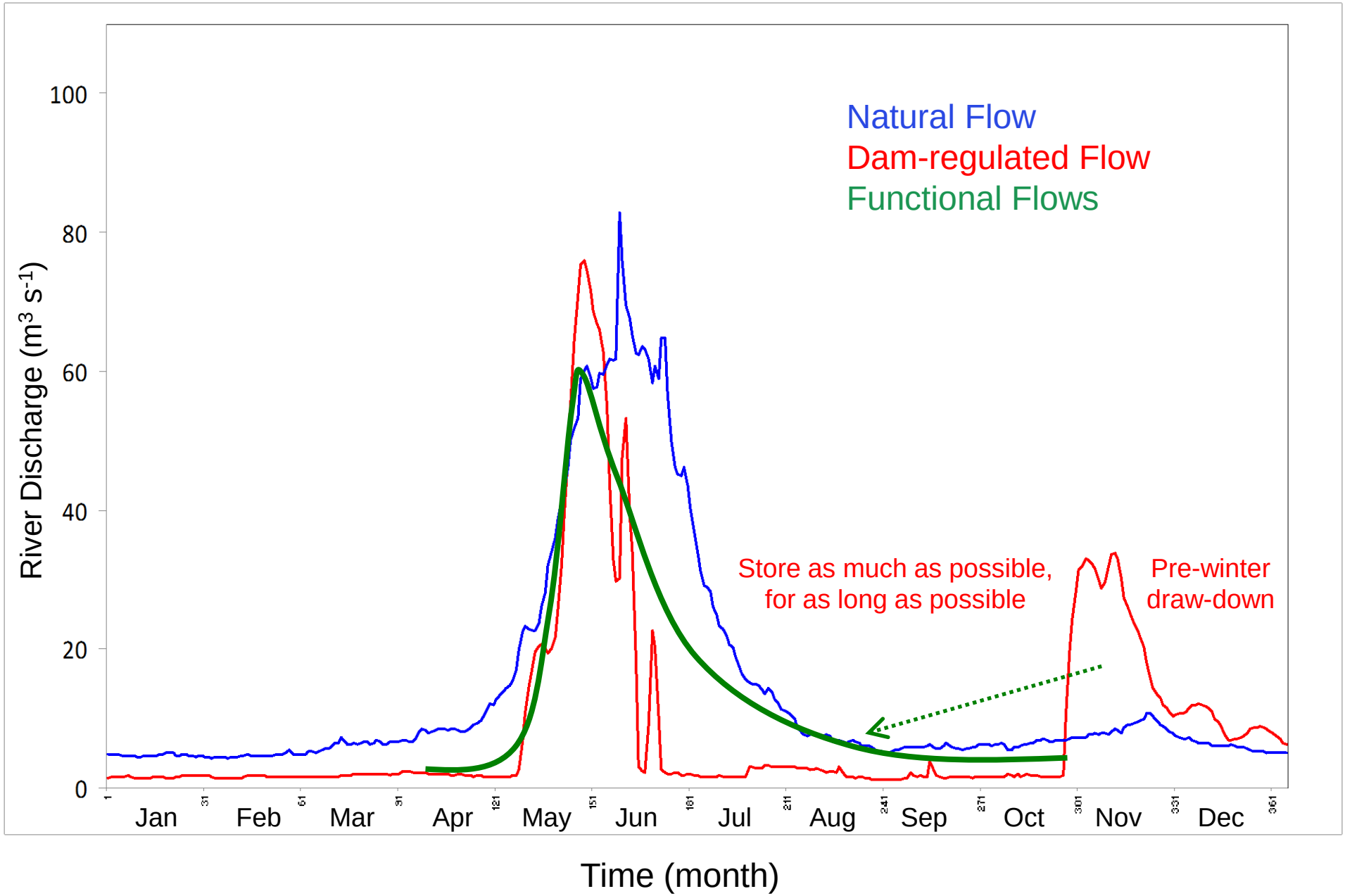
St. Mary River: Down-stream of water diversions

Photo: S.B. Rood

Flow requirements for healthy cottonwood ecosystems




Natural Flow
Dam-regulated Flow
Store as much as possible,
for as long as possible
Pre-winter
draw-down
River Discharge (m3 s-1)
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Time (month)


Natural Flow
Dam-regulated Flow
Functional Flows
Store as much as possible,
for as long as possible
Pre-winter
draw-down
River Discharge (m3 s-1)
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Time (month)

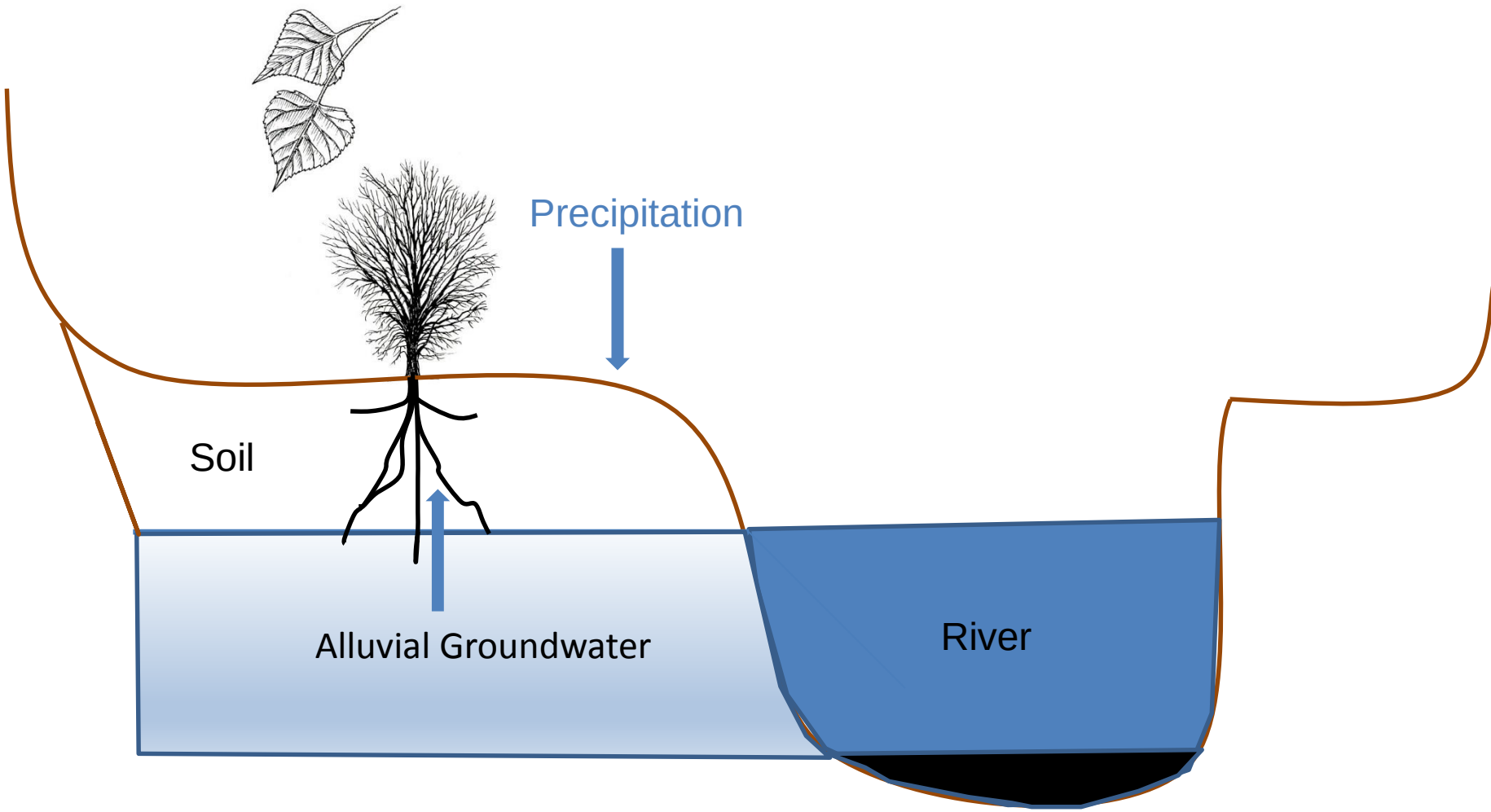
River flows and health of floodplain ecosystems

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?

Cottonwood Tree Water Sources



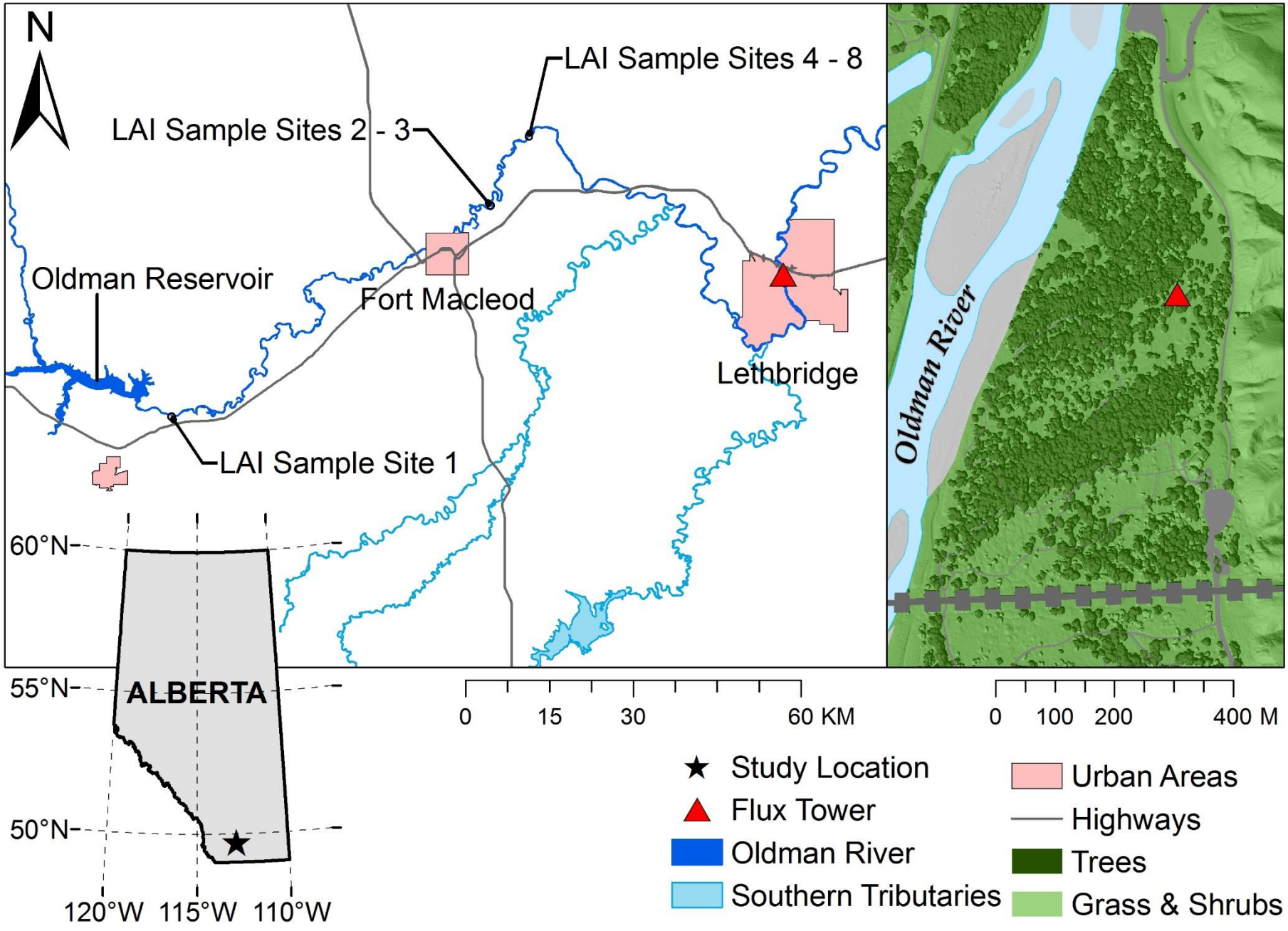
Shallow roots absorb nutrient-rich soil moisture from precipitation.

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


N
LAI Sample Sites 4 - 8
LAI Sample Sites 2 - 3
Oldman Reservoir
Fort Macleod
Lethbridge
LAI Sample Site 1
Oldman River
60°N
55°N
50°N
ALBERTA
120°W 115°W 110°W
0 15 30 60 KM
0 100 200 400 M
Study Location
Flux Tower
Oldman River
Southern Tributaries
Urban Areas
Highways
Trees
Grass & Shrubs

Cottonwood Forest in Helen Schuler Nature Center - Lethbridge, Alberta, Canada

Cottonwood Species:

Populus deltoides
Populus angustifolia
Populus trichocarpa

Cottonwood Tree Size and Tree Density

Height	18 ± 5 m
DBH	37 ± 15 cm
Density	276 ± 300 stems hectare^{-1}
LAI	1.8 m^{2} m^{-2}

Determining Water Sources: Stable Isotope Studies

Stable isotopes of hydrogen and oxygen in water:

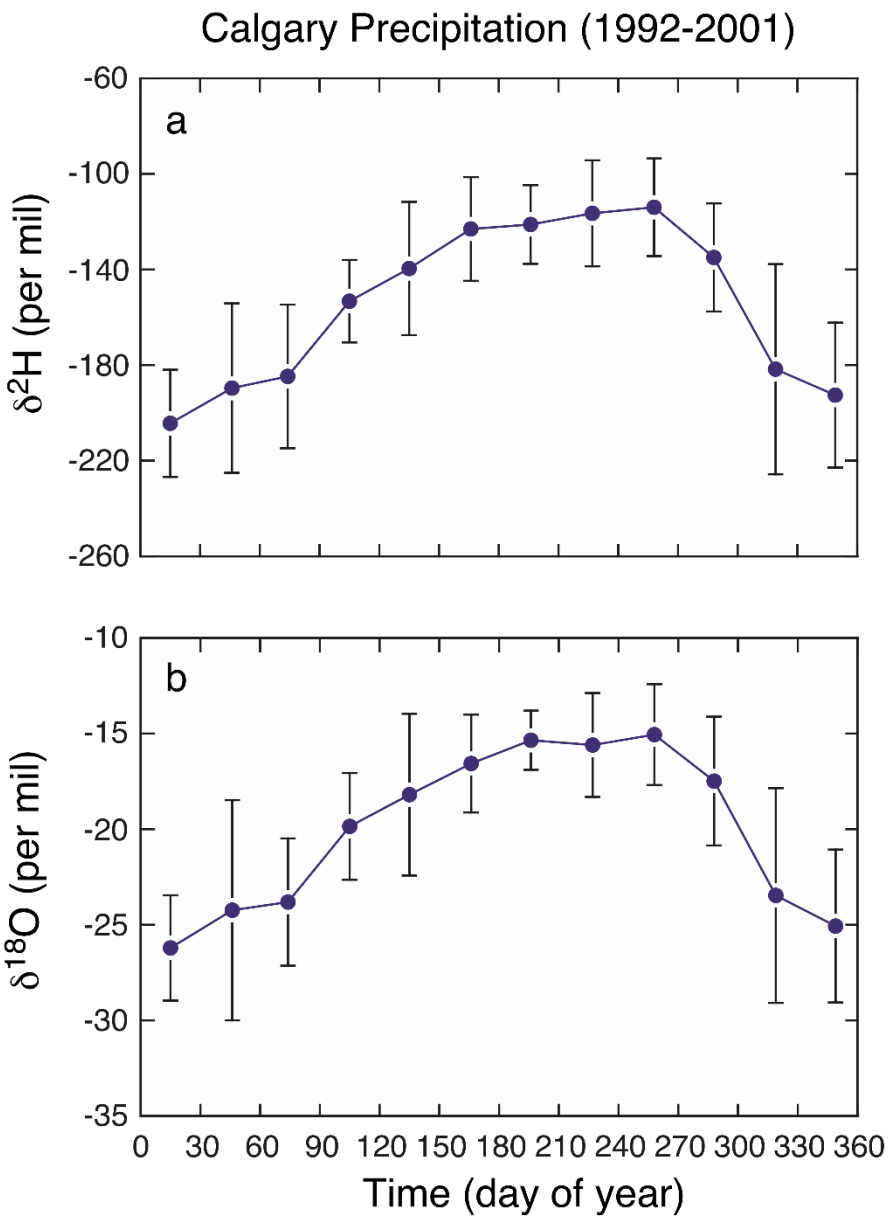
- ^{1}H - 99.985% (**$^{1}H_2O$**)
- ^{2}H - 0.015% (**$^{2}H_2O$**)
- ^{16}O - 99.759% (**$H_2{}^{16}O$**)
- ^{18}O - 0.204% (**$H_2{}^{18}O$**)

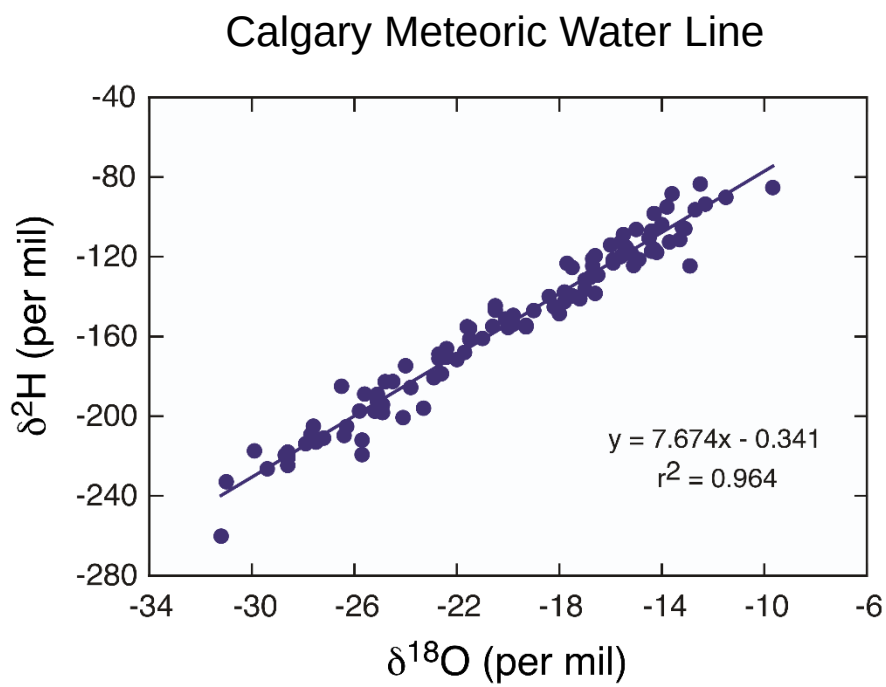
$$\delta = \left(\frac{R_{sample}}{R_{standard}} - 1\right) \times 1000\ (‰)$$

where R is $^{2}H/^{1}H$ or $^{18}O/^{16}O$

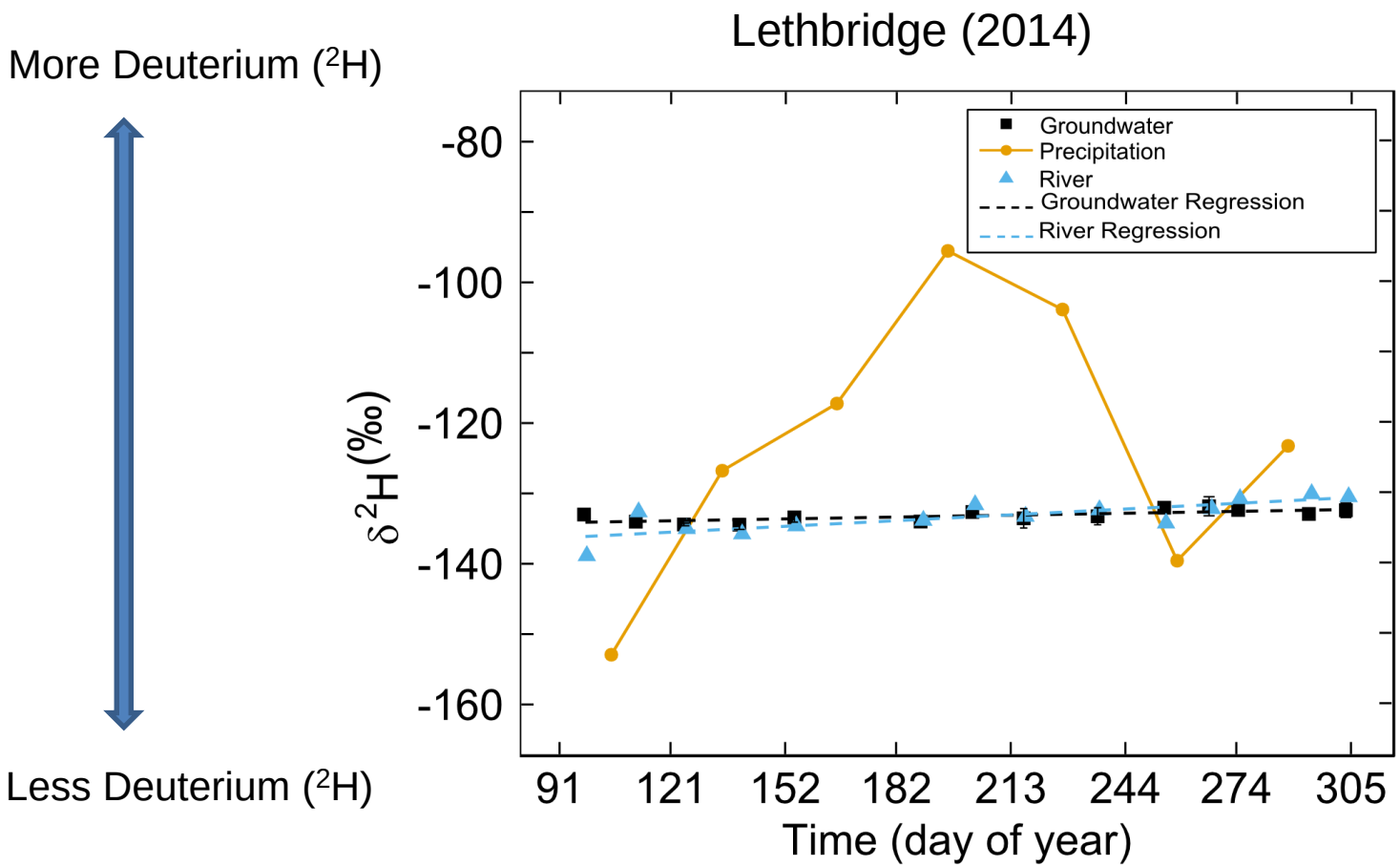
Isotope composition of stem water reflects isotope composition of water sources available to the plant (no fractionation during plant water uptake)

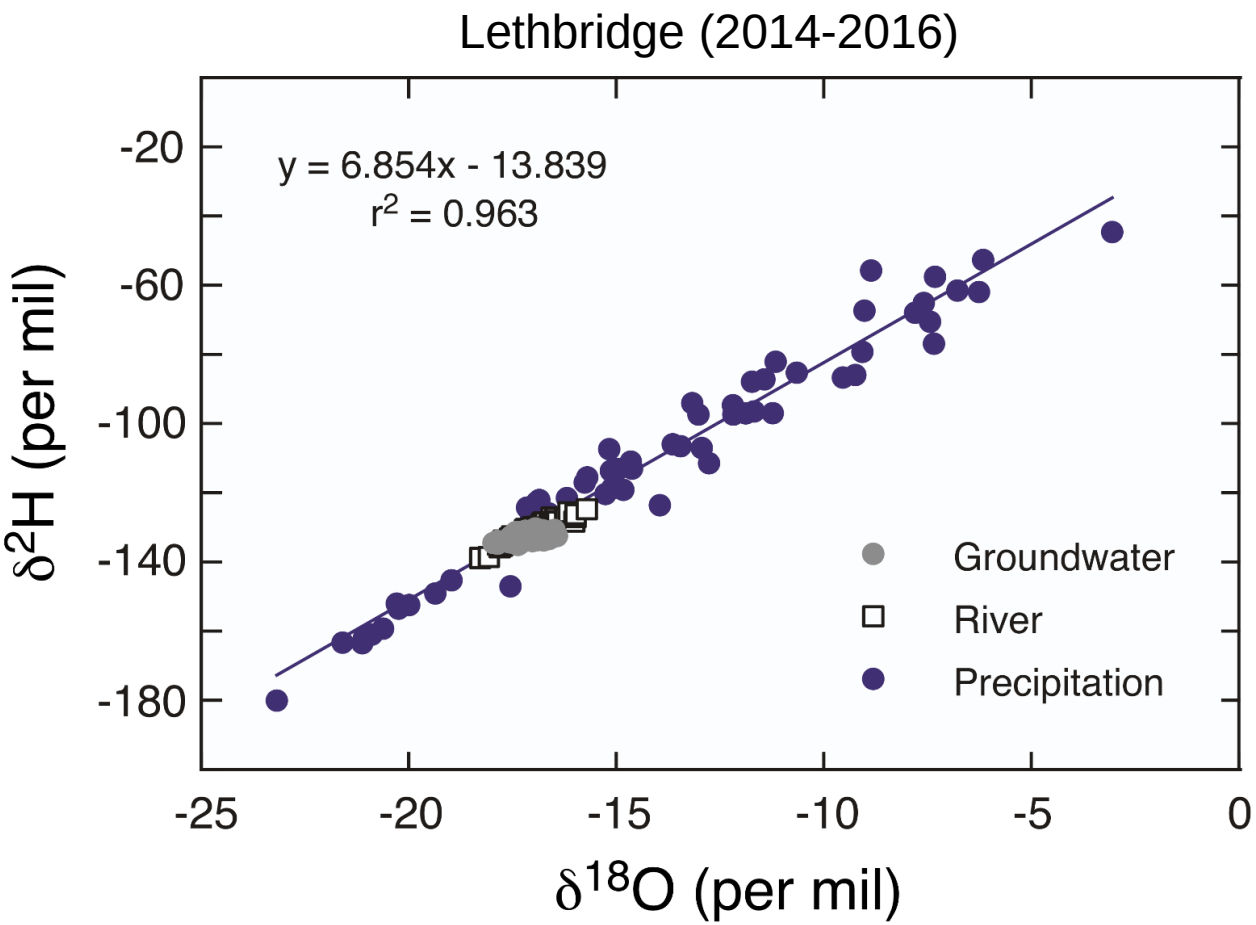
Determine water sources used by comparing the stable isotope compositions of stem water and water sources (summer precipitation, groundwater)

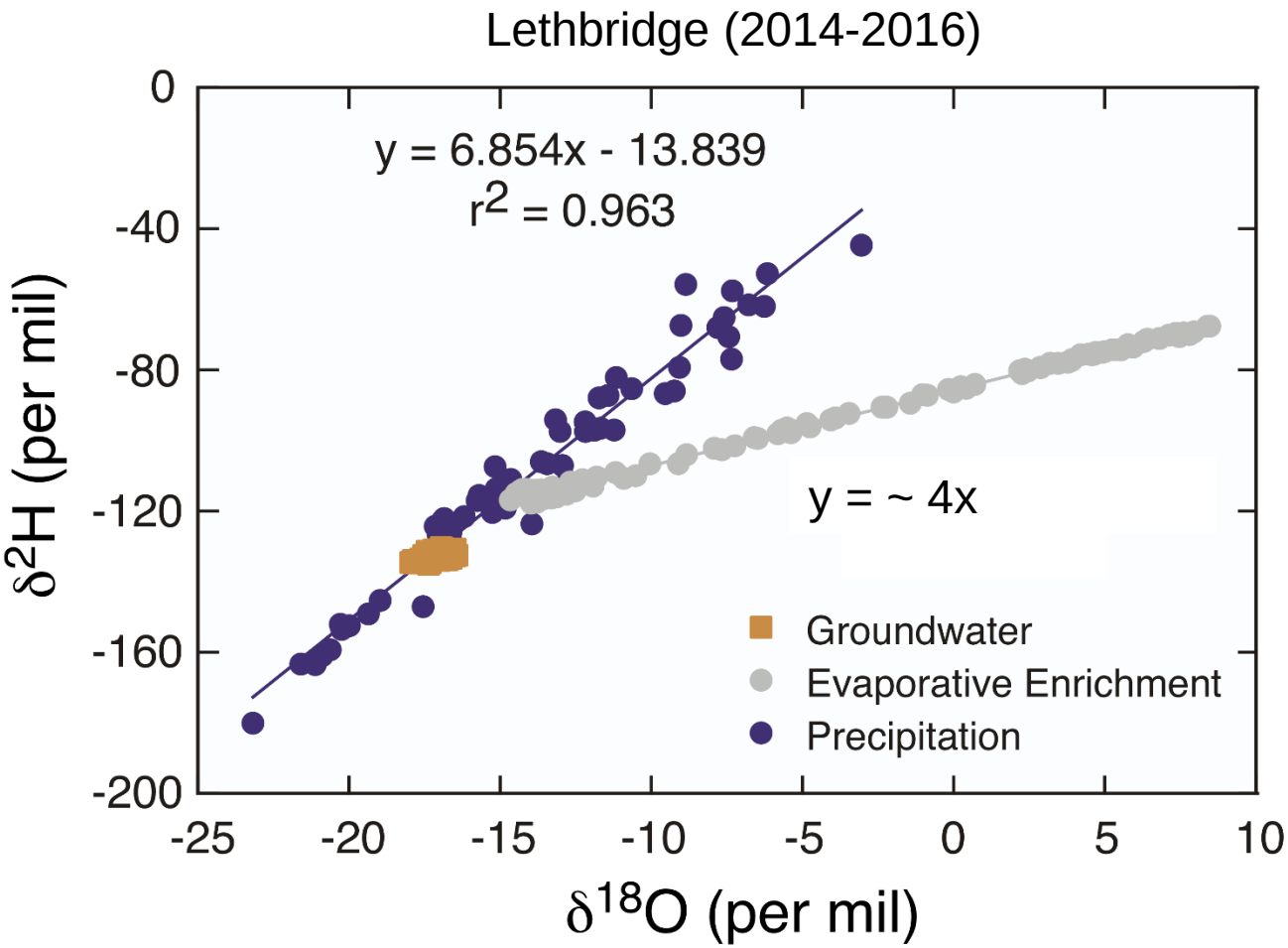




Peng et al. (2004) Tellus 56B: 147-159


More Deuterium (^{2}H)
Less Deuterium (^{2}H)
Lethbridge (2014)
Groundwater
Precipitation
River
Groundwater Regression
River Regression
-80
-100
-120
-140
-160
δ^2H (‰)
91
121
152
182
213
244
274
305
Time (day of year)


Lethbridge (2014-2016)
y = 6.854x - 13.839
r2 = 0.963
Groundwater
River
Precipitation
δ2H (per mil)
δ18O (per mil)
-20
-60
-100
-140
-180
-25
-20
-15
-10
-5
0


Lethbridge (2014-2016)
y = 6.854x - 13.839
r2 = 0.963
y = ~ 4x
Groundwater
Evaporative Enrichment
Precipitation
δ2H (per mil)
δ18O (per mil)
0
-40
-80
-120
-160
-200
-25
-20
-15
-10
-5
0
5
10

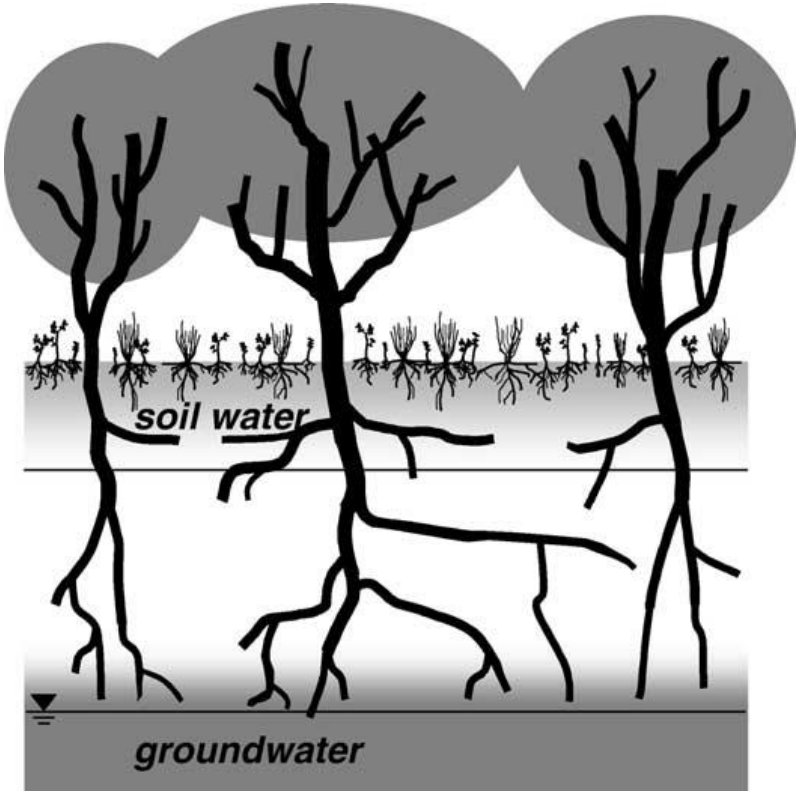
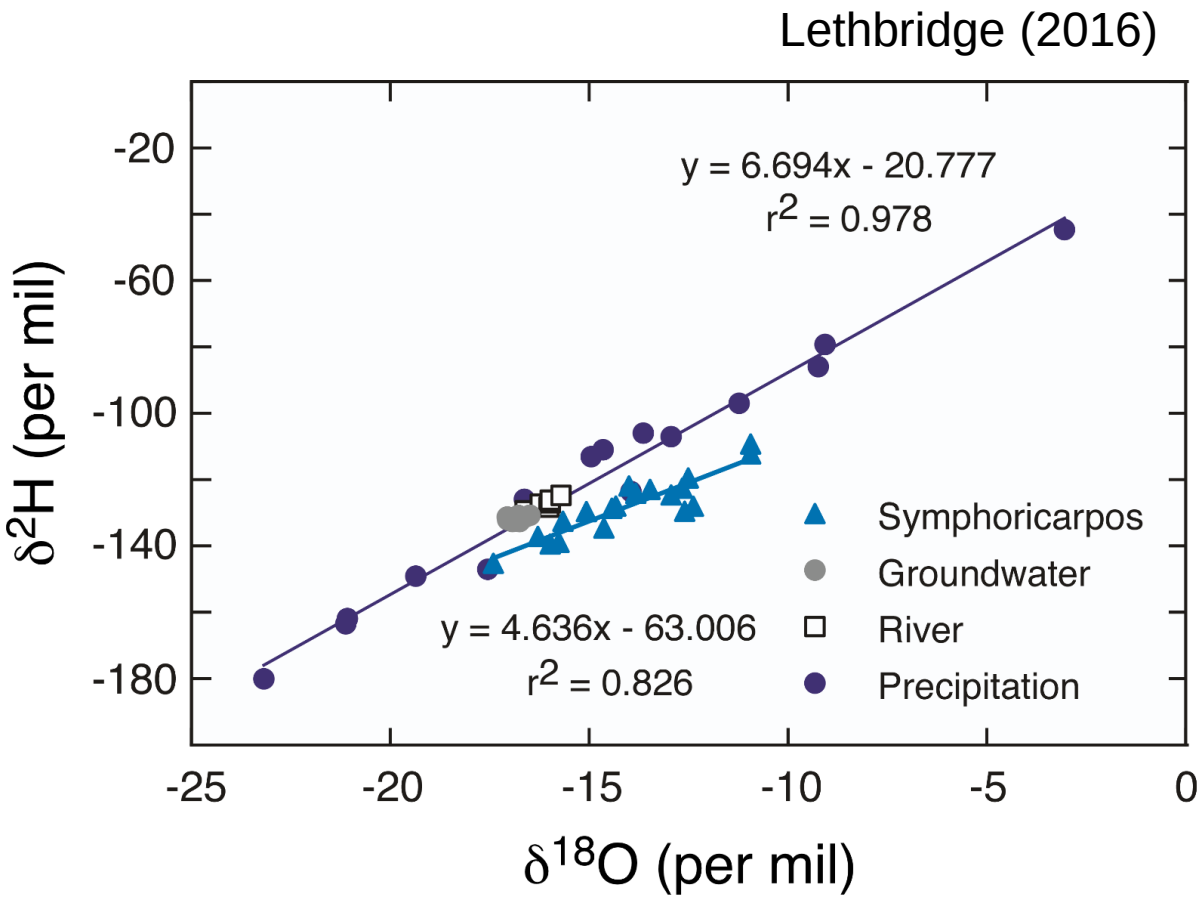


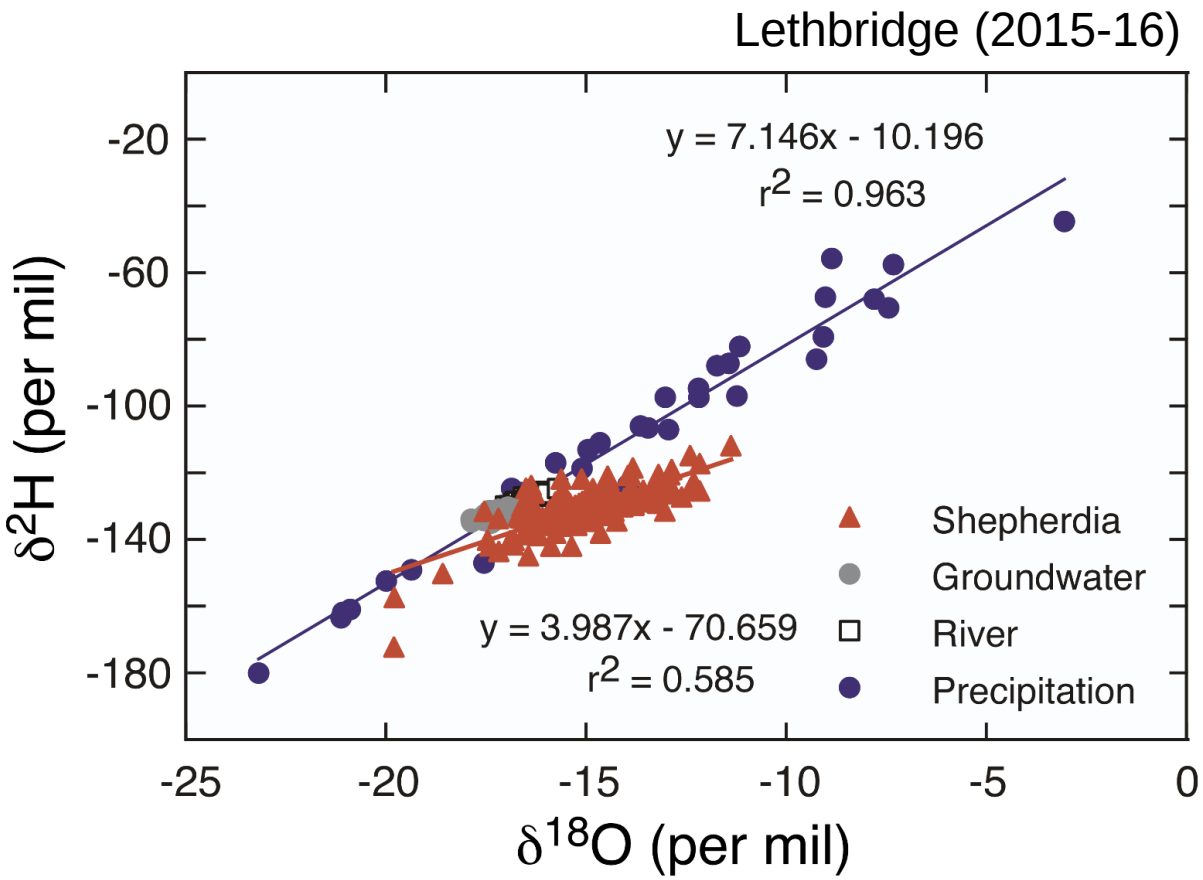
Diagram of hypothesized primary water sources. Deep roots of trees can access groundwater, while shallow-rooted understory plants are dependent on precipitation. (diagram from Scott et al. 2003).

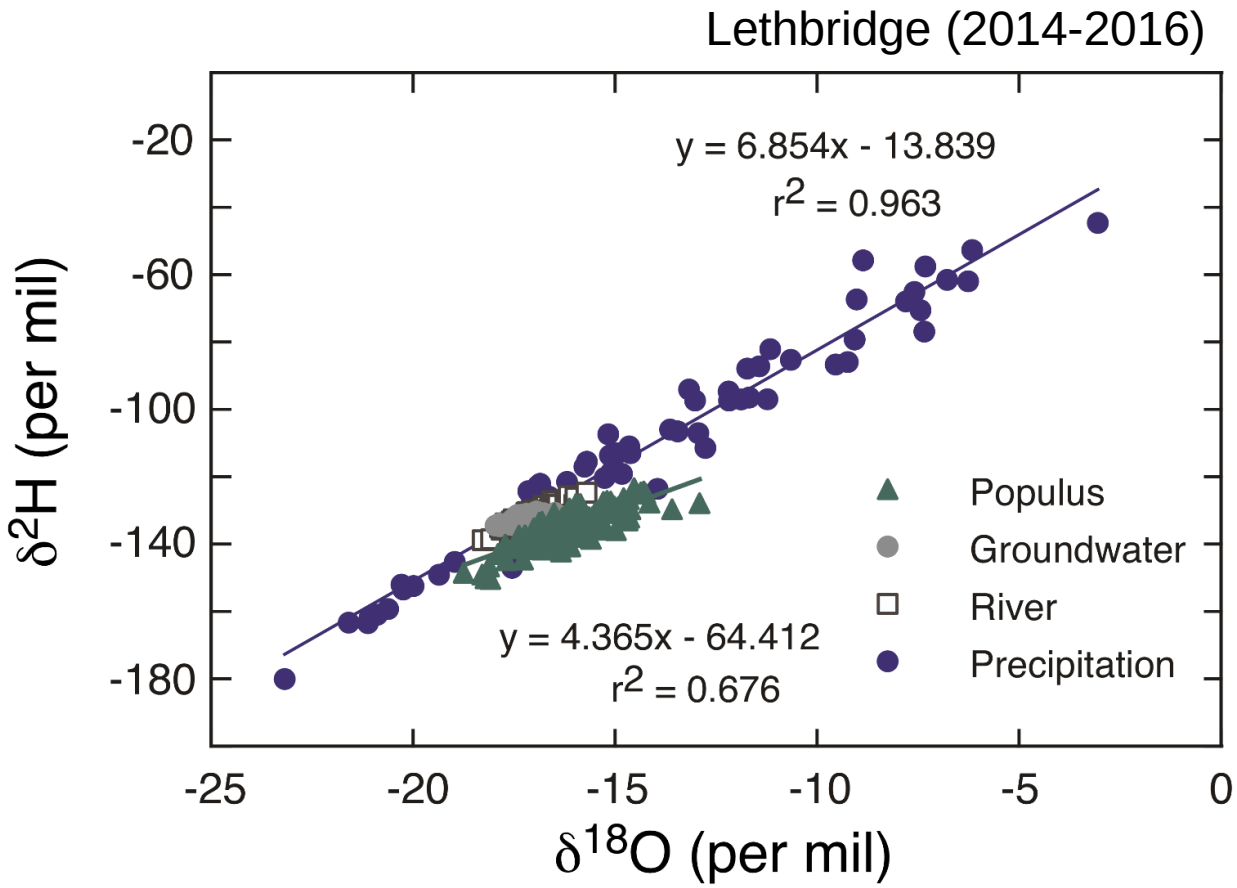
Symphoricarpos occidentalis
(snowberry)

Sherpherdia argentea
(buffaloberry)

Photos: J. Flanagan


Lethbridge (2016)
y = 6.694x - 20.777
r2 = 0.978
y = 4.636x - 63.006
r2 = 0.826
Symphoricarpos
Groundwater
River
Precipitation
δ2H (per mil)
δ18O (per mil)
-20
-60
-100
-140
-180
-25
-20
-15
-10
-5
0


Lethbridge (2015-16)
y = 7.146x - 10.196
r2 = 0.963
y = 3.987x - 70.659
r2 = 0.585
Shepherdia
Groundwater
River
Precipitation
δ2H (per mil)
δ18O (per mil)
-20
-60
-100
-140
-180
-25
-20
-15
-10
-5
0


Lethbridge (2014-2016)
y = 6.854x - 13.839
r2 = 0.963
y = 4.365x - 64.412
r2 = 0.676
Populus
Groundwater
River
Precipitation
δ2H (per mil)
δ18O (per mil)
-20
-60
-100
-140
-180
-25
-20
-15
-10
-5
0

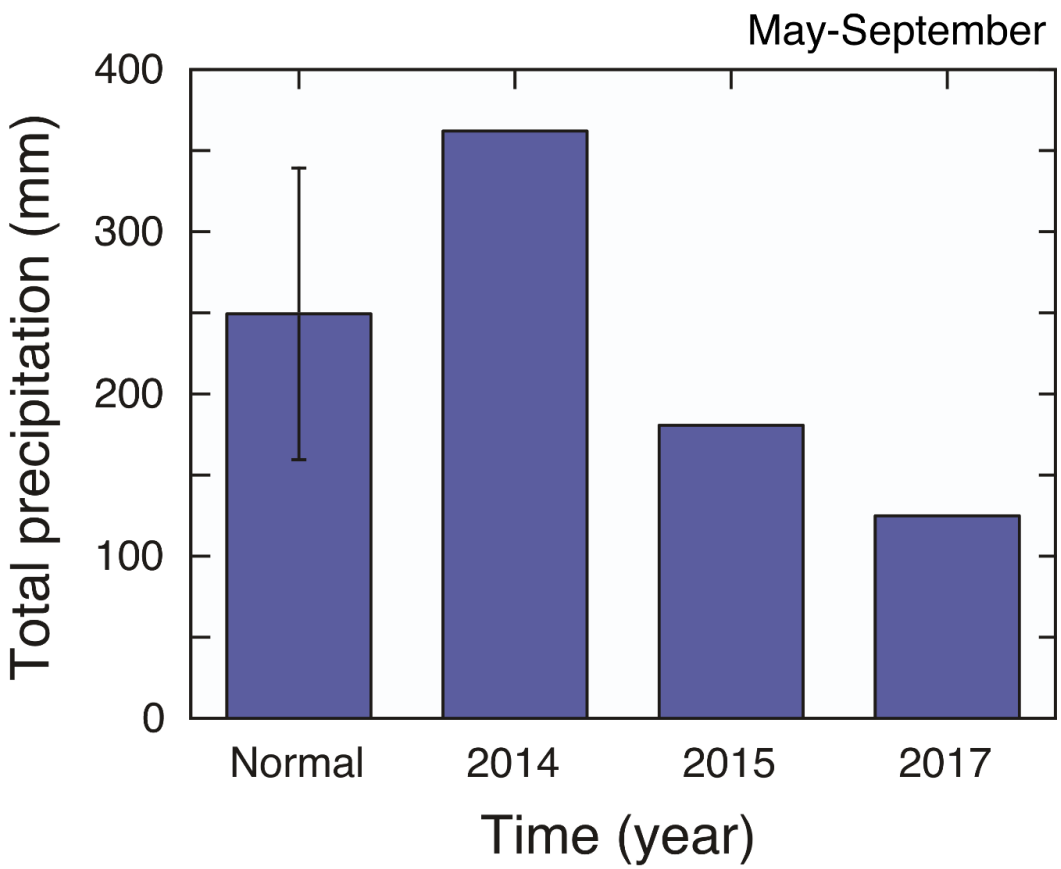
River flows and health of floodplain ecosystems

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 Cottonwood Forest Flux Site

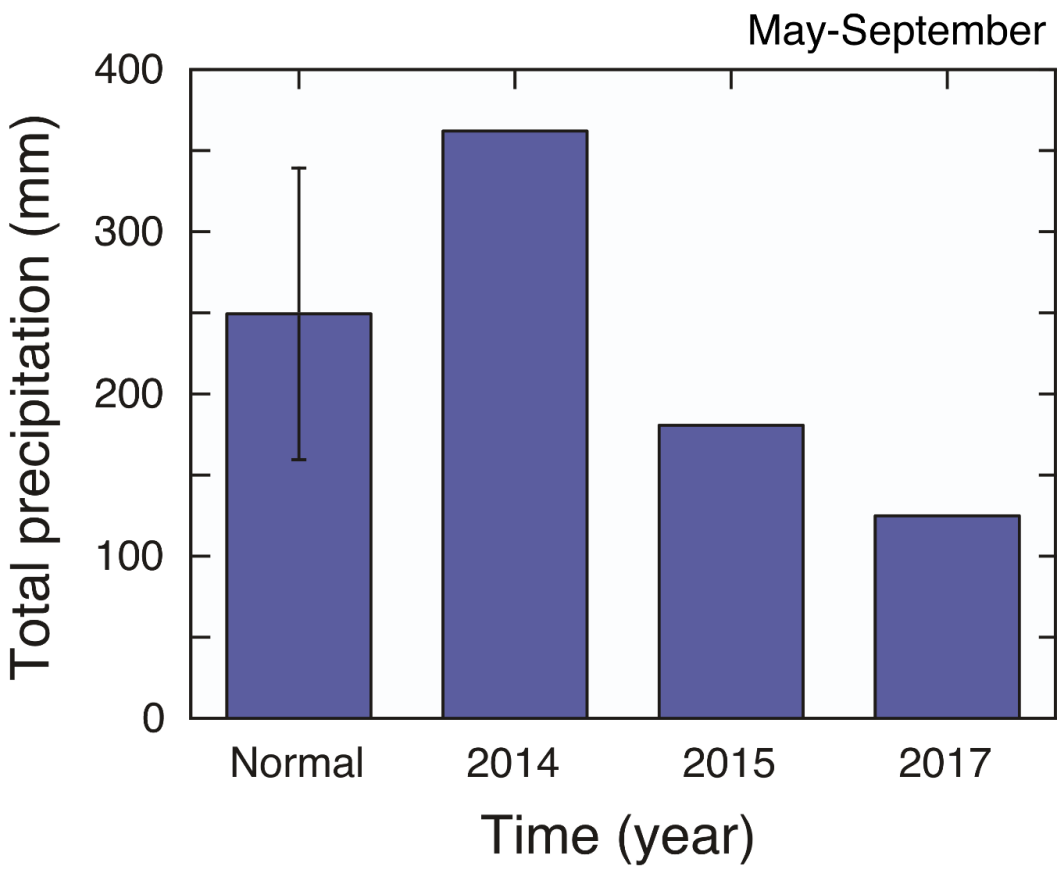
Lethbridge Growing Season Precipitation
(compared to average ±SD during 1971-2000 (Normal))



Oldman River, Lethbridge: June 22, 2014

Photo: S.B. Rood

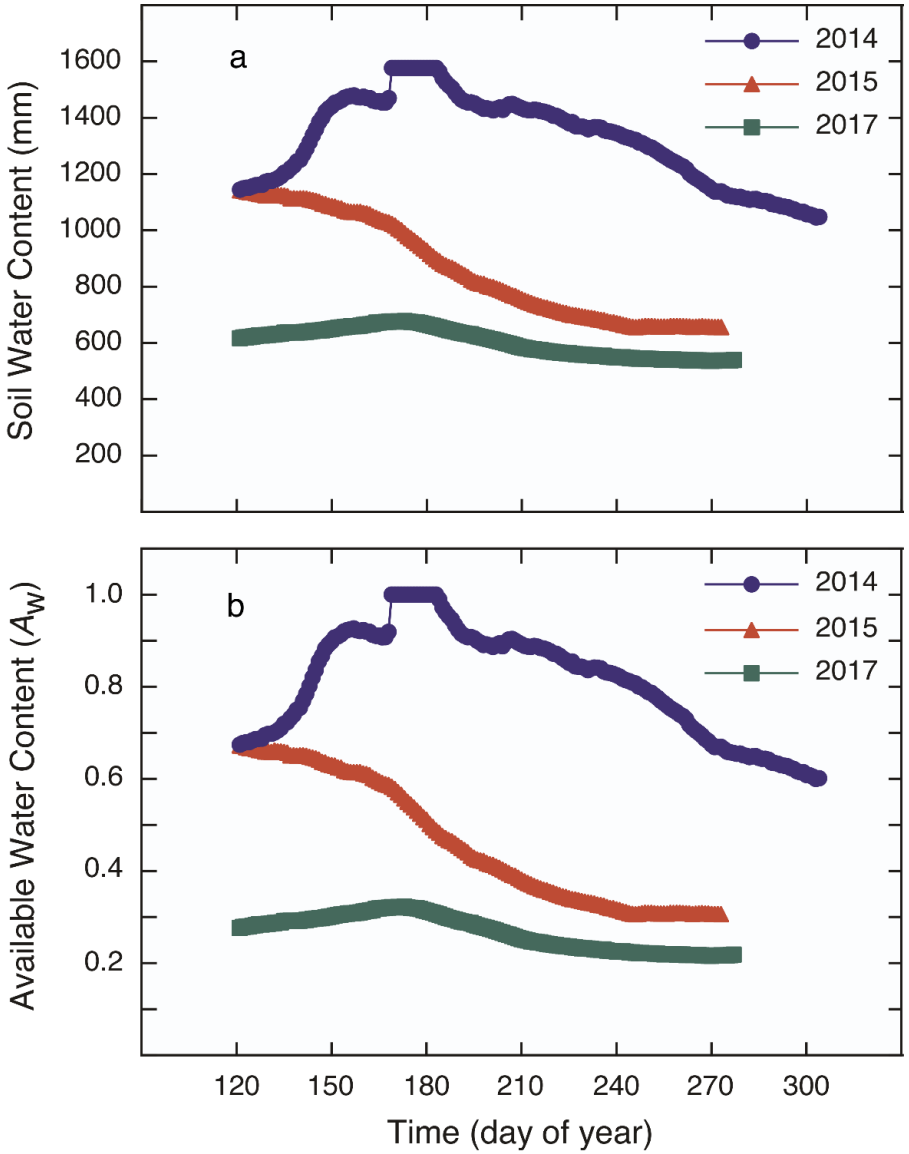
Lethbridge Growing Season Precipitation
(compared to average ±SD during 1971-2000 (Normal))



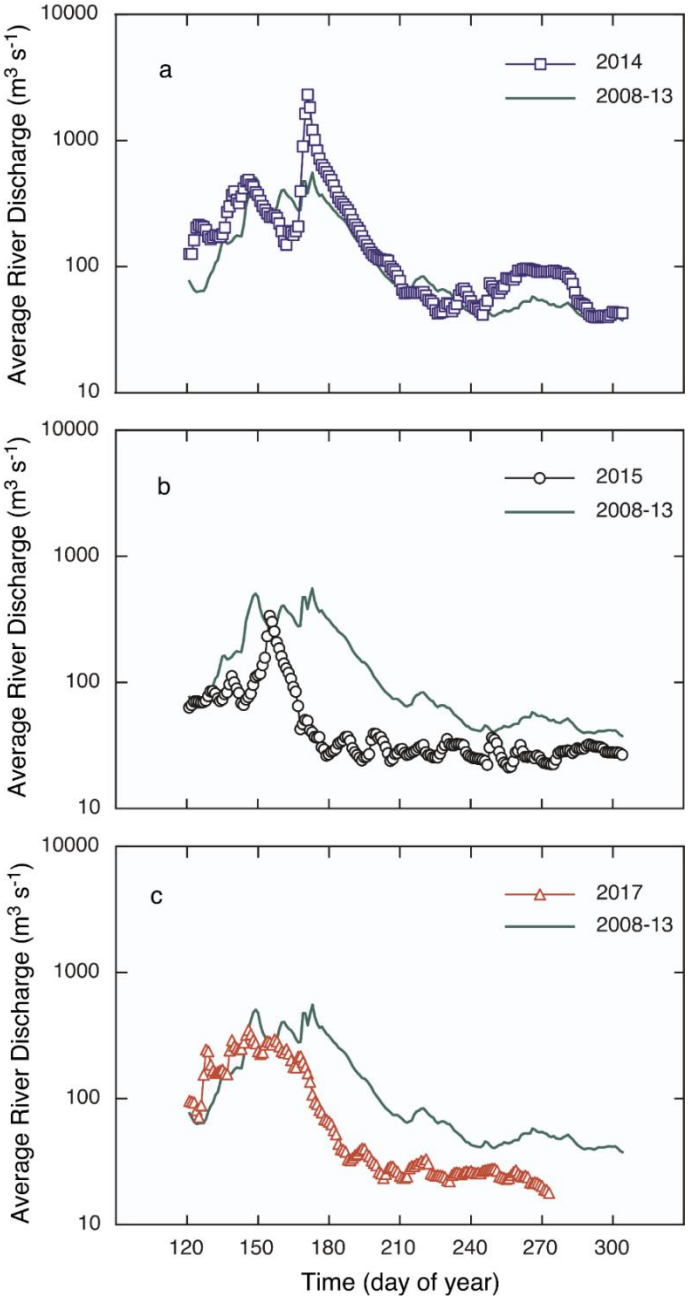
Comparison of daily average (± SD) air temperature and vapour pressure difference in Lethbridge, Alberta during June and July.

	2014	2015	2017
Air Temperature (°C)	21.0 ± 4.9	23.3 ± 4.9	24.7 ± 5.0
Vapour Pressure Difference (kPa)	1.5 ± 0.7	2.2 ± 0.9	2.5 ± 1.0

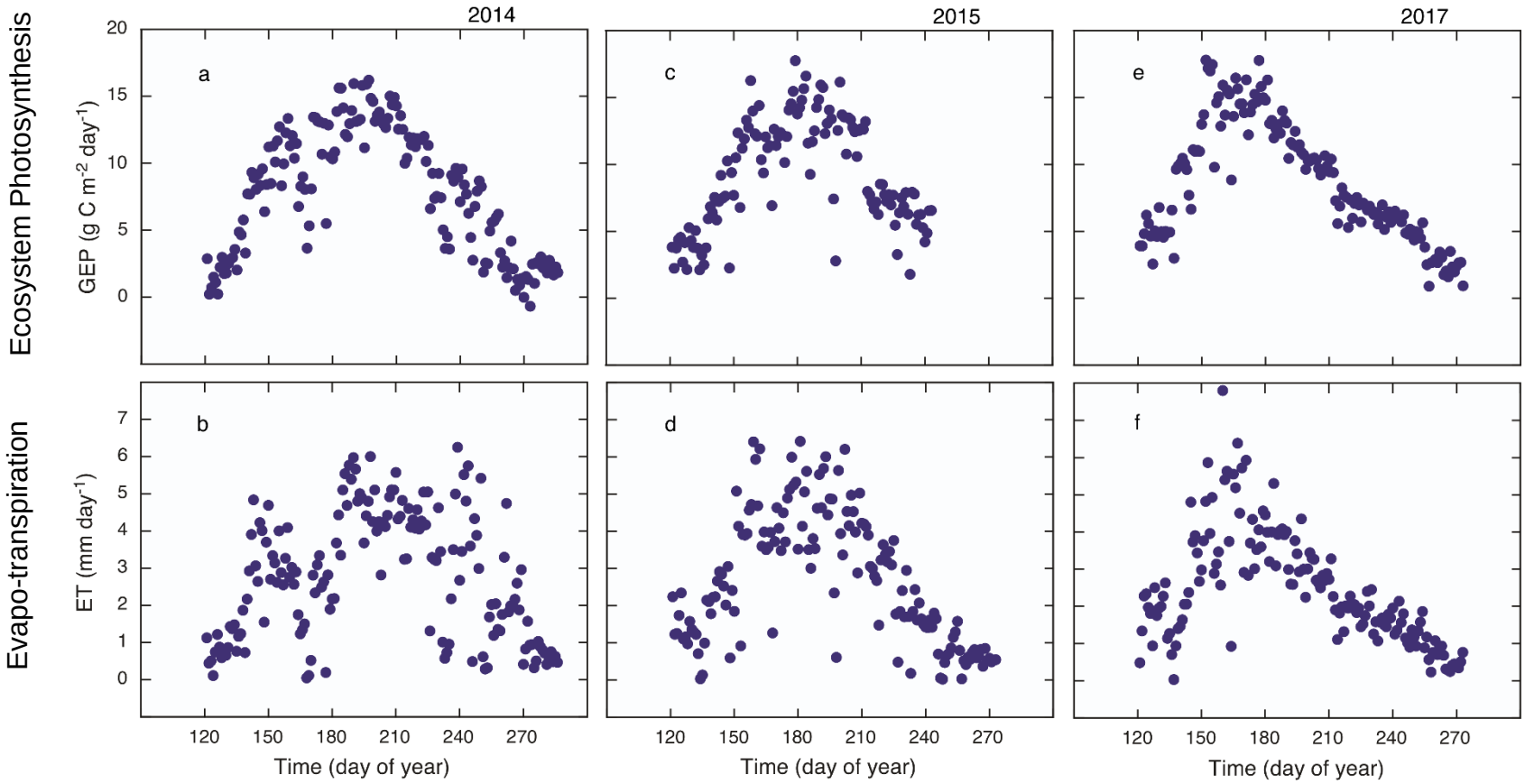
Floodplain Soil Water Content Integrated over 0-2.5 m depth

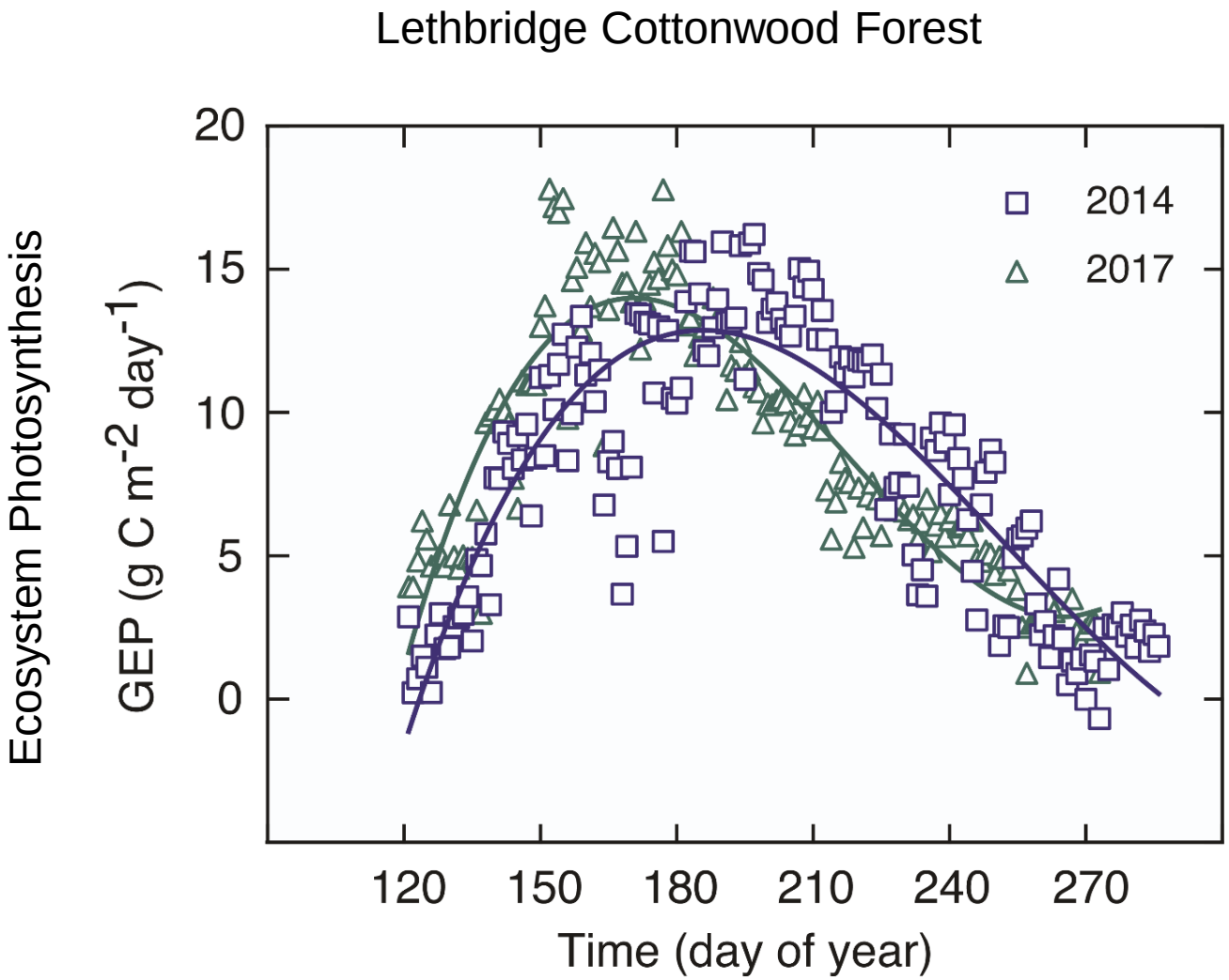


Oldman River Discharge

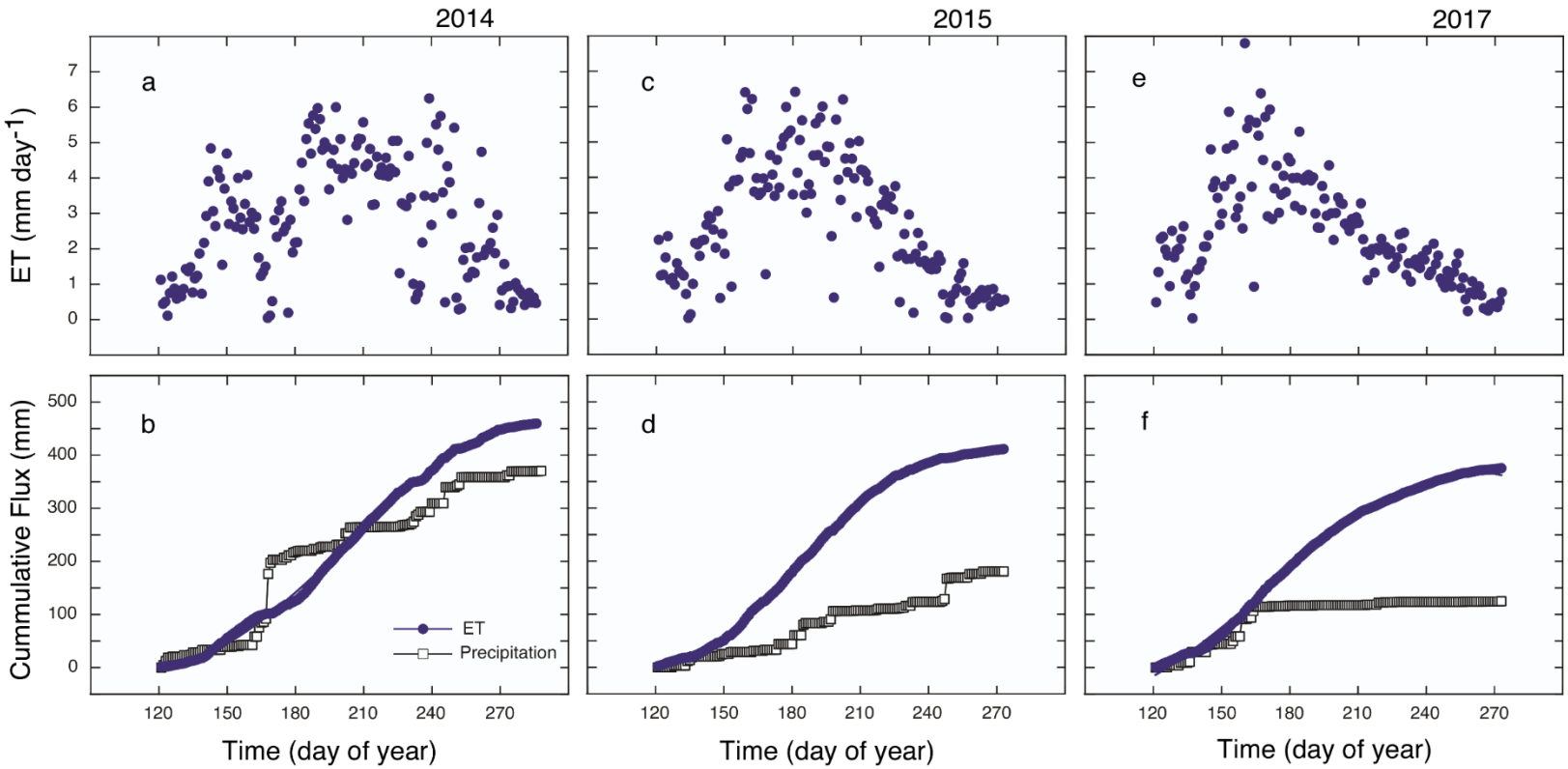


Lethbridge Cottonwood Forest (May-September)




Lethbridge Cottonwood Forest
Ecosystem Photosynthesis
GEP (g C m-2 day-1)
20
15
10
5
0
120
150
180
210
240
270
Time (day of year)
2014
2017

Lethbridge Cottonwood Forest (May-September)



Lethbridge Cottonwood Forest (May-September)

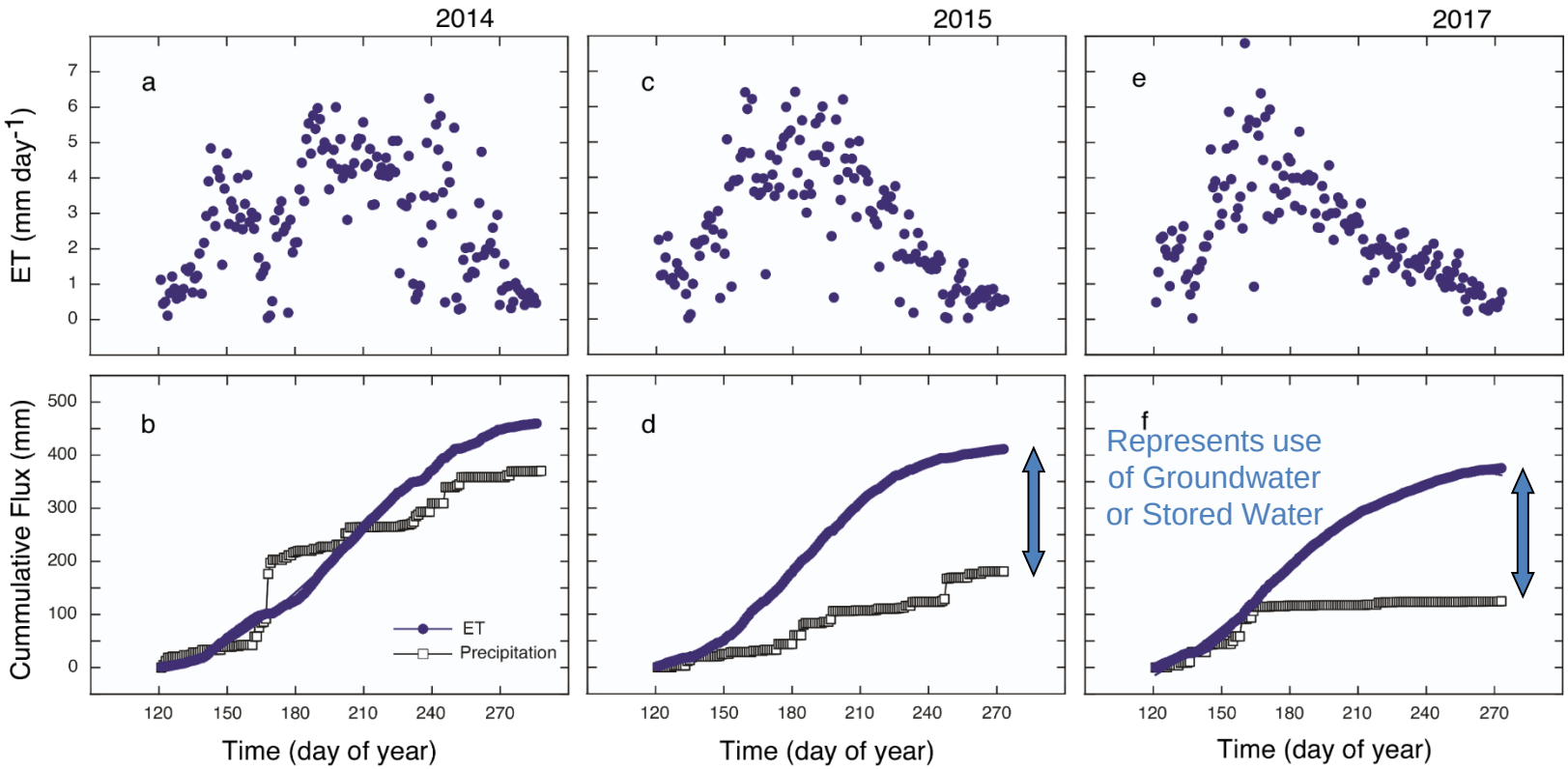
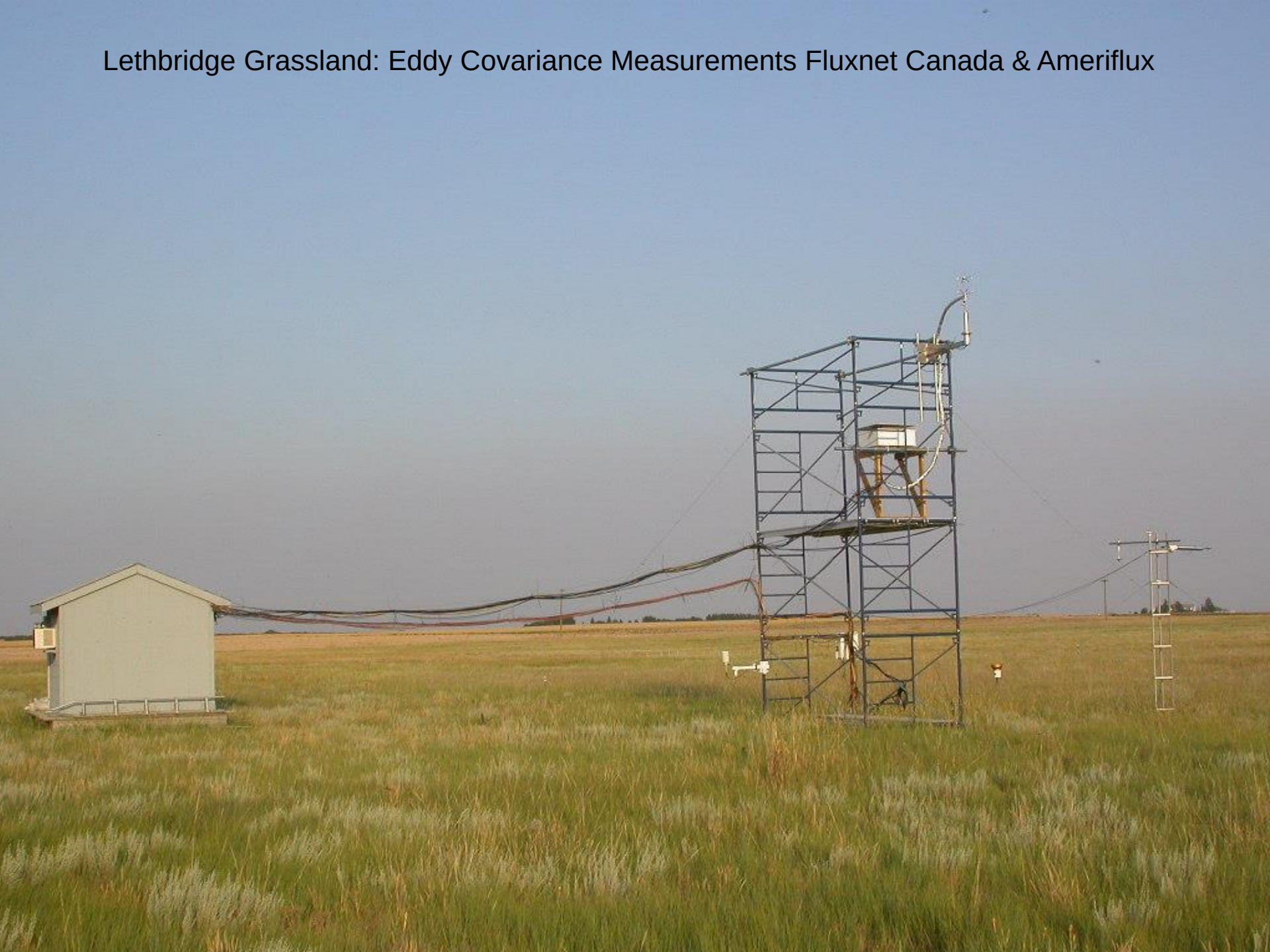
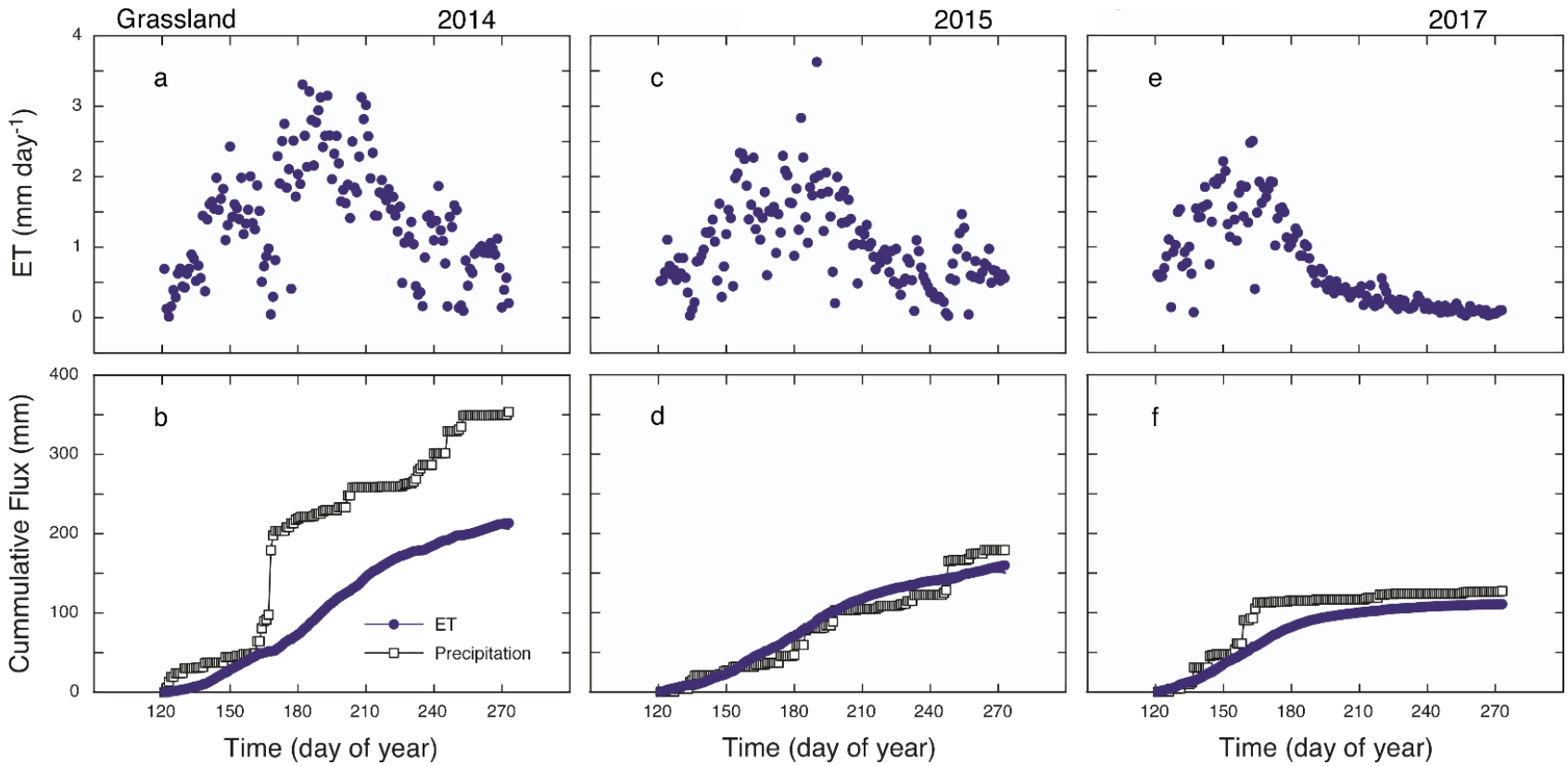


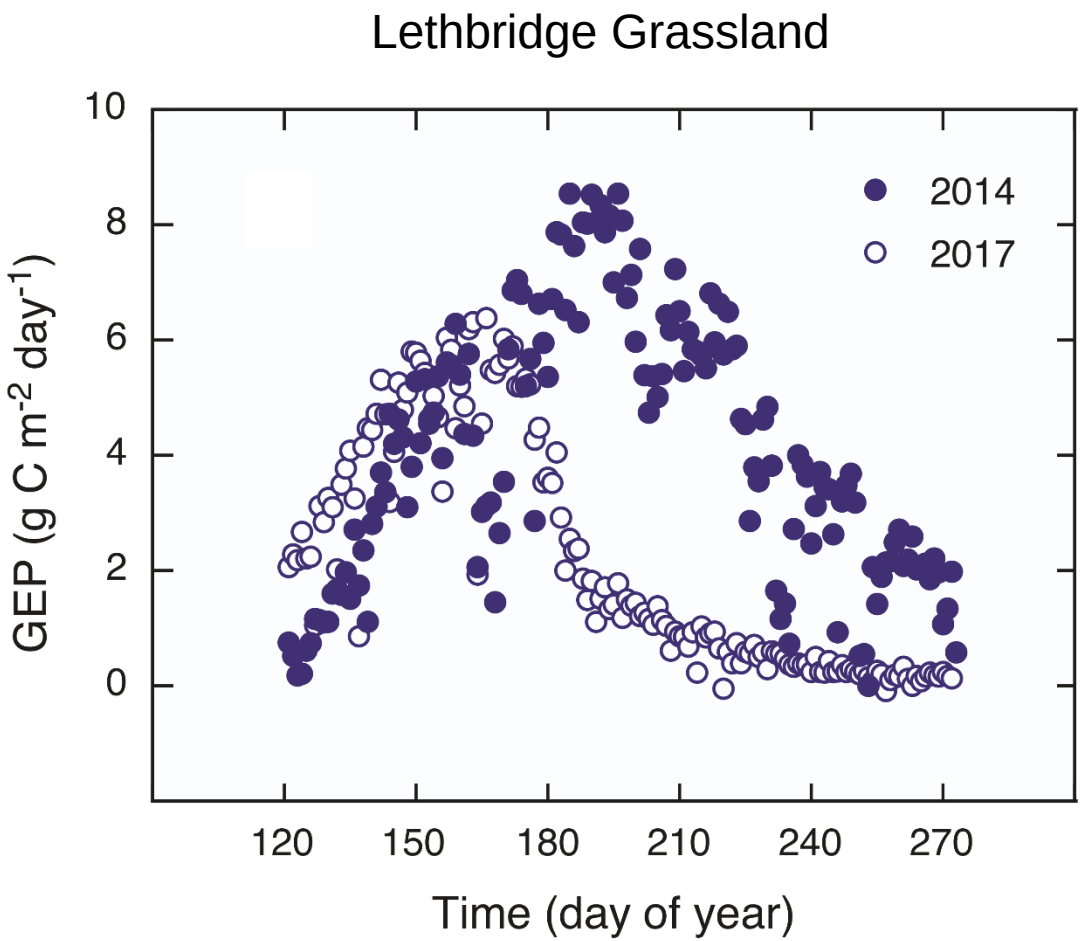
Photo: June Flanagan

Lethbridge Grassland: Eddy Covariance Measurements Fluxnet Canada & Ameriflux

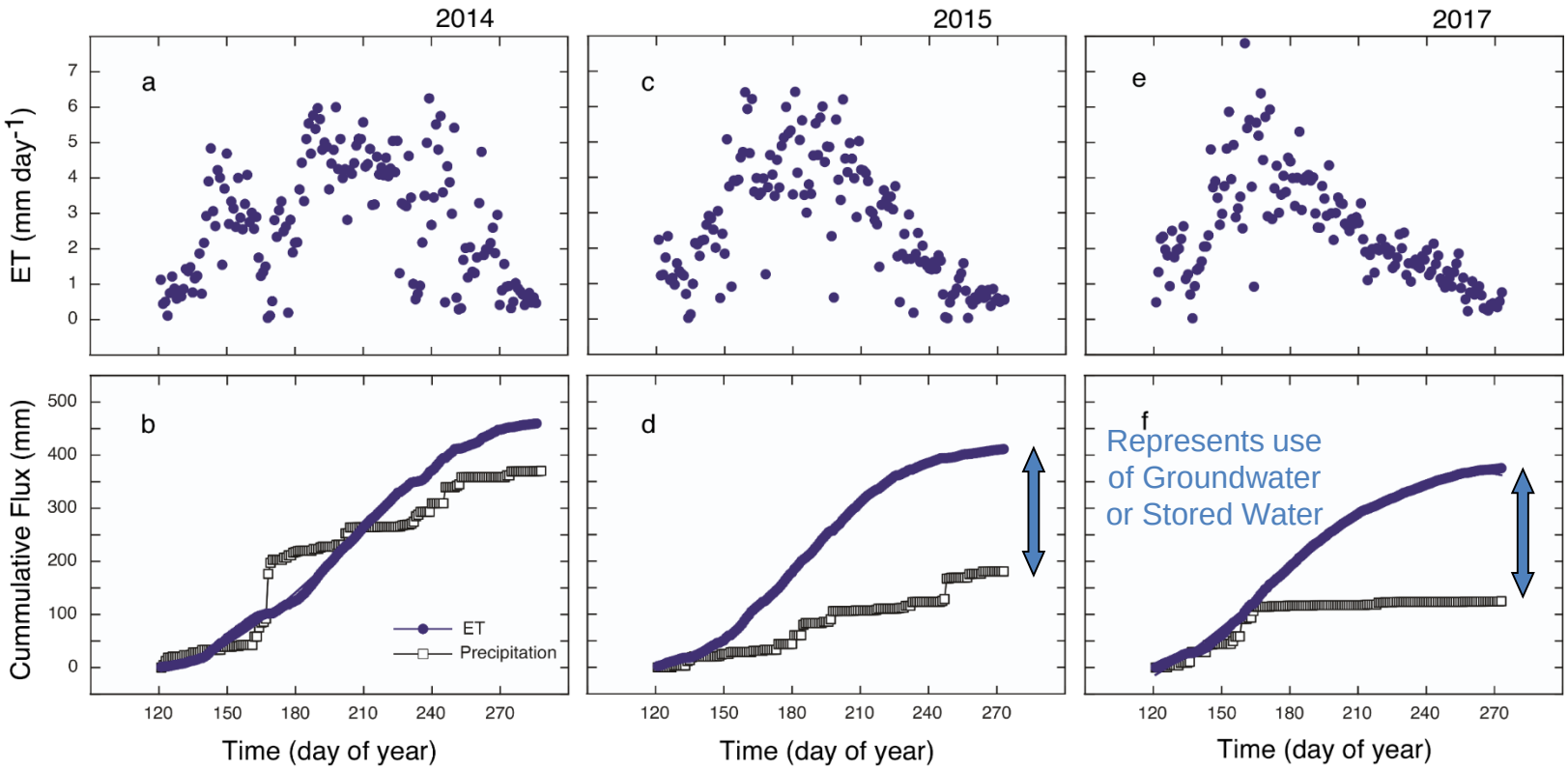


Lethbridge Native Grassland (May-September)




Lethbridge Grassland
2014
2017
GEP (g C m-2 day-1)
10
8
6
4
2
0
120
150
180
210
240
270
Time (day of year)

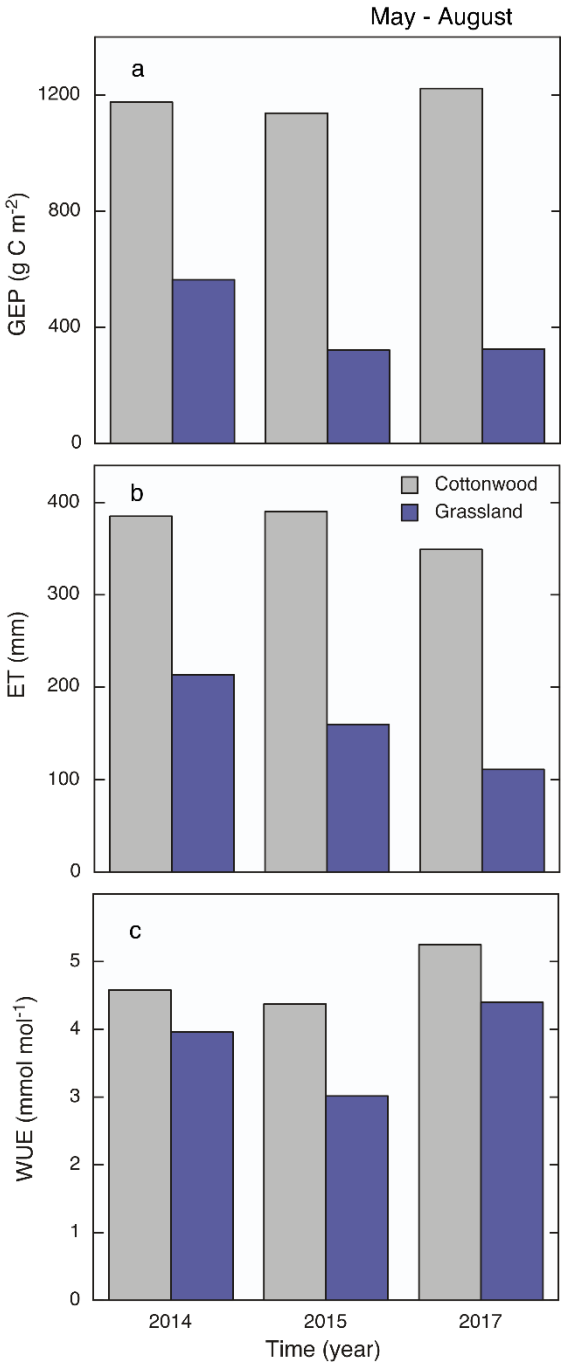
Lethbridge Cottonwood Forest (May-September)



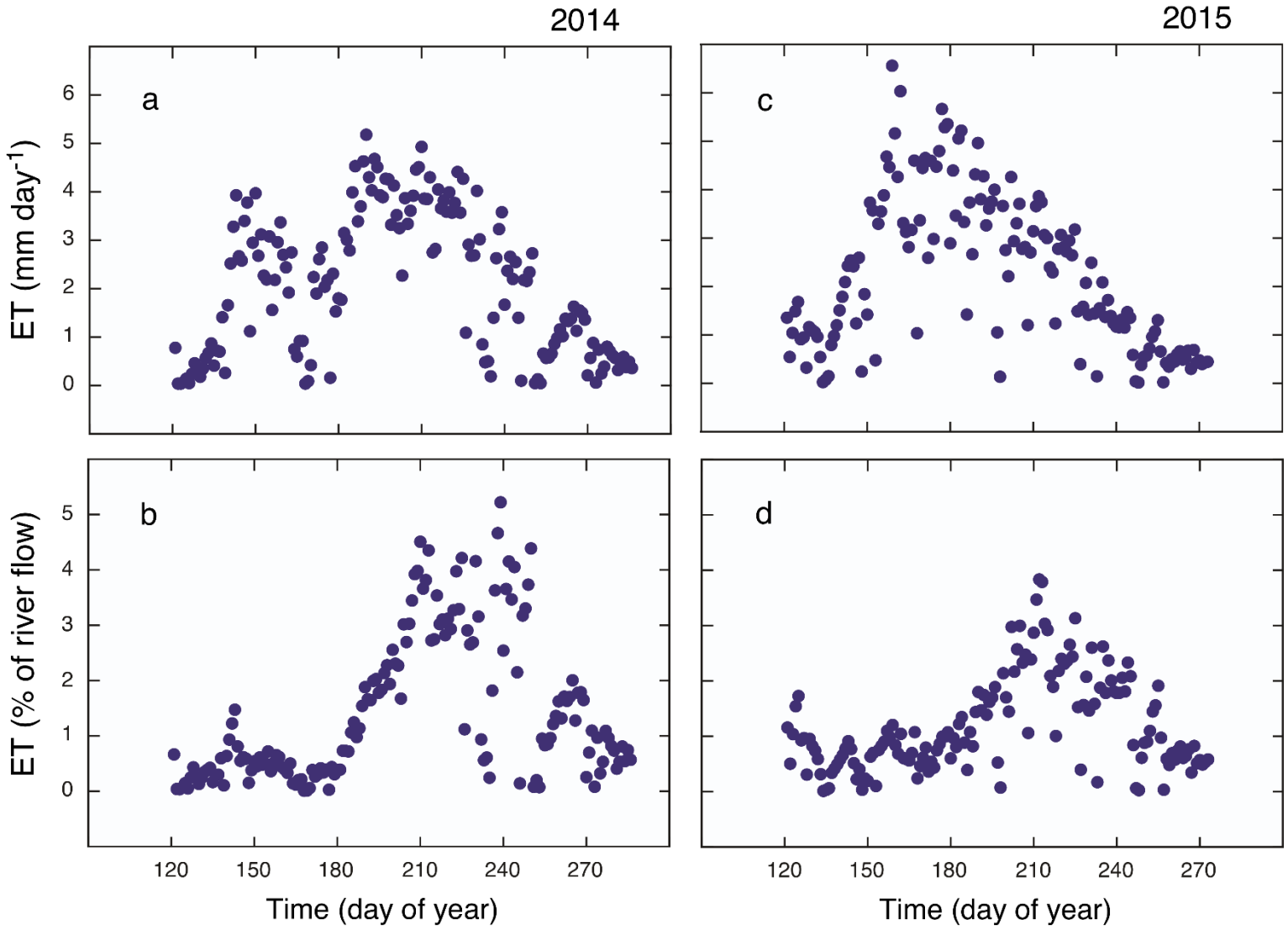
Ecosystem Photosynthesis

Ecosystem Evapo-transpiration

Ecosystem Water-use Efficiency



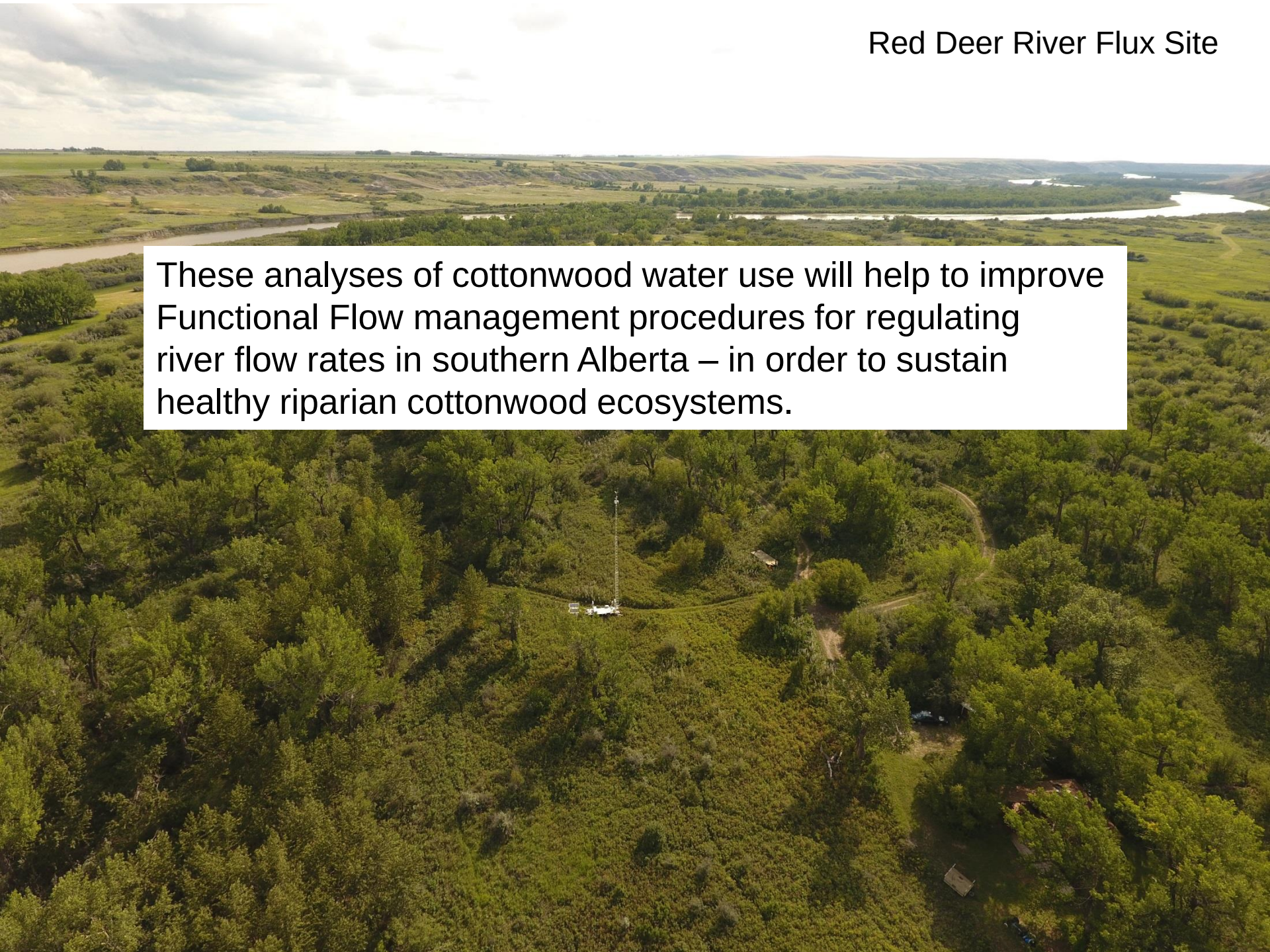
Scaled-calculations of forest ET along the Oldman River corridor



River flows and health of floodplain ecosystems

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.

Red Deer River Flux Site

Project Publications

2016

Evans, L.M.*, S. Kaluthota, S., Pearce, D.W., Allan, G., Floate, K., Rood, S.B. & Whitham, T.G. 2016. Bud phenology and growth are subject to divergent selection across a latitudinal gradient in *Populus angustifolia* and impact adaptation across the distributional range and associated arthropods. *Ecology and Evolution* 6: 4565-4581. (https://onlinelibrary.wiley.com/doi/full/10.1002/ece3.2222) (AB Innovates, NSERC)

Hillman, E.J., Bigelow, S.G., Samuelson, G.M., Herzog, P.W., Hurly, A.T. & Rood, S.B.* 2016. Increasing river flow expands riparian habitat: Influences of flow augmentation on channel form, riparian vegetation, and birds along the Little Bow River, Alberta. *River Research and Applications* 32: 1687-1697. (https://onlinelibrary.wiley.com/doi/full/10.1002/rra.3018) (AB Env, AB Innovates, NSERC)

Rood, S.B.*, Foster, S.G., Hillman, E.J., Luek, A. & Zanewich, K.P. 2016. Flood moderation: Declining peak flows along some Rocky Mountain rivers and the underlying mechanism. *Journal of Hydrology* 536: 174-182. (AEP, AB Innovates, NSERC) (https://www.sciencedirect.com/science/article/pii/S0022169416300774)

Rood, S.B.*, Kaluthota, S., Gill, K.M., Hillman, E.J., Woodman, S.G., Pearce, D.W., & Mahoney, J.M. 2016. A twofold strategy for riparian restoration: Combining a functional flow regime and direct seeding to re-establish cottonwoods. *River Research and Applications* 32: 836-844. (https://onlinelibrary.wiley.com/doi/full/10.1002/rra.2919) (AB Innovates, NSERC)

Rood, S.B.*, Kaluthota, S., Philipsen, L.J., Rood, N.J. & Zanewich, K.P. 2016. Increasing discharge from the Mackenzie River system to the Arctic Ocean. *Hydrological Processes* 31: 150-160. (https://onlinelibrary.wiley.com/doi/full/10.1002/hyp.10986) (AEP, AB Innovates, NSERC)

2017

Flanagan, L.B.*, Orchard, T.E., Logie, G.S.J., Coburn, C.A. & Rood, S.B. 2017. Water use in a riparian cottonwood ecosystem: Eddy covariance measurements and scaling along a river corridor. *Agricultural and Forest Meteorology* 232: 332-348. (AB Innovates, CPC, NSERC) (https://www.sciencedirect.com/science/article/pii/S0168192316303793)

Foster, S.G., Mahoney, J.M. & Rood, S.B.* 2017. Functional flows: An environmental flow regime supports cottonwood colonization and growth along the Waterton River, Alberta. *Restoration Ecology* (https://onlinelibrary.wiley.com/doi/pdf/10.1111/rec.12654) (AEP, AB Innovates, CPC, NSERC)

Foster, S.G. & Rood, S.B.* 2017. River regulation and riparian woodlands: Cottonwood conservation with an environmental flow regime along the Waterton River, Alberta. *River Research and Applications*. 33: 1088-1097. (https://onlinelibrary.wiley.com/doi/full/10.1002/rra.3156) (AEP, AB Innovates, NSERC)

Rood, S.B.*, Goater, L.A., McCaffrey, D., Montgomery, J.S., Hopkinson, C. & Pearce, D.W. 2017. Growth of riparian cottonwoods: Heterosis in some intersectional *Populus* hybrids and clonal expansion of females. *Trees* 31:1069-1081. (https://link.springer.com/article/10.1007/s00468-017-1531-9) (AEP, AB Innovates, NSERC)

2018

Benson, R.D.* & Rood, S.B. 2018. Bringing 20th century water projects into the 31st century: The case for revisiting dam operations in Alberta, Canada. *Canadian Water Resources Journal* (https://www.tandfonline.com/doi/full/10.1080/07011784.2018.1455539 (AEP, AB Innovates)

Gill, K.M., Goater, L.A., Braatne, J.H. & Rood S.B.* 2018. The irrigation effect: How river regulation can promote some riparian vegetation. *Environmental Management*. (AEP, AB Innovates, Idaho Power Co., NSERC) (https://link.springer.com/article/10.1007/s00267-017-0991-4)

Zanewich, K.P., Pearce, D.W. & Rood, S.B.* Heterosis in poplar involves phenotypic stability: Cottonwood Hybrids outperform parental species at suboptimal temperatures. *Tree Physiology*. (https://onlinelibrary.wiley.com/doi/full/10.1002/hyp.10986) (AEP, AB Innovates)

Project Publications

Submitted papers

Pearce, D.W.*, Woodman, S.G., Letts, M.G. & Rood, S.B. Morphology and gas exchange of *Populus* species and native intersectional hybrids and their responses to soil water deficit. *Trees* (invited for resubmission following revision) (AEP, AB Innovates, NSERC)

Philipsen, L.J., K.M. Gill, A. Shepherd, S.B. Rood* Climate Change and Hydrology at the Prairie Margin: Historic and Prospective Future Flows of Canada's Red Deer and other Rocky Mountain Rivers. *Hydrological Processes* (favorably reviewed, revised and returned) (AEP, AB Innovates, NSERC)

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)

Tai, X., D.S. Mackay, J.S. Sperry, P. Brooks, W.R.L. Anderegg, L.B. Flanagan*, S.B. Rood, C. Hopkinson. Groundwater controls over the susceptibility of riparian woodland trees to drought-induced mortality. *Water Resources Research* (favorably reviewed, under minor revision) (AB Innovates, NSERC, CFI)

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)