Water and Forests: Sensitive (and not so sensitive) interactions in changing climate

OR
Sometimes snow does matter in slightly less marginally northern catchments

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Broader context of climate change in snow-dominated regions: Focus on mountainous Western US - Forests and Water?

What happens to water availability (supply) for and water use (demand) by forests in a warming climate?

How do changes in supply and demand impact forest productivity and sensitivity to disturbance (fire, disease, drought related dieback)?

Do these changes have implications for streamflow timing and magnitude?

Relevance for Northwatch:
large topographic-temperature moisture gradient (representing a diversity of climate conditions) – Water stress increasing issues in other Northern regions (boreal aspen drought response e.g Barr et al., 2007, GCB)

Figuring out where and when an increase or decrease in water use by forests will occur in snow-dominated regions:

A good job for a coupled model of eco-hydrologic processes

Two parts
1. Parameterizing and testing (quantifying uncertainty)

2. Using the model to look at forest water use responses
   • short-term (no change in forest structure)
   • medium term (change in productivity, disturbance events)
   • long term (dieback, species change responses)
Hydrologic processes in RHESSys

Carbon and Nitrogen cycling in RHESSys
Study sites

Sagehen Experimental Watershed (UC Berkley Field Station)

Sierra Nevada Mountain watershed (183ha)
Elevation range 1800-2700m
Vegetation: conifer (Jeffrey and Lodgepole pine and fir with substantial meadows)

http://sagehen.ucnrs.org/Photos/scenics/index.html

Classic hydrology parameterization-evaluation
RHESSys hydrologic model performance – post calibration
Streamflow (1960-2000)

- NSE (monthly) 0.7
- NSE (log transformed daily) 0.75
- Annual total R2 = 0.95

CC related flow metrics
- Timing of Center of Mass of Streamflow (Bias 1 day, R2)
- Minimum 7 day flow ()
### Broader context of climate change in mountainous Western US?

Summer drought (both ecologically and hydrologically) is common

A: Warmer temperature (increased PET) DEMAND

B: With change in timing of inputs (with shifts from snow to rain and earlier melt), more summer drought stress SUPPLY

Net effect (assuming no change in vegetation – so short term) becomes:

\[ \text{IS } A - B + \text{ or } - \]

Tague et al., (2010) *Ecohydrology*
Watershed scale ET highly variable: both temperature and water limited conditions – Also interesting departures from a general
Scatter in ET/P relationship is due to the timing of when that precipitation became recharge – and the synchronicity of the recharge with forest water demand.

At plot scale, similarly, scatter is significant

Higher elevations: lower biomass

Much scatter for years when P is > 1000m – it is as great as difference in ET due to precipitation variation < 1000m

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The timing of recharge – that relates a lot to the timing of snowmelt.

Years where more rain falls as snow – shifts the timing of recharge to earlier in the year.

So, with a warmer climate (+3°C) and no change in precipitation for same 50 years -> increased demand (ET should stay the same or go up) – but also a shift in timing (ET should go down).

Average watershed wide – over 50 years of pre-climate variation, very slight decline (15mm/year, 3%) Change in ET greater for wet years with large shifts in timing of recharge.
So, with a warmer climate (+3°C) and no change in precipitation – we get increased demand (ET should stay the same or go down) – but also a shift in timing (ET should go up)

Note that the effect of timing occurs across all P, but is greater in wetter years, but also biggest increases occur in the wettest years.

What is the role of redistribution? Sensitivity to non-local conditions

Note that the effect of timing occurs across all P, but is greater in wetter years, but also biggest increases occur in the wettest years.
Contribution of lateral redistribution of water

All else being equal, mean watershed ET when lateral redistribution is included is 33% higher than when watershed is run assuming no-lateral redistribution.

As we might expect – with lateral redistribution included = similar shape but more large declines AND increases in ET.

Similar, slightly greater large declines in ET,
How does a warming climate influence the likelihood of crossing these thresholds? How do soil/rooting and drainage characteristics impact this relationship?

Decline in Transpiration → Temperature vs. water limited productivity → Drought stress mortality

NPP has similar “messy” threshold, above which additional water does not increase NPP and timing of recharge is important. Temperature does not change this threshold. Warming more frequently shifts to a reduction in NPP – particularly in drier years.
Drought stress mortality potential is much more sensitive to temperature and demonstrates a less clear relationship with precipitation (multi-year process).
Effect of soil/rooting storage uncertainty/variability is greater than CC effect for NPP and ET but reverses for mortality estimates.

What about timing?
Vegetation growth (and water stress mortality) risk are multi-year time scale phenomena and as such are influenced by timing of “wet” (good) and “dry” (stress) years.

SCENARIO: Same total precipitation: 10 years (5 wettest, 5 driest from 50 year record); 5 wet, followed by 5 dry, 5 dry followed by 5 wet, alternating.
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For drier, (mid and low elevation sites), mortality risk is greater for BOTH, wet to dry, and dry-wet, relative to alternating.

Similar to Westerling et al (2007) who show fire risk greatest with wet years following dry years.

Reduced capacity following dry period (leaf drop, low NPP) reduces capacity in subsequent wet years (by a lot!) leading to lower mean NPP (almost ½).
Classifications based on mean annual supply vs. demand (Budyko Curve) give a general sense of shifts between temperature and water limited forests.

Patch-watershed vegetation scale water use in SDS often shift between the two from year to year.

Year to year variation and CC can alter the temporal synchronicity of recharge, leading to departures from annual curves.

Greatest sensitivity to timing shifts with warming occurs in intermediately wet patches/years but both +-. Shifts in the timing of recharge tend to lower ET in wetter years.

Similarly, locations with lateral subsidy can sometimes show greater declines in forest water use (relative to those that do not) – Lateral redistribution overall enhances forest water use.

Forest NPP responses to water availability alter water demand (at short and long time scales) to more closely match that water availability – “Eco-optimality” for water limited environments.

This tends to buffer streamflow responses.

However, responses to multi-year climate forcing patterns – and particularly increases in extremes – can reduce the efficiency of long-term vegetation water use – and are most likely to lead to drought-related disturbances.

Which exacerbate streamflow response.
Tague and Dugger (2010) Ecohydrology and Climate Change in the Mountains of the Western USA – A Review of Research and Opportunities. Geography Compass 4(11): 1648-1663