Bio-hydro-micrometeorology of a Sierra Nevada montane meadow

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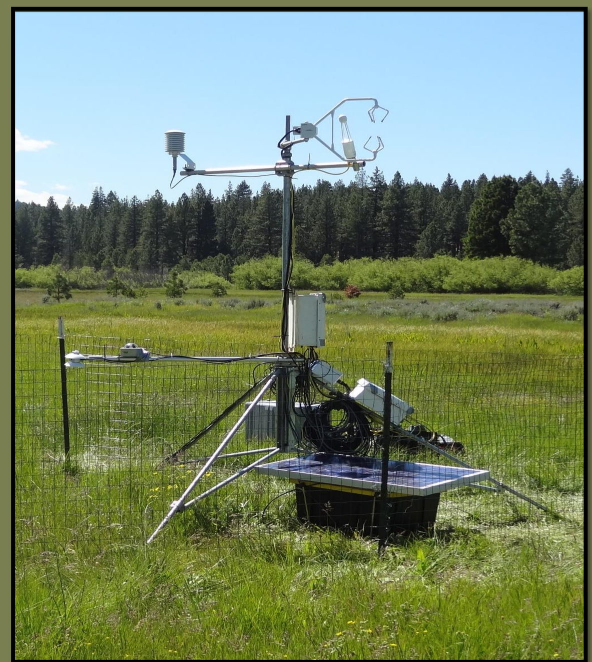


Figure 1 left: Micrometeorological equipment at Knuthson Meadow, June 15th-July 15th, 2012. See instruments in Table 3

Figure 2 left: Knuthson Meadow July 2012.

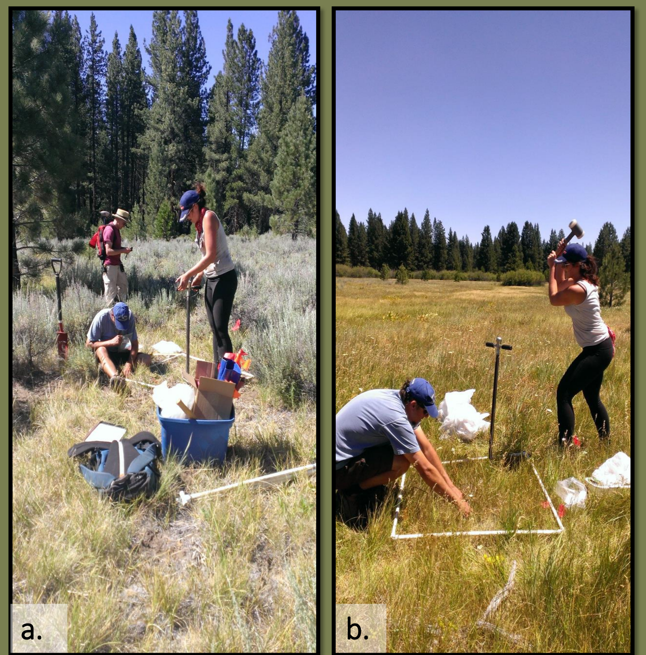


Figure 3 right: Vegetation and soil sampling of (a.) Carmen Creek (degraded meadow) and (b.) Knuthson Meadow (restored meadow) on July 3rd, 2014.

Introduction:

Montane meadows of the Sierra Nevada commonly support riparian wetland ecosystems found at elevations between 600 and 3,500 m where sediment or low permeable soils accumulate on an impermeable surface and result in water accumulation. Healthy meadows store, filter, and regulate water and support hydrologic systems by capturing bed load and reducing erosion. The high soil moisture levels support diverse plant and wildlife communities.

Most montane meadows in the Sierra Nevada are degraded due to local historic land use such as grazing, logging, mining, road and railroad construction, and dams and diversions. The impact of which is channel incision and a lowering of the water table. As the meadow dries out, the diverse wet meadow plant species, such as sedges and rushes, transition to dry meadow species such as sagebrush. Dry meadows support a significantly lower biodiversity and have a diminished positive impact on the hydrology of California.

A relatively new "pond and plug" restoration technique is being utilized by Tahoe National Forest and Feather River Coordinated Resource Management in select meadows to restore the high water table.

Figure 4: Eroded gully in Knuthson Meadow before restoration. Predominantly xeric plant community (Photo courtesy of Paul Jones, EPA).

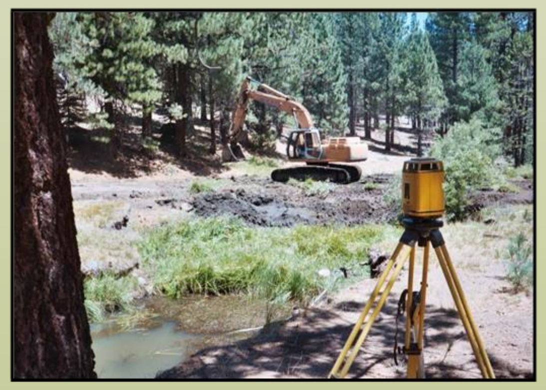


Figure 5: Example of pond and plug restoration at Two Cone Meadow (SVRCD, 2004)

Figure 6: Knuthson Meadow after restoration in the spring of 2004 (SVRCD, 2004).

The **objective** of this research is to investigate montane meadow systems using an interdisciplinary approach to shed light on the interactions between land, water, plants and atmosphere in these important mountain landscape features. In particular we aim to:

- Compare vegetation and soil characteristics between a degraded and restored meadow in the same valley; and
- Investigate surface-atmosphere interactions in the restored meadow using eddy covariance, with particular focus on energy, water and CO_2 exchanges.

Study Site: Upper Feather River, Sierra Nevada

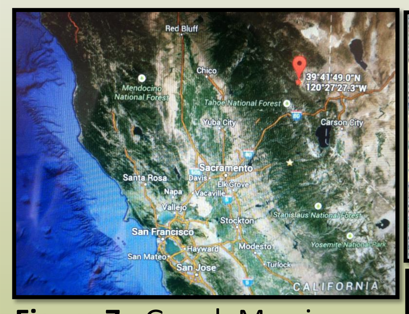
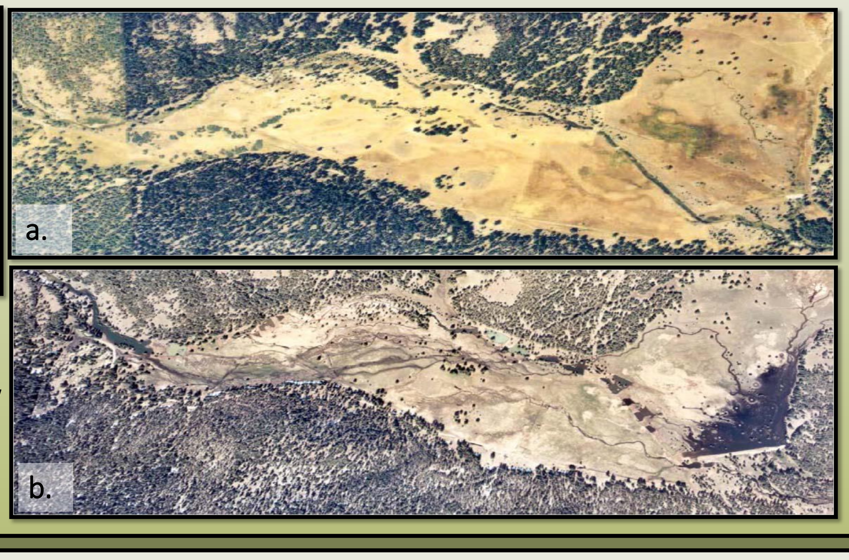


Figure 7: GoogleMap image of Northern California



Figures 8: Knuthson Meadow before (a) and after (b.) 2001 restoration (SVRCD, 2004).

Knuthson Meadow is located in Sierra County at 1507 m and has an area of approximately 60 Ha (150 acres).

The pond and plug method was used to restore the meadow which recovered a high water table along with long lasting, low intensity saturating flow improving water quality, yield, and timing.

Biogeomorphological research in restored montane meadows

Studies of channel development in montane meadows with small watershed areas similar to Knuthson (30 km²) have revealed a system that exhibits considerable influence of vegetation and soil properties on bedforms. Willow (*Salix*) is the most common tree species and is a significant planform control of channel development. In many of these small channels, especially those reoccupied after meadow restoration, thickly sodded soils formed under sedge (*Carex*) cover creates a longitudinal profile (Fig. 9) illustrating an energy dissipation system with high roughness cross-sedge flows and step pools formed where the resistant sod is penetrated (Fig. 10).

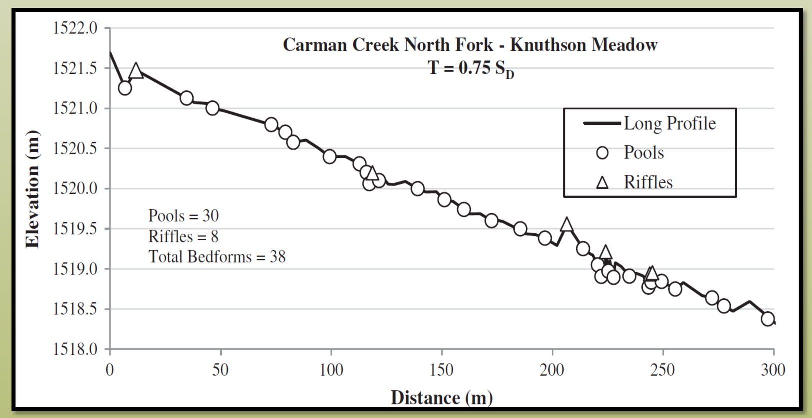


Figure 9: Longitudinal profile of a post-restoration channel near the head of Knuthson Meadow.

Figure 10: Step and scour pool cut into a thickly sodded *Carex*-dominated wet meadow soil

Comparison of vegetation and soil between a degraded and restored meadow:

Sampling and analysis of vegetation and soil from the restored meadow (Knuthson) and a nearby degraded meadow (Upper Carmen) were used to compare ecosystem characteristics including; species composition and cover, above ground and below ground living biomass, and soil moisture and organic content. Three distinct vegetation communities were found (Table 1).

Table 1: General features of the three plant communities documented at the two meadow sites.

	Restored Meadow Swales (RMS)	Restored meadow (RM)	Degraded meadow (DM)
Microscale topography	Low relief swales and perennial channels <0.3 m deep	Wide, flat interfluves	Gently sloped surface Incised by 3 m deep gully
Soil Moisture	Wettest	Moist	Dry
Primary Vegetation	Perennial graminoids (mainly sedges)	Mixed grass, herbaceous	Non-native grasses and sagebrush dominant

Fieldwork: 1m² plots were randomly established for each of the three distinctive plant communities found (RMS & RM n=6, DM n=8). Above ground vegetation was hand clipped at ground level from 10x10cm square within the plot. Dead biomass was discarded. Root samples were taken from the 1000 cm³ soil volume directly below the vegetation sample. Field work was conducted on July 3rd 2014 (Figure 3).

Laboratory analysis: Above ground vegetation and washed roots were oven dried at 70 C for 24 hrs in a well ventilated oven. Soil percent composition was determined by weight. Soil sample dried at 105 °C for 24hrs in a well ventilated oven. Furnaced at 360 °C for 2 hrs to incinerate organic content. Mineral content was determined as the residual. Soil texture was determined by measuring sediment suspension in a 5 % Calgon solution.

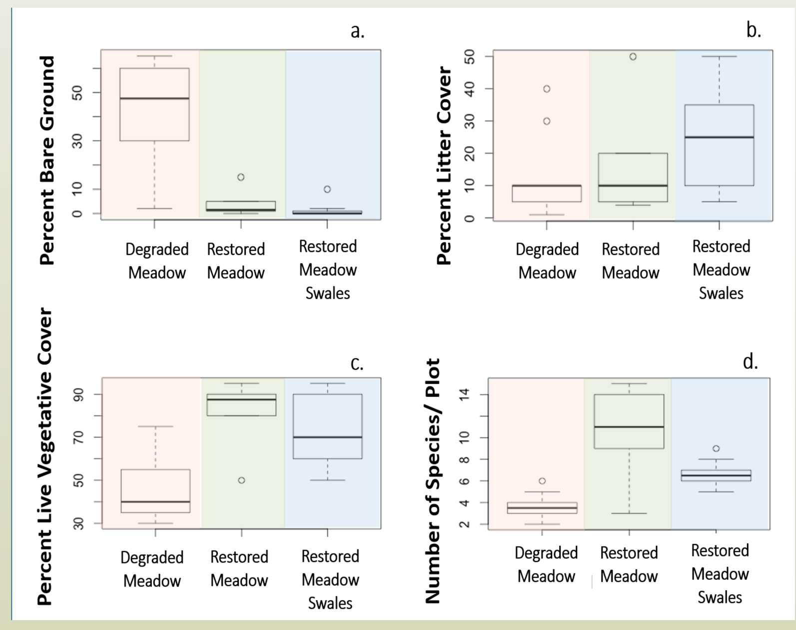


Figure 11: Characteristics of the three dominant plant communities

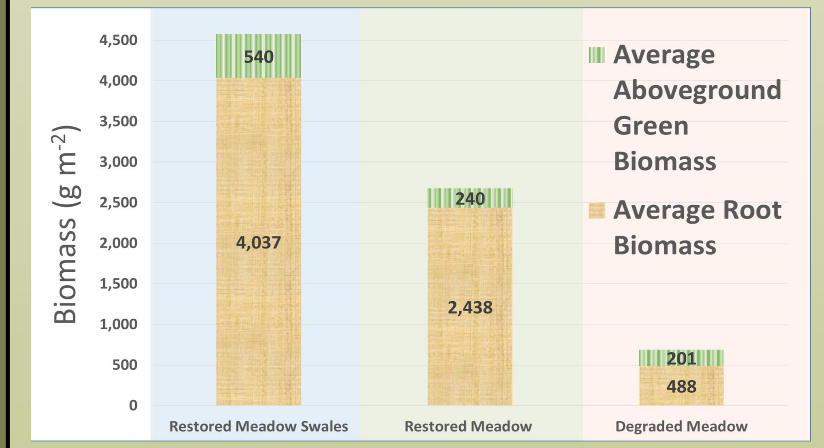


Figure 12: Above and below ground biomass for the three plant communities

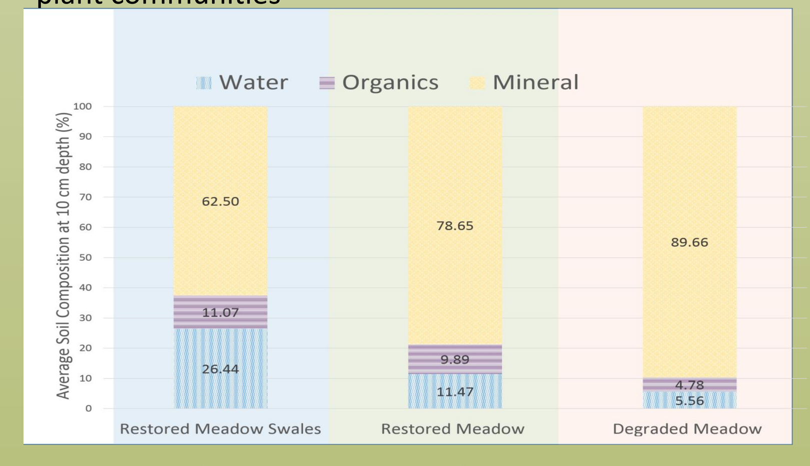


Figure 13: Relative proportions of mineral, organic and water content in soils

Table 2: Average and standard deviation of plant and soil characteristics in the three main plant communities

	Restored Meadow Swales		Restored Meadow		Degraded Meadow	
	Av	**SD**	**Av**	**SD**	**Av**	**SD**
Aboveground living biomass (g m⁻²)	539	145	239	112	201	280
Roots (g m⁻²)	4036	1597	2437	1289	488	499
Soil water content - 10 cm (% by weight)	26.4	3.4	11.5	3.7	5.6	2.7
Soil organic content - 10 cm (% by weight)	11.1	1.7	9.9	2.6	4.8	1.4
Soil mineral content - 10 cm (% by weight)	62.5	3.9	78.8	5.7	89.7	3.7
% Clay content -10 cm	3.6	0.9	3.3	2.0	3.4	1.8
% Silt content -10 cm	14.9	4.7	18.7	5.8	21.0	8.3
% Sand content -10 cm	81.5	5.1	78.0	7.2	75.7	8.5
Soil organic content -50 cm (% by weight)	3.4	2.9	4.0	1.5	4.0	1.9

Key findings: The degraded meadow (DM) had much lower biomass, plant cover and species diversity than the restored meadow. The DM was dominated by non-native grasses, woody shrubs and sedge. It appeared to be excessively drained with low water and organic content of the soil.

Of the two distinct communities within the restored meadow, the swales (RMS) had the higher biomass, litter, soil water and organic content, suggesting that it is the more productive of the two. The wide flat interfluves in the restored meadow (RM) contained about half the biomass but more than double the species richness.

Though the sample size was small, all differences in ecosystem characteristics between the three communities were strongly significant (p-value < 0.02) except organic content of the soil between RMS-RM, above ground biomass between RM-DM and the soil texture at all locations. When applied to a soil texture triangle, the samples were found to be either sandy loam (5 samples) or loamy sand (7 samples).

Ecosystem-atmosphere water, energy and CO_2 exchanges:

Micrometeorological variables and terrestrial ecosystem exchanges of CO_2, water vapor, momentum and heat were measured using instruments mounted on a tower at 3 m in Knuthson Meadow June 15 –July 15, 2012 (Figure 1 & Table 3). 30-minute block covariances were used to calculate mean convective fluxes. **Data rejection:** (1) Friction velocity (u*) < 0.15 m/s due to low turbulence to avoid the underestimation of flux variables (2) Data that fell out of plausible thresholds (3) when the 90% boundary of the flux source area fell outside the meadow boundary. The source area of the EC measurements contained approximately half RMS and RM communities. Ground heat fluxes were measured at 5 cm and the storage of heat energy in the soil column above this was estimated using a spatial averaging thermocouple and soil moisture probe

Table 3: Equipment	Variable Measured	Value	Height of Instrument
CSAT3 3D Sonic Anemometer	3-D wind speed and sonic temperature	m/s	2.4 m
LiCor 7500 Infrared Gas Analyzer	CO2, water vapor	%, mg/m³	2.4 m
HMP45C Thermistor	Ambient Temp.	C	2.4 m
HMP45C Hygristor	Humidity	%	2.4 m
NR01 Pyranometer	Short wave radiation	W m²	1.5 m
NR01 Pyrgeometer	Long wave radiation	W m²	1.5 m
CS107 Ground Temp. Sensors	Soil Temp	C	Depth 5 & 10 cm
E-type Thermocouple	Soil Temp	C	Between 0-5 cm
HukseFlux Heat Flux Plates	Soil heat flux	W m²	5cm
CS616 Soil Moisture Probe	Soil moisture content	%	0-15 cm

Surface heat fluxes: The diurnal ensemble (hourly average) and daily total heat budget components were calculated for the entire study period as well as for each of the four weeks of the experimental period. The main feature of the change over time was the shift from spring moist conditions to summer dry conditions.

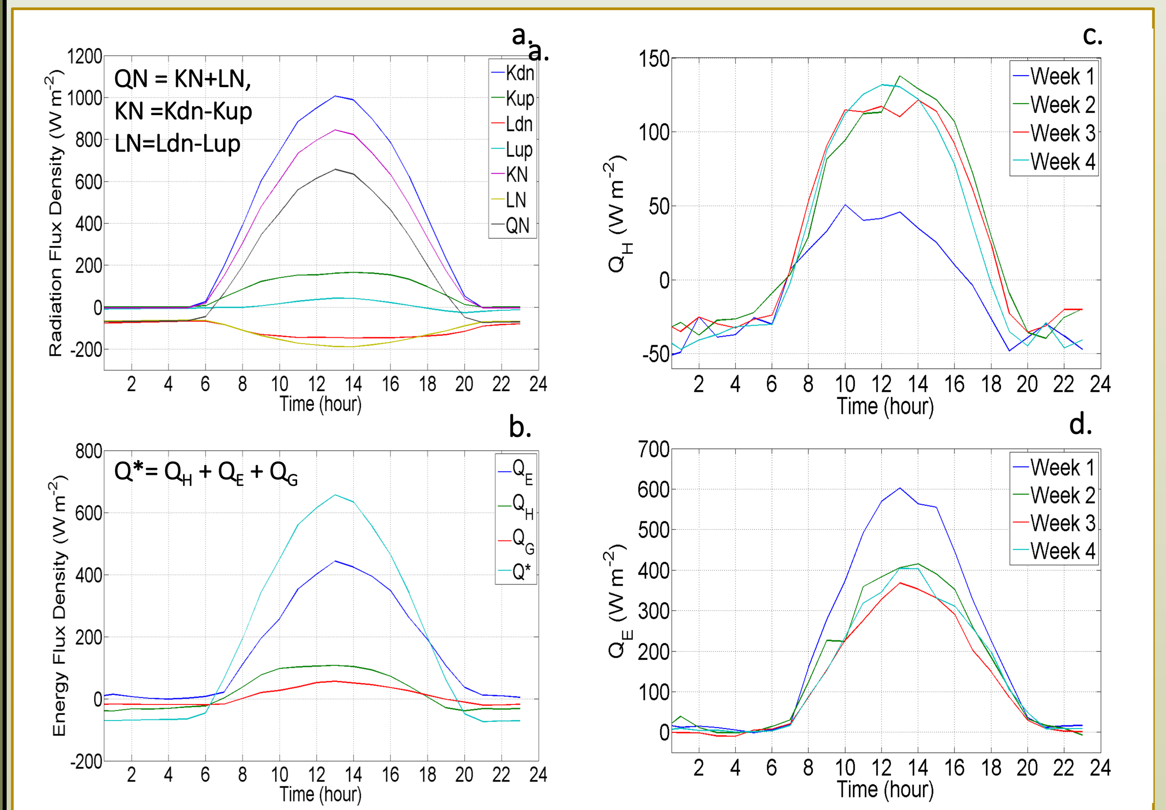


Figure 14: Hourly ensemble averages of **(a)** surface radiation budget, where QN is net all wave radiation which is governed by the balance of incoming (dn) and outgoing (up) shortwave (K) and longwave (L) radiation, **(b)** surface energy balance components of energy flux density where Q_E is the latent heat flux (heat released or absorbed in phase change), Q_H is the sensible heat flux (heat energy transferred by convection) and Q_G is the ground heat flux, **(c)** Q_H and **(d)** Q_E for each of the four weeks in the observation period.

Available energy (QN) is predominantly utilized by evapotranspiration, with very low Bowen ratios by comparison to global ecosystems. This increases over time as soil moisture declines. The negative Bowen ratio in Week 1 and late afternoon negative Q_H suggests an **Oasis effect**, whereby relatively warm dry air imported from surrounding terrain enhances ET (Q_E) to the point where it can be larger than the energy that QN provides.

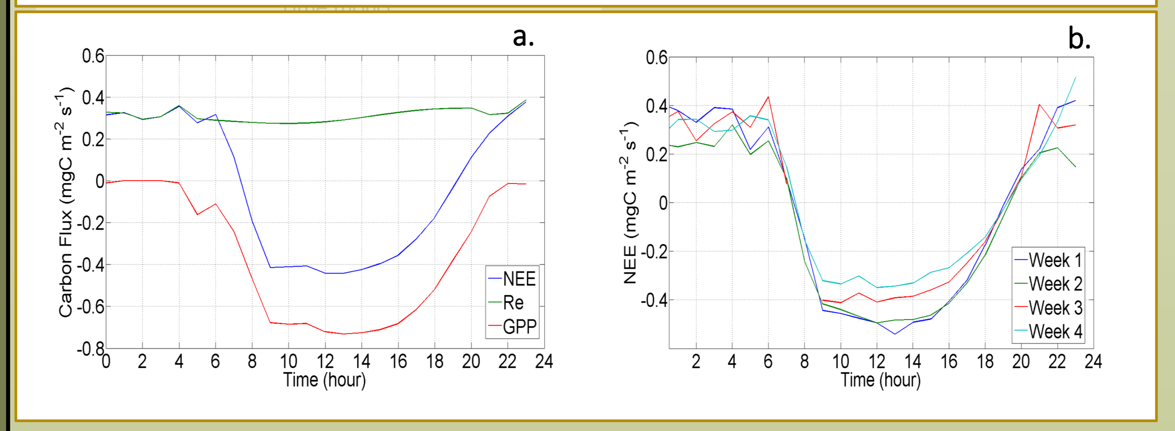


Figure 15: Diurnal ensemble average carbon fluxes **(a)** for the entire study period and **(b)** on a weekly basis, where NEE is the net ecosystem-atmosphere flux of CO_2, GPP is gross primary production and Re is ecosystem respiration. Negative CO_2 values represent carbon uptake by the ecosystem.

Table 4. Diurnal total fluxes and derivatives	Total Study	Week 1	Week 2	Week 3	Week 4
Albedo	0.189	0.187	0.191	0.186	0.192
Bowens Ratio (Qh/Qe)	0.127	-0.04	0.20	0.24	0.16
Evapotranspiration (mm d⁻¹)	5.29	7.19	5.26	4.27	4.80
QN (MJ m⁻² d⁻¹)	15.89	16.97	15.81	16.26	14.83
NEE (gC m⁻² d⁻¹)	-2.32	-1.85	-7.21	-2.09	1.62
PAR	784	792	761	799	781
Soil water Content (% vol)	15.40	19.48	15.62	14.32	13.26
Soil Temperature 10 cm (°C)	17.54	16.99	16.27	17.63	18.83
Air Temperature (°C)	16.25	17.14	12.01	16.53	18.60
Specific Humidity (g kg⁻¹)	5.74	5.47	5.01	7.08	5.42
Mean Wind Speed (m s⁻¹)	2.23	2.15	2.36	2.18	2.26

The large daily GPP and Re values (approximately -30 and +27 gC m⁻² d⁻¹ respectively) produce a relatively small average sink of CO_2 over the study period (Table 4). A large reduction in soil moisture content over the study period correlated with a shift in NEE from a sink to a source of atmospheric CO_2. The largest sink occurred in the second week of study, when the strongest environmental difference was relatively low temperature, suggesting the increase in sink was due to a lowering of ecosystem Re.

Both the overall magnitudes of carbon fluxes and their sensitivity to soil moisture are comparable to observations of grassland CO_2 fluxes elsewhere. This illustrates the important impact that restoring meadow water table levels has on increasing ecosystem biomass, biodiversity and atmospheric carbon uptake as well as their cooling and humidifying impact on the overlying atmosphere.

Acknowledgments

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References

Sierra Valley Resource Conservation District (SVRC), 2004. Carmen Valley Watershed Restoration Project. State Water Resources Control Board-Proposition 204 Agreement. November 2004 FINAL REPORT.