

Report of the workshop

Hydrologic effects from ecosystem responses to climate change and land use change

Julia Jones

November 8, 2010

An LTER-supported workshop at Sevilleta National Wildlife Refuge, Nov 4-7, 2010

List of attendees:

1. Emery Boose, Harvard Forest (HFR) <boose@fas.harvard.edu>
2. Warren Brown, U. Georgia, brown@cviog.uga.edu
3. John Campbell, USFS, Hubbard Brook EF (HBR) <jlcampbell@fs.fed.us>
4. Dave Clow, USGS, Loch Vale (LOV) <DWCLOW@USGS.GOV>
5. Alan Covich, Univ Georgia, Luquillo (LUQ) <alanc@uga.edu>
6. Irena Creed, U Western Ontario, Canada <icreed@uwo.ca>
7. Cliff Dahm, Univ New Mexico, Sevilleta (SEV) <cliff.dahm@deltacouncil.ca.gov>
8. Nancy Grimm, NSF, Central Arizona-Phoenix (CAP) <NBGRIMM@asu.edu>
9. Kendra Hatcher, Oregon State Univ., (AND) hatcheke@science.oregonstate.edu
10. Julia Jones, Oregon State U., Andrews Forest (AND) jonesj@geo.oregonstate.edu
11. Steve Sebestyen, USFS, Marcell EF (MAR) <ssebestyen@fs.fed.us>
12. Asa Stone, Univ New Mexico, Sevilleta LTER (SEV) <asastone@unm.edu>
13. Robert Warren, Coweeta (CWT) hexastylis@gmail.com
14. Mark Williams, U. Colorado, Niwot Ridge (NWT) <markw@culter.colorado.edu>

Workshop overview:

This workshop explored social and ecological resilience of water yield to climate change, in contrasting regions of the US. We examined evidence for ecological resilience of the water cycle to climate change, defined as the capacity of a hydrologic system to provide a sustained flow of water despite climate warming. We discussed social resilience of the water cycle to climate change, defined as the capacity of a social system to modify water use to provide a sustained flow of water despite climate warming, and its manifestations in various regions of the US and Canada. We examined evidence for climate change effects on hydrology, by season, for LTER and USFS sites in headwaters of major river basins in the US and Canada, identified testable hypotheses to relate climate change and land use to ecosystem response and water yield, as well as to social factors, in the different regions of the US, and outlined potential approaches and analyses to examine ecological and social resilience of water yield in major river basins in the US (Table 1). These ideas will be explored and described in (1) a proposal for a further workshop on social resilience to water in large river basins; (2) a manuscript for the 30-year LTER anniversary in BioScience, (3) additional proposals and manuscripts (see notes below). Major outcomes of the workshop are summarized below.

Findings of a workshop, Social and ecological resilience of water yield responses to climate change: contrasting capacities for adaptation among regions in the US and Canada

Part A: Ecological resilience of water yield to climate change in headwater basins.

1. Long-term records from eleven LTER and USDA-Experimental Forest sites were examined for trends in air temperature, precipitation, and streamflow, on an annual, seasonal, and daily basis. Results indicate that air temperatures have increased for annual daily minimum (CWT, FER, FRA, HBR, HJA, LUQ, MAR) and annual daily maximum (HBR, HFR, LUQ, MAR) temperatures. Increases were observed for daily minimum temperatures in spring (MAM) (CWT, FRA, HBR, HJA, LUQ, MAR), summer (CWT, FER, FRA, HJA, LUQ, MAR), fall (CWT, LUQ), winter (HBR, LUQ, MAR). Increases were observed for daily maximum temperatures in spring (MAM) (CWT, FRA, HFR, LUQ, MAR), summer (FER, LUQ), fall (LUQ), winter (HBR, HFR, LUQ, MAR). Long-term climate records at some sites did not show evidence of warming (NWT, JRN, SEV). Mean daily precipitation increased at (FRA, HBR, JRN, NWT), but did not change at others (CWT, FER, HJA, HFR, LUQ, MAR, SEV). Precipitation at LUQ has declined over the past 100 years. These trends are (?) consistent with regional changes (ref?).
2. Control (reference, untreated) watersheds in headwaters of major river basins are displaying the effects of climate change on hydrology. Annual runoff ratios (Q/P) declined at one site (HJA8). Runoff ratios declined in spring at HBR and HJA. Analysis of daily records showed an advance of a couple of weeks in the pulse of discharge associated with seasonal snowmelt (AND, FRA?, HBR, LOV, MAR). In most cases the pulse of stream discharge associated with snowmelt has shifted earlier by 10-14 days in three-four decades. These trends are consistent with published studies (Steward, Knowles, Cayan, Dettinger, Clow).
3. All sites show some evidence of ecological resilience to climate change effects on hydrology, defined as a lack of hydrologic response despite regional warming of air temperatures accompanied (in some cases) by earlier snowmelt.
 - a. Some sites show no warming, despite regional warming trends (list sites). This lack of response may be attributable to countervailing effects on air temperature such as cold air drainage. Other sites (CWT) show warming despite regional cooling trends; this response may be attributable to reductions in forest cover or other factors.
 - b. There has been no change in spring streamflow at several forested sites lacking snowpacks (AND9, CWT, FER), despite an increase in spring air temperatures at these sites. Possible hypotheses to explain this lack of response include (a) forest vegetation at these sites is adapted to reduce water uptake when vapor pressure is high, (b) increased atmospheric humidity may mitigate changes in vapor pressure, leading to no change in evapotranspiration, (c) forest vegetation at these sites is undergoing

succession involving changes in species composition of leaf area that reduce water use.

- c. At NWT, despite an increase in spring air temperatures and an advance in snowmelt timing, spring discharge rate has not changed. Apparently earlier snowmelt is infiltrating and contributing to groundwater rather than surface flow; a change in the chemical composition of baseflow supports this hypothesis (Williams, unpublished).
 - d. At AND2 and AND8, despite an increase in spring air temperatures, advanced snowmelt timing, and a decrease in spring runoff at the time of snowmelt, there is no corresponding increase in runoff. Apparently conifer forests at this site are adapted to photosynthesize and respire when conditions are favorable, and can utilize the earlier soil moisture made available by earlier snowmelt (Moore, Jones, unpublished data).
 - e. None of the sites which show a shift in spring discharge timing (or a decline in spring discharge) show declines in summer discharge or increases in winter discharge (AND2, AND8, HBR, FRA?, MAR). Apparently climate change effects on runoff ratios do not extend beyond the immediate period of snowmelt in headwater basins – what hypotheses explain this finding?
 - f. The analysis should be expanded to include other basins in clim/hydroDB: Bonanza Creek and Toolik Lake, Tenderfoot EF.
 - g. Additional long-term records not on clim/hydroDB were shown for Luquillo (Alan Covich), Sycamore Creek (CAP, Nancy Grimm), Jemez River, Rio Puerco, Rio Grande (SEV, Cliff Dahm).
 - h. Additional records pertinent to this analysis may be available from USFS-EF sites such as Sierra Ancha, San Dimas, Fraser EF? (Stephen Sebestyen), USGS WEBB sites (Loch Vale, Panola Mountain, Sleeper's River, and two other sites (Dave Clow), and Canada, including Turkey Lake, Carnation Creek (Irena Creed).
4. In summary, headwater basins from LTER and USFS-EF sites provide essential information about the effects of climate change on water yield. This information can serve as a reference for understanding how water yield responses to climate change compare with other effects on water yield, such as land use/land cover change and water withdrawals, in headwater and large basins.
 5. We formulated questions about ecological resilience of hydrologic responses to climate change in headwater basins, including
 - a. How is variability of flow related to major changes in biological diversity (habitat connectivity, suitability)?
 - b. How will changes in hydro regime in different regions influence regional water quality problems? For example, How will changes in snowmelt influence the timing, of the acid pulse in acid-rain-affected basins?
 - c. How will changes in hydro regime in different regions influence coupling of aquatic/terrestrial species?

6. In addition, we formulated questions about how legacies of past practices might affect hydrology in headwater basins, and how hydrologic responses to climate change in headwater basins might affect water availability in larger basins, including:
 - a. How have land use history, disturbance, influenced present-day water yield?
 - b. How is global change being sensed in headwater ecosystems? How are these changes propagating downstream? Do headwater basins matter to the downstream?
 - c. Are tipping points in ecohydro systems different in headwaters vs. downstream?

Part B: Social resilience of water yield to climate change in large basins.

1. We agreed that a key objective for understanding climate change effects is to connect the long-term data on climate and water yield in headwater basins to water availability as experienced by water users. To do this, we must start with an understanding of social resilience to climate change and associated changes in water availability.
2. Social resilience of the water cycle to climate change was defined as successful human behavioral change at the societal level that leads to sustained functioning of a society (Asa Stone). It may occur through mitigation (external, reduces vulnerability to climate change, e.g., by enhancing groundwater recharge) or adaptation (internal, increases resilience to climate change, e.g., by adaptive water management). Factors that influence social resilience include knowledge (vs. uncertainty); ethics (values) – environment, economic, social norm; perceived risk (vs. lack thereof), and culture (way of living)-motivation to maintain a lifestyle.
3. Census data may be a source of information for testing hypotheses about social resilience (Warren Brown). Census data include information on three dimensions: Socio-demographic characteristics (socio-economic status, land use/density, life stages of residents, geographic mobility, racial/ethnic composition), geographic scale (river basin/watershed, economic region/labor shed, local government/municipality, neighborhood/census tract), and time (decade from 1970 to 2010). Census data may be available for large river basins containing LTER or USFS-EF sites and large cities.
4. We formulated a number of questions about social resilience and its relationship to water. These include:
 - a. How are population pressures influencing infrastructure for water and in turn affecting headwater and large basins?
 - b. How may climate change effects on hydrographs influence perceived needs for water management infrastructure?
 - c. How do the inherent socio-ecological characteristics of a region mitigate/exacerbate its water yield response to climate change?

- d. What scale of human behavior data is appropriate to use with climate/eco/hydro data?
 - e. Is there any evidence for (retirement) moves shifting northwards due to a perception of water shortages, Gulf Oil spill, climate hazards?
 - f. What are the implications of climate-related migration patterns for municipal water infrastructure?
 - g. Do small-scale adaptations (in headwaters) for water conservation mitigate or exacerbate adaptive capacity at large basin scale (downstream)?
 - h. Is there an underlying theory that links the downstream perceptions of water availability to the absolute water availability based on headwaters and physical system, that can explain the variety of human responses in different regions or time periods?
 - i. What are the relative thresholds for perception/action in response to different water-related challenges from climate change? Water quality threshold may be lower than water quantity. Thresholds for response to biological impacts (fish kills, algal blooms) of climate change might be even lower.
 - j. How do community level responses vary according to the existence of watershed councils, riverkeepers, etc.?
 - k. What are the causes and consequences of cultural legacies of views toward rivers?
5. We formulated a number of hypotheses about social resilience and its relationship to water:
- a. People respond to climate change impacts that propagate to large basins and not to those confined to small basin scale.
 - b. Urban communities (e.g. Denver vs. Boston) may be highly responsive to water source variability in headwaters that are physically close to them. Perception of scarcity depends on physical proximity and jurisdiction.
 - c. Strategies to seek institutional resilience to water scarcity (e.g, diversifying water sources) may diminish perceptions of scarcity
 - d. Current perceptions of risk are basin on legacies of past water management strategies (Phoenix vs. Tucson).
 - e. Socioeconomic status may interact with regional climate to affect water conservation – e.g., educated people may be more likely to conserve water in a drought-affected area or time period.
 - f. Water use elasticity varies among users, less elasticity for ag, energy, industry compared to residential – map along hydrologic flowpath.
 - g. Social resilience (mitigation, adaptation measures) seem to be conditioned on world view. How can world view be measured? Ethics. World view dataset. Voting records. Political legitimacy.
 - h. Many water management actions are spurred by perceptions of biology associated with water and climate – declining salmon, etc. dam removal.

- i. Many water management actions are spurred by recreational users, who value amenity – water quality.

Part C. Products and further activities from this workshop.

1. Proposals

- a. LTER workshop proposal. Array social, ecological, hydro info along hydro flowpaths. Focus on connecting to end users of water.
- b. Geography and spatial science proposal. Asa Stone, Kelli Larson, etc.
- c. WSC proposal 2011
- d. CNH proposal Nov 2011
- e. Working group proposal for new synthesis center

2. Papers

- a. Bioscience
 - i. Ideas – conceptual model. Show how discharge is related to climate drivers (precipitation, temperature, snow), vegetation and its drivers (successional stage, vegetation type, legacy of disturbance), ecological responders (biota, chemistry), and human responders (water use by agriculture, drinking water, etc.)
 - ii. Study sites: 11-20 LTER, USFS-EF, USGS (?data from Dave Clow?), and Canadian long-term watersheds, in 6 regions of US, plus Canada
 - iii. Budyko curve. To what extent are reference watersheds utilizing maximum possible water, given the energy balance at the site?
 - iv. Climate indices. How is monthly streamflow at various sites coupled to climate indices (sea surface temperatures) from the northern/southern Atlantic, northern/southern Pacific?
 - v. Change in temp, precip, hydro resp by season. How have annual, seasonal, and daily air temperatures, precipitation, and discharge (runoff ratios) changed over the periods of record at the various sites?
 - vi. Land use – forestry experiments, IHA. How has past land use (e.g. forest harvest, agriculture, etc.) altered annual, seasonal, and daily runoff at the various sites? How has the IHA altered compared to the “natural flow regime” at each site?
 - vii. Ecosystem response to hydrologic change. What are the consequences of changes in hydrology for aquatic ecosystems? Examples: acid pulse, disconnection of stream net, refugia, cienaga, endangered species.
 - viii. Social science: how to connect to end users of water. How are downstream users affecting and affected by climate change and water yield? Define social resilience, list some questions, approach, data for future research.
 - ix. Information management: LTER and USFS-EF and USGS sites provide unique long-term datasets on hydrology of headwaters and disturbance

effects on hydrology. clim/hydro DB provides comparable datasets, value of long term records and info mngt.

- x. Why continue LTER?
 - b. Climate effect on potential/actual water use using Budyko curve (Irena Creed et al). The character of annual water balance can be represented on the so-called Budyko diagram, which presents the ratio E/P as a function of E_p/P . E/P (evaporation= $P-Q$ /precipitation) is a measure of annual water balance -- it measures the way rainfall is partitioned into evaporation and runoff. On the other hand, the ratio E_p/P is a measure of the climate, and is called the dryness index (or index of dryness). The radiative index of dryness is the ratio of net radiation to latent heat of vaporization, divided by precipitation (Donohue et al 2007). Large E_p/P (>1) represents dry or arid climate, while small E_p/P (<1) represents a wet or humid climate. Thus the Budyko diagram encapsulates a major climatic control on annual water balance. The results of the simple model essentially produces two straight lines on the diagram: $E/P = E_p/P$ for $E_p/P < 1$ and $E/P = 1$ for $E_p/P > 1$. This can also be written as $E/P = \min \{1, E_p/P\}$ (Sivapalan, unpub.). In this paper we will use data from reference (and treated?) watersheds at LTER, USFS-EF, and Canadian experimental watershed sites, to test the hypotheses: (1) long-term mean values from reference watersheds fall on the Budyko curve, indicating that the vegetation water use at these sites is close to the maximum possible under these climate conditions, and (2) annual values from reference watersheds may depart from the Budyko curve, indicating either (a) inability of vegetation to use water under certain transient climate conditions, or (b) legacies of past disturbance that may limit vegetation water use.
 - c. DOC export trends and causes (John Campbell et al). Conduct intersite comparative analysis of trends in DOC export from headwater streams and evaluate alternative hypotheses. Could be combined with experiments. Sites interested: Hubbard Brook, Loch Vale, Harvard Forest, Marcell, Miwot, all of Irena's catchments, Sycamore Creek (CAP), Luquillo, Andrews, Sevilleta? Could do ratioing with DON:DOC, DOP:DOC. Check DOC/NO₃ ratio versus NO₃. Taylor and Townshend Jan 2010 in Nature. Carbon-limited versus N-limited system.
 - d. Climate indices and hydro trends (Robert Warren, Stephen Sebestyen, Kendra Hatcher et al). How is monthly streamflow at various sites coupled to climate indices (sea surface temperatures) from the northern/southern Atlantic, northern/southern Pacific? How does coupling vary by season? Can past streamflow records be reconstructed? How does last 50 years of record compare with reconstructed records?
 - e. Climate change consequences for hydrology in headwater and large basins. (Kendra Hatcher, Julia Jones, et al). How have annual, seasonal, and daily air temperatures, precipitation, and discharge (runoff ratios) changed over the periods of record at the various sites?
3. Further activities.
- a. Links with CUAHSI/CZO, NEON. (Mark Williams).