Evapotranspiration Analysis

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Preface on study task intent

Our primary intent in this study was to measure riparian evapotranspiration at two different sites within the Cosumnes watershed. In conjunction with the hydrology group, we were to estimate the amount of water lost from the hydrologic budget via evapotranspiration and likewise observe the effect of groundwater availability on riparian ecosystem evapotranspiration.

General background on study system

Restored riparian areas including vegetation regeneration needs to be monitored to determine the effects of restoration efforts. A major determinant of restoration involves hydrological cycle modification for the sites. To understand the effects of the hydrological cycle changes, the cycle itself must be studied in depth. Groundwater and vegetation interactions are substantially affected by evapotranspiration dynamics. Our sub-task was to quantify evapotranspiration at two sites, where other data were being gathered by hydrological researchers.

Operational hypotheses

Evapotranspiration from riparian vegetation is greater than that for other dryland ecosystems.

Narrow bands of riparian vegetation (along side streambeds) evapotranspire at higher rates than more extensive riparian forest ecosystems.

Brief methods

At the upstream, Deer Creek Costello site we used an infra-red surface temperature/ aerodynamic resistance method that we developed for use in this riparian area of narrow fetch. Our technique allowed us to estimate the amount of evapotranspiration occurring at the upstream site by measuring surface temperature of the ecosystem (T_s), net radiation (R_n), air temperature (T_a), relative humidity, and ground heat flux (G). Using these direct measurements we estimated the sensible heat flux (H) and the only remaining important unknown component of the energy budget was latent energy (LE), from which evapotranspiration can be calculated directly. The energy budget of the ecosystem is expressed as follows:

$$R_n - G = \overbrace{\frac{\rho \cdot C_p}{r_h}(T_s - T_a)}^{H} + \overbrace{\frac{\rho \cdot C_p[e_s(T_s) - e_a]}{\gamma (r_h + r_c)}}^{LE}$$

LE is solved for as a residual, and converting LE from units of energy (W m^{-2}) to units of mass or volume of water is trivial. The most challenging part of this technique involves estimating aerodynamic resistance (r_h) as a function of wind speed. Our approach was to solve for r_h under simplified conditions, describe this aerodynamic resistance as a function of wind velocity, and then use this estimated resistance value to calculate LE at ½ hour intervals during times when we cannot measure r_h.

At the Accidental Forest site we used eddy-covariance to measure the exchange of sensible heat, water vapor, and carbon dioxide with the atmosphere. Using a fast response three dimensional sonic anemometer and a fast response infrared gas analyzer we measured wind speeds and gas concentrations ten times per second. We then calculated the covariance between the vertical wind speed and the temperature or the gas concentrations, including a correction for the changing density of the air moving through the gas analyzer. Under ideal conditions these covariances calculated every half-hour are equal to net exchange with the atmosphere. The half hour covariances were screened for times when conditions are far from ideal, such as when very stable micrometeorological conditions suppress turbulence or when winds are from directions with low fetch, and this data were removed from the reported results and when the gaps were small the data were replaced using adjacent half hour results.

The complete budget equations involve water vapor exchange caused by both mean flows and the turbulent component of flows. Over a volume of air sampled by micrometeorological sensors, the full equation would be:

$$ET = \int_{h_m}^{r} \left(\bar{\rho} \frac{\partial \bar{s}}{\partial t} - \bar{s} \frac{\partial (\overline{w' \rho'})}{\partial z} + \bar{u} \bar{\rho} \frac{\partial \bar{s}}{\partial x} + \bar{w} \bar{\rho} \frac{\partial s}{\partial z} + \frac{\partial (\overline{w' \rho'_w})}{\partial z} \right) dz$$

where the ET is expressed as a mass flux density, ρ is the dry air density (kg m^{-3}), *s* is the humidity as a mixing ratio (kg H2O per kg dry air), ρ_ω is the absolute humidity (kg water vapor per cubic meter), *u* is the horizontal wind velocity along the mean wind direction, ω is the vertical wind velocity, the overbars indicate ensemble or time averaging, and the primes (') indicate perturbations from the mean values (turbulent contributions). The second term in the integrand is the so called "Webb-Pearman-Leuning" correction (Webb et al., 1980) which can be estimated with reasonable accuracy from the sensible (convective) heat flux density.

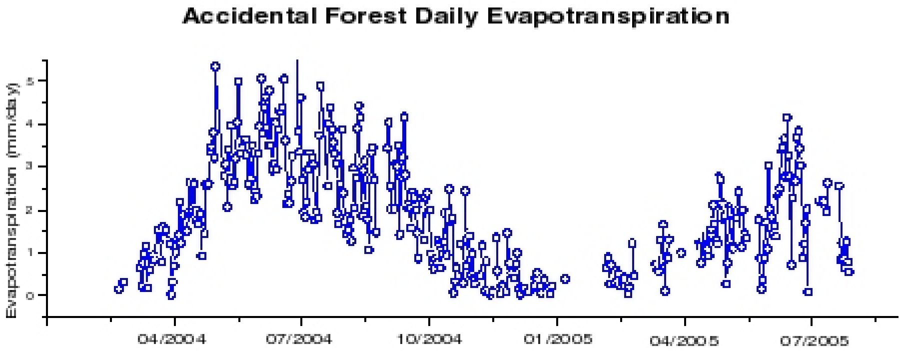
Conventionally, most micrometeorological estimates of exchange fluxes, such as ET, have been made over relative uniform terrain and vegetation over extensive regions, which allows simplification of the energy and mass budget equations to the vertical eddy-covariance of energy or mass, because all of the other terms are close to zero:

$$ET = \bar{\rho}\,\overline{w's'}$$

In this school, followed by most micrometeorologists, one rotates the coordinate system of an anemometer and forces the mean vertical velocity ω to zero to eliminate the mean flux term. However, exchange from a riparian system could not be estimated so simply, because the vegetation was not extensive nor was it uniform.

Key findings

During the measurement period (2004-2005) at the Accidental Forest the Cottonwood (*Populus fremontii*) dominated forest appeared to always have free access to ground water, although its ability to photosynthesize may have been affected adversely by persistent late season flooding. Net daily evapotranspiration rates in millimeters are below.



At the Deer Creek Costello site evapotranspiration rates were higher for the stand of willows we measured, but in general much less of the riparian area is covered with trees. During the summer, when the potential for evapotranspiration is highest, much of the area is covered with dead grasses. As a result the net evapotranspiration including the grass and the trees at the Deer Creek Costello site is much lower than the evapotranspiration rates measured at the Accidental Forest. Unlike the Accidental Forest the vegetation we monitored at Deer Creek experienced water stress during the measurement period. This is due to the fact that in this area the trees use water from perched aquifers during the summer, and these aquifers can dry up seasonally depending upon the timing and the strength of rainy season recharge. See Niswonger et al. (in review) for a more in depth analysis of hydrologic support of evapotranspiration at this site.

Recommendations for management & monitoring

Evapotranspiration from narrow strips of vegetation can be monitored using a method we developed in this project.

Eddy-covariance can be used for evapotranspiration measurements over more extensive regions of vegetation than narrow riparian strips.

Reference

- Niswonger, Fogg, Kochendorfer, Paw U, Dahan, and Stewman (in review) *Support of phreatophyte vegetation by heterogeneous-alluvial deposits in a water-stressed environment* (Water Resources Research)