WATER RESOURCES IMPACT

DATASETS FROM LONG-TERM ECOLOGICAL RESEARCH (LTER) SITES AND THEIR USE IN ECOLOGICAL HYDROLOGY

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We believe that communication among ecosystem scientists is hampered by the lack of ecologically relevant descriptors of hydrologic properties. To partly remedy this situation, we are attempting to define hydrologic response in ecologically meaningful ways. What this means is :

◆ How do hydrological processes, including the types, rates, timing, and pathways of water throughput at various timescales, influence ecological processes?

◆ What feedbacks and constraints are imposed by ecosystems and landforms on hydrologic processes, including the role of vegetation as a mediator of water input, storage, and usage?

Work in ecological hydrology brings the diverse perspectives of ecologists and hydrologists together into a common framework, and galvanizes insights relevant to terrestrial and stream ecology, geomorphology and biogeochemistry of landscapes, and regionalization and modeling of hydrologic processes over wide space and time scales.

Small paired experimental watersheds, with their long-term monitoring systems for data collection and their integrated ecosystem approach to analysis, have been key to recent advances in ecological hydrology. Decades of work at sites such as Hubbard Brook (Likens *et al.,* 1977; Bormann and Likens, 1979; Likens, 1983) and Coweeta (Swank and Crossley, 1988) have provided fundamental insights into site-level interactions among hydrology, climate, and ecology and their response to human uses. Previous meta-analyses have emphasized the variability in streamflow responses to landuse and climate variability among these in-depth site-level studies (e.g. Hewlett and Hibbert, 1967; Meyer *et al.,* 1993).

Significant advances in ecological hydrology will require collaborative efforts to bring together the original long-term datasets from geographically diverse sites in order to examine them in a common analytic framework. Original long-term datasets include hydrologic and climatic records, as well as data on vegetation and landforms. A common analytic framework means putting data in comparable formats and combining them in comparative intersite statistical and modelling analyses to derive general principles.

To achieve this, a study is currently underway to identify interactions among vegetation, climate, and streamflow for the sites shown in Figure 1. Thus far, work has concentrated on the seasonal variations among the Andrews, Coweeta, Hubbard Brook, Luquillo and Caspar Creek sites, which span a range of precipitation amounts, types, and timing as well as a range of forest vegetation types. However, data have now been collected

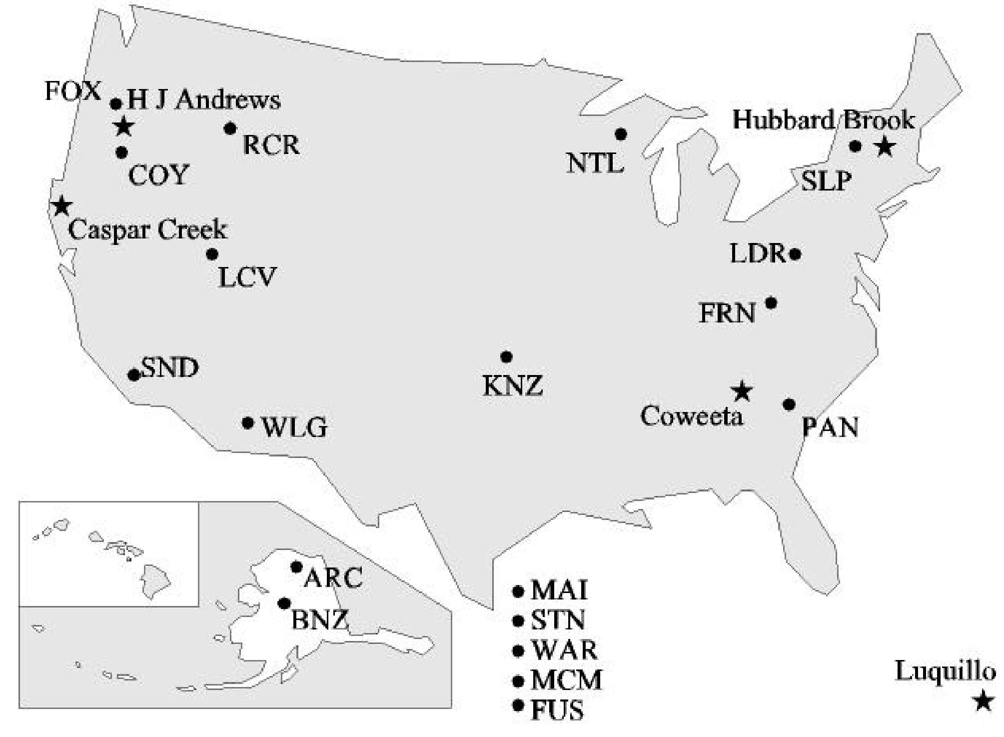

Figure 1. Sites Spanning a Range of Biome Types and Hydroclimatological Regimes Where Long-Term Ecological and Hydrologic Research Have Been Underway for as Long as Six Decades. Sites examined in this paper (marked with a star) include H. J. Andrews, OR; Coweeta, NC; Hubbard Brook, NH; Luquillo, PR; and Caspar Creek, CA. Sites that are currently being incorporated into the study (marked with a circle) include Arctic Tundra, AK (ARC); Bonanza Creek, AK (BNZ); Coyote Creek, OR (COY); Fox Creek, OR (FOX); Fernow, WV (FRN); Fushan, Taiwan (FUS); Konza Prairie, KA (KNZ); Loch Vale, NV (LCV); Leading Ridge, PA (LDR); Mai Mai, New Zealand (MAI); McMurdo Dry Valley, Antarctica (MCM); North Temperate Lakes, WI (NTL); Panola, VA (PAN); Reynolds Creek, ID (RCR); Sleepers River, VT (SLP); San Dimas, CA (SND); Station Creek, Australia (STN); Warra, Australia (WAR); and Walnut Gulch, AZ (WLG).

for the other sites shown in Figure 1, and work will shortly begin on developing an ecohydrological classification scheme across this extended range of sites. The project homepage may be found at http://www.fsl.orst.edu/~post/ hydro.

Sites examined thus far display a range of ecologically-important patterns of seasonal streamflow variability driven by climate-vegetation-streamflow interactions (Figure 2). Climatically-imposed seasonal variation in precipitation is amplified by asynchrony between precipitation and evapotranspiration (ET) at Andrews and Caspar Creek, producing highly variable seasonal streamflow patterns. On the other hand, at Coweeta precipitation is uniformly spread throughout the year, and seasonal variation in streamflow is produced by summer ET. At Hubbard Brook, seasonal variation in streamflow is the result of snowpack storage and melt during the spring period of leaflessness, as well as summer ET. At Luquillo, ET is almost constant throughout the year because of evergreen vegetation, and streamflow response thus displays little seasonal variation.

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This type of cross-site comparison is useful in identifying the relative strength of climate, vegetation, and landscape controls on streamflow generation by holding some factors constant while examining the variation in other factors. For example, Caspar Creek and Hubbard Brook have approximately the same mean annual precipitation (MAP), but mean annual discharge (MAQ) is much higher at Hubbard Brook (Figure 2). This reflects the higher ET at Caspar Creek due to its relatively warm winter temperatures, whereas subfreezing temperatures and leaflessness at Hubbard Brook conspire to store water in plant-unavailable form (snow) while ET is practically zero. Peak runoff at Hubbard Brook occurs in spring during snowmelt when the deciduous trees have not yet begun transpiring, whereas peak runoff in the temperate rainforest at Andrews and Caspar Creek occurs during winter when unfrozen soils and dormant conifers let the high amounts of precipitation pass through the system. Vegetation induces soil moisture deficits and reduces streamflow at Andrews, Caspar Creek, Coweeta, and Hubbard Brook for predictable periods defined by the phenology of the vegetation and the available soil water, but soil moisture surpluses and deficits are not regulated by these processes at Luquillo (Figure 2). Many other similar comparisons and contrasts are possible.

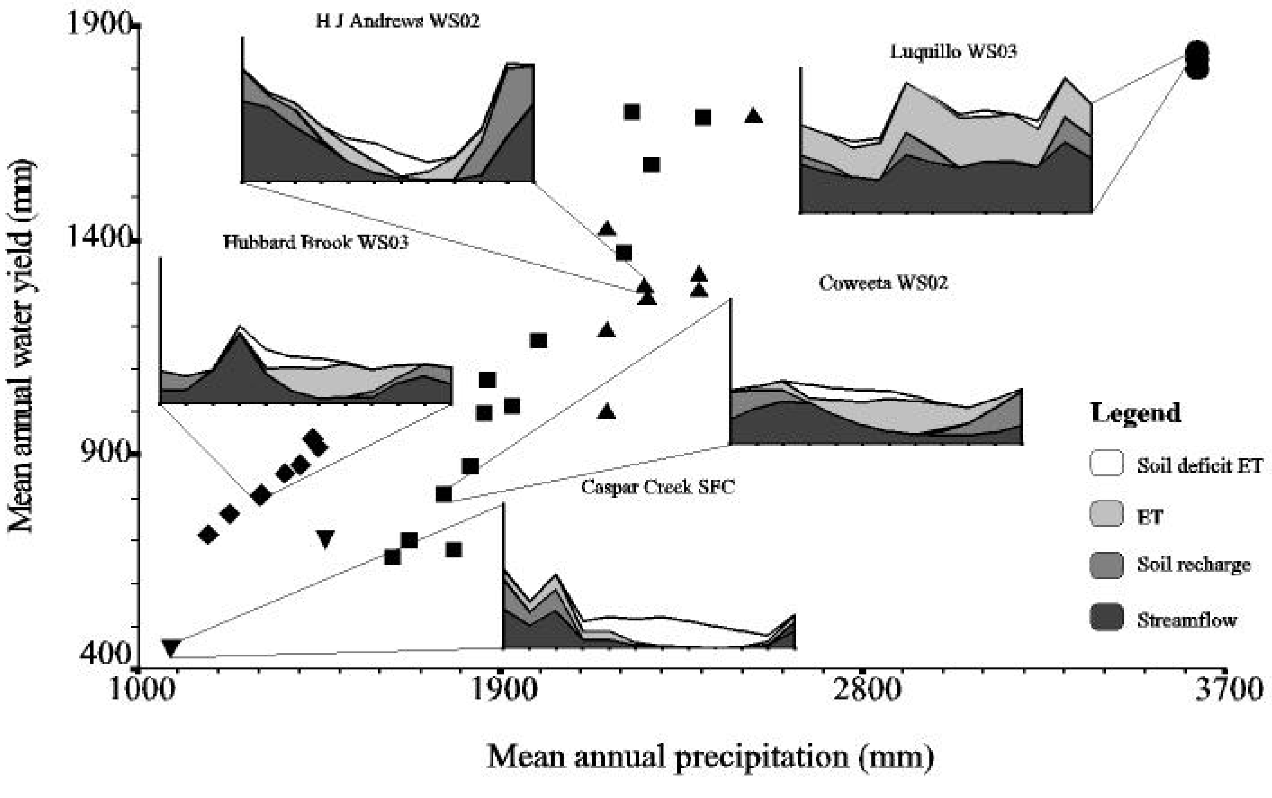

Figure 2. Mean Annual Streamflow Plotted Against Mean Annual Precipitation for Small Experimental Catchments at Five Sites. The distribution of precipitation, streamflow, ET, and soil recharge/deficit throughout the year are shown for one representative catchment at each site. The top of the solid portion represents monthly precipitation. The x-axes range from January to December, and the scale on all five plots is the same, the top of the y-axis being 450 mm.

A workshop held on November 20-21, 1997, and a special session held at the Spring AGU meeting in Boston on May 27, 1998, brought together scientists from the LTER network and USDA Forest Service and Agricultural Research Service experimental watershed study sites to discuss a common framework for comparing climate, hydrology, and vegetation interactions across their widely varying sites. Currently, the controls on hydrologic response are examined on an *ad-hoc* basis, focusing on a particular issue for an individual study. These scientists' interest in a collaborative approach to ecological hydrology reflects, in part, a recognition that their combined long-term datasets have the potential to contribute to issues extending beyond initial treatment effects, to ecosystem analyses and the causes and consequences of vegetation succession, climate, and landuse change.

One commonality emerging from these discussions was the role played by storage at each site. Intersite ecological hydrology comparisons have the potential to reveal the contribution of water storage to daily, seasonal, or inter-annual variability in streamflow. The influence upon streamflow patterns of various forms of water storage – in snow, soil, and forest canopies – varies among sites. Storage is dominant when and where the inputs to that storage are volumetrically and temporally compatible with the volume and rates of discharge from the store. When the temporal distribution or volumetric inputs overwhelm the store, it becomes unimportant. For example, the canopy store at Luquillo is an important process when the inputs of precipitation are relatively small, short-lived, and well-spaced temporally. However, during flood events, the store is overwhelmed by the volume and timing of the inputs, and thus rendered ineffectual. Timing of storage turnover – from daily interception and evaporation of canopy water to seasonal snowmelt and soil moisture drawdown – has critical implications for streamflow, availability of water to vegetation, and key feedbacks to stream ecology by determining the timing of base flow periods when maximum ecological stresses may occur in streams. The degree to which landscapes 'remember' the previous climate is also strongly conditioned by the type of storage (where dominant storages have rapid rates of turnover, little memory may persist, but groundwater dominated systems transmit a water surplus or deficit over periods of years). For example, at Coweeta, with a large volume of soil storage, the effects of a single drought year can be felt for a number of years afterwards. However, the seasonal nature of the snowpack storage at Hubbard Brook means that the effects of a drought are rarely felt even in the following year.

Intersite ecological hydrology comparisons also have the potential to clarify how anthropogenic or natural disturbances produce varying hydrologic responses in different landscapes. Different types of climate-vegetation-streamflow interactions imply that the removal of vegetation will have different, but predictable, impacts on hydrologic response. For example, forest cutting produces increases in streamflow peaks at sites (or during seasons) when transpiration by the undisturbed vegetation accounts for large water losses. Thus, we expect transpiration-related increases in spring and autumn at H.J. Andrews and Caspar Creek, in summer at Coweeta and Hubbard Brook, and all year round at Luquillo. However, forest removal may also produce declines in streamflow at sites (or during seasons) where vegetation modifies precipitation by affecting cloudwater interception or snow accumulation. Examples include interception-related decreases in summer at Caspar Creek, or snow accumulation-related decreases in winter at Hubbard Brook. If consistent relationships between climate, vegetation, landscape attributes and streamflow can be inferred from intersite ecological hydrology comparisons, predictions of the hydrologic response of ungaged catchments may be facilitated.

Ecological hydrology as we have defined it also faces major challenges. Foremost among these is data quality, comparability, and access. The most difficult challenge for ecological hydrology is the lack of hydrologically-relevant data about vegetation, soil, snow, and stream ecology. The importance of such deficiencies depends upon study objectives. For example, critical data are lacking on how vegetation structure affects interception of rain and snow, or how soil water availability and vapor-pressure deficits control transpiration rates for functionally distinct groups of plants. Currently-available vegetation and soil maps are rarely compiled using mapping units that relate to hydrologic function. Many sites also do not have data available in a readily transferable (i.e., computerized) format. To conduct a meaningful ecological hydrology analysis may require re-interpretation of available data, additional mapping, or even detailed field measurements.

Inconsistencies among sites or monitoring periods in the type and quality of precipitation and streamflow data also impose constraints on what we can learn from intersite ecological hydrology analyses. For example, at some sites the raingage network is dense and dispersed throughout the catchment being monitored (Hubbard Brook), while at other sites there may be one raingage per catchment (Coweeta), or a single raingage may be used to determine the inputs for a number of catchments (H.J. Andrews). Similarly, at some sites, the hydrologic data is of high quality, being measured by v-notch weirs (Coweeta, Hubbard, and Brook) while elsewhere, less accurate flumes are used (H.J. Andrews and Caspar Creek), and in some places, no weir or flume is used at all (Luquillo). A major accomplishment of this project will be to collect relevant data from several sites and convert them into consistent formats and units and make them available on the World Wide Web.

Many opportunities remain in ecological hydrology. These initial intersite comparisons were all carried out at an annual or monthly timestep (other ecological hydrology linkages come into focus when data are examined at shorter timescales). A coordinated research program, involving field experiments at plot, small catchment and landscape scales, historical analyses of long-term data, and modeling and simulation, will be required to capture these subtle patterns. Such a research program may also lead to more consistent monitoring of key environmental variables, and promote interactions across sites. The payoff will be an improved understanding of how hydrologic processes both provide the template for ecological systems but are themselves modified by the very ecosystems they support.

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