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Long-term lysimeter database, Reynolds Creek Experimental Watershed, Idaho, United States

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Abstract. We describe long-term lysimeter data collected at the Reynolds Creek Experimental Watershed. The length of record is >15 years for lysimeters at two sites representing different soil and climatic conditions. These data describe changes in soil water during the snow-free season. In addition to measuring changes in total soil water, soil water content profiles and soil temperature profiles were measured within or adjacent to the lysimeters and are reported in accompanying reports. These data are available to the public via the U.S. Department of Agriculture, Agricultural Research Service, Northwest Watershed Research Center anonymous ftp site ftp.nwrc.ars.usda.gov.

1. Introduction

Lysimeters are instruments that measure water and/or solute movement in soils [*Howell et al.*, 1991]. In this report we describe lysimeters designed to measure the net movement of water across the soil-atmosphere boundary. Lysimeters have been used extensively for this purpose for many years [*Tanner*, 1967]. Although there is great variety in lysimeter design, two types are generally recognized, weighing and nonweighing lysimeters. With nonweighing lysimeters, changes in soil water content are determined indirectly. With weighing lysimeters, changes in soil water within a constructed container are measured. The lysimeters on the Reynolds Creek Experimental Watershed (RCEW) are weighing lysimeters.

The primary purpose for these lysimeters was to measure evapotranspiration (ET). Calculation of ET for a specified time period is based on the following equation:

$$\mathrm{ET} = P - (V_L + V_R + \Delta V_S)/A, \tag{1}$$

where P is precipitation (millimeters), V_L is the volume drainage loss (cubic millimeters), V_R is volume of net surface runon/runoff (cubic millimeters), ΔV_S (cubic millimeters) is the change in the volume of soil water in the lysimeter, and A (square millimeters) is the area of the lysimeter [*Tanner*, 1967]. If the lysimeter is well sealed and overland flow is prevented, V_L and V_R are 0. Therefore ET can be calculated from measured values of P, A, and ΔV_S. Enclosed lysimeters of the type used at the RCEW measure weight-induced pressure changes for a known constant soil volume. Measured weight changes are attributed to changes in soil water and converted to a volumetric basis. These are reported as the lysimeter water content change per unit area ($\Delta V_S/A$ or ΔW) in millimeters of water as is precipitation. In this report we describe how the data were collected, assess the measurement accuracy, and illustrate applications of the data. A more detailed description of the lysimeter calibration and performance is given by *Seyfried et al*. [2000].

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2. Lysimeter Description

Two pairs of soil lysimeters were installed in the RCEW in 1967, one pair at the Lower Sheep Creek climate station (designated the east and west lysimeters), separated, center to center, by 3.6 m, and the other pair at the Reynolds Mountain climate station (designated north and south), separated by 4.7 m [see *Slaughter et al*., this issue, Plate 3c]. These lysimeters were hydraulic weighing lysimeters [e.g., *Tanner*, 1967; *Kruse and Neale*, 1991] in which an inner cylindrical tank containing soil is set within a slightly larger outer cylinder. The inner cylinder rests on a coil of 0.05 m diameter butyl tubing filled with liquid (different low-freezing point liquids were used). The inner cylinder was 1.22 m deep and 1.47 m in diameter. The butyl tubing was hydraulically connected underground to a pressure transducer or manometer. Changes in pressure were related to changes in weight of the lysimeter, hence ΔW, via calibration.

The soil in each lysimeter was extracted from near the lysimeter sites. A soil core was taken by repeatedly excavating a soil cylinder of slightly larger diameter than the lysimeter and forcing the lysimeter sleeve over the soil to the depth of the sleeve (1.22 m). A metal plate was then forced across the cylinder bottom and welded to it in place. The inner cylinder, thus filled with soil, was then transported to the previously excavated outer cylinder via crane and set on the butyl tubing. A neutron probe access tube was installed in the center of each lysimeter [*Seyfried et al*., this issue (b)] to monitor soil water content changes with depth, and two 1.2 m ceramic suction "candles" were placed at the bottom of the lysimeters through a separate entrance.

This operation resulted in an undisturbed soil monolith with extant vegetation in place [e.g., *Schneider and Howell*, 1991]. This is critical for two reasons: (1) Growing native vegetation under natural conditions is problematic in this environment, and plant development is slow. (2) The soil horizonation, particularly the argillic and calcic horizons which are both strongly embedded in coarse fragments, would be essentially impossible to reproduce artificially.

The vegetation at the Lower Sheep Creek site is dominated by low sagebrush (see *Seyfried et al*. [this issue (a)] for vegetation distribution) which grows to a height of ~0.3 m and is accompanied by perennial bunchgrasses and forbs. The per-cent vegetative cover is typically around 40%, and individual shrubs are separated by ~1 m. The two lysimeters each contained a mature shrub along with the naturally associated plants, which resulted in a slightly higher vegetative density than the surrounding landscape. The leaf area index (LAI) for each of the lysimeters, which varied seasonally from 0.3 to 1.5, was monitored several times each year using the point quadrature method [*Clark and Seyfried*, 2001]. Measured LAIs at the two lysimeters were nearly identical.

The vegetation near the Reynolds Mountain site is dominated by mountain sagebrush, which is taller (height is ~0.6 m) and usually grows more densely than low sagebrush. These two lysimeters also contained a single shrub. As at Lower Sheep Creek, the timing and magnitude of LAI changes are practically identical at the two lysimeters. Measured LAI ranged from 0.5 to 2.0 seasonally and was also a little higher than LAI observed over most of the area. The date of maximum LAI at Reynolds Mountain occurs ~40 days after that at Lower Sheep Creek reflecting the deeper, later lying snowpack, cooler air temperatures, and greater precipitation at Reynolds Mountain.

The soils at the RCEW are described by *Seyfried et al*. [this issue (a)], and more detailed soil profile descriptions are referenced by *Seyfried et al*. [this issue (b)]. The soil at the Lower Sheep Creek site was formed in welded tuff. The fine earth fraction texture is loam in the upper 10 cm which is underlain by a strongly contrasting argillic horizon that has up to 50% clay. The texture beneath the argillic horizon, from 60 to 122 cm, is sandy loam. Coarse fragment content varies with horizon but averages about 0.40 kg/kg. Calcium carbonate is visible below 60 cm. A discontinuous duripan was noted by surveyors. The soil at Reynolds Mountain was also formed in welded tuff. The fine earth textures are loam throughout with a weak argillic horizon at 60 cm depth. Coarse fragment content varies little with horizon and averages about 0.55 kg/kg.

3. Data Collection

Although the lysimeters became operational in 1968, there were a number of problems associated with the measurement instrumentation, and consistent digital data are not available until 1976 at Lower Sheep Creek and 1979 at Reynolds Mountain. Data collected through 1984 are daily or monthly values. Each year data were recorded from spring until fall, starting with $\Delta W \approx 0$ mm each spring. Thus the last ΔW reading each year represents the net ΔW for that time interval. During 1984, digital data logging systems were installed that recorded hourly values all year. Hourly data are reported from January 1 of 1985 through 1991. Lightening strikes in 1992 interrupted data collection, and the systems were discontinued.

4. Calibration

All four lysimeters were calibrated each fall. The calibration procedure was to place known weights on the lysimeters and then to record the resultant pressure changes. The weights used were as follows: 19.9 kg for supportive blocks placed on the lysimeter, 43.4 kg for the tank which contained the weights, and then twenty-four 22.7 kg sacks of rock added in four-sack increments. The weight of each sack corresponded to about a 13 mm addition of water, so that weight increments were equivalent to ~52 mm and the total range was ~360 mm of water. Measurements were made both as weight was added and removed.

The coefficient of determination (r^2) between measured pressure and added weight for each individual lysimeter was very high (≥0.99). Since difference alone is of interest and the relationship was linear, the calibration required to convert measured pressure changes to ΔW is simply the slope of the pressure-weight (converted to water volume) relationship. The measured calibration constants (slopes) were significantly different among individual lysimeters. There was no significant ($\alpha = 0.05$) difference between calibration constants measured while adding or subtracting weight for the years investigated, indicating that the butyl tubing was appropriately filled [*Kruse and Neale*, 1991]. In addition, there was little change in calibration constant or precision over the years and no apparent trend. We therefore represented each lysimeter with a single calibration constant.

The 95% confidence interval about the mean calibration constant was 0.796 Pa/mm H_2O at the Reynolds Mountain south (RMS) lysimeter and 0.8895 Pa/mm H_2O at the Lower Sheep Creek west (LSCW) lysimeter. For perspective, a change in calibration constant to the extreme of the 95% confidence interval for a year in which $\Delta W = 200$ mm (which is common) resulted in a deviation of ±5 mm at the RMS lysimeter and ±8 mm at the LSCW lysimeter. Thus year to year variation in calibration should have little effect on lysimeter measurements.

5. Lysimeter Performance

Despite excellent calibration statistics for all four lysimeters, comparison of the paired lysimeters often reveals considerable differences. For example, in 1987 at Lower Sheep Creek the paired lysimeters agreed closely at the beginning and end of the year but differed by as much as 70 or 80 mm during the year (Figure 1). Thus either at least two of the lysimeters (one at each site) did not represent soil water dynamics well, or those dynamics were quite different for each individual lysimeter. The second explanation seems unlikely given that the lysimeters were in practically the same location with practically the same soil and vegetation.

Values of ΔW calculated from complimentary neutron probe measurements were very similar for each lysimeter pair (e.g., Figure 1). Linear regression statistics for ΔW between paired lysimeters for the period of record support this with high r^2 values (0.98 at Reynolds Mountain and 0.96 at Lower Sheep Creek), slopes near 1.0 (0.96 at Reynolds Mountain and 1.03 at Lower Sheep Creek), and y intercept values near 0 (−0.11 at Reynolds Mountain and 0.18 at Lower Sheep Creek). We therefore concluded that the soil water dynamics were similar for both lysimeters at each site.

Furthermore, we found that the neutron probe–calculated ΔW generally agreed closely with that calculated from at least one of the two lysimeters at each site (e.g., Figure 1). This relationship is described in more detail by *Seyfried et al*. [this issue (b)]. When these two independent measures of ΔW are in agreement, then it is likely that both are reasonably accurate because it is very unlikely that bias in either approach would be exactly matched by bias in the other. Therefore we have included lysimeter data for which the ΔW calculated using both approaches is in close agreement. This resulted in two consistently functioning lysimeters, at RMS for 12 years and at LSCW for 15 years (Table 1). We have no good explanation for the fact that while the calibration statistics for the four lysimeters were similar, two of the lysimeters did not seem to func-

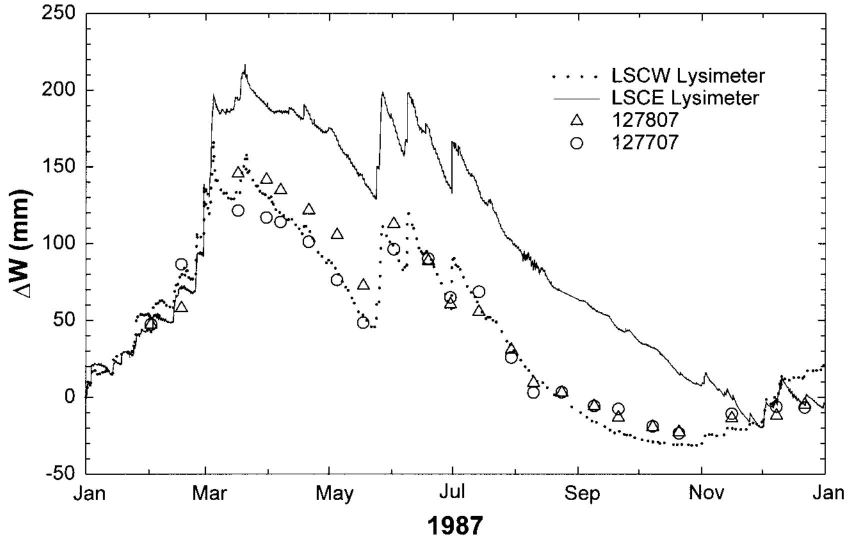

Figure 1. Changes in lysimeter water content (ΔW) during 1987 for the Lower Sheep Creek east (LSCE) and Lower Sheep Creek west (LSCW) lysimeters compared with the corresponding neutron probe-calculated ΔW using the access tubes in each lysimeter. The six-digit number refers to a specific access tube (127707 for LSCE and 127807 for LSCW). The neutron probe values from the lysimeters are in close agreement with each other and with only one of the lysimeters, LSCW.

tion most years. Apparently, there was some resistance in the system that was overcome by the relatively large weight increments used for calibration but effectively "caught" with small weight increments.

Prior to the collection of hourly data (1985), missing data are common and were treated as follows: (1) When the record was sparse or inconsistent for extended times, a single, monthly ΔW value was recorded near the end of each month (denoted M). (2) Where there were small (1 or 2 day) data gaps, intermediate values were estimated (denoted E) by interpolation considering weather inputs. (3) Where data were interrupted for longer, irregular times (i.e., several days) the pooled ΔW value at the end of that time is recorded (denoted P). No pooled, estimated or monthly data are included in the hourly data set.

6. Other Considerations

The lysimeter data are difficult to interpret during times when there was significant snow cover. Data obtained during those times tend to be more variable than other times. What is more perplexing is the pronounced apparent decline in ΔW at the time of snowmelt which is obvious during snowmelt almost every year at Reynolds Mountain (e.g., Figure 2). Since neutron probe data were not collected during periods of deep snow cover, there is no check on the soil-water dynamics during those times.

Ceramic drainage "candles" were installed in all the lysimeters for drainage. The timing and amount of drainage are not known except that drainage was performed most years in the spring at both sites. Contrary to expectation, no water was collected from the Reynolds Mountain lysimeters, and only a small amount was collected from the Lower Sheep Creek lysimeters. It seems reasonable to assume that the soil in the lysimeters had artificially high water contents at times. This effect would be more evident at Reynolds Mountain, where there is considerably more precipitation, than at Lower Sheep Creek, where the wetting front often fails to penetrate much more than a meter.

Table 1. Lysimeter Data Availability

Site	Years Available	Notes
LSC east[a]	1978, 1979, 1981, and 1982	monthly
LSC west	1976, 1978–1991	daily through 1984, hourly to 1991
RM north[b]	1980	daily
RM south	1980–1991	daily through 1984, hourly to 1991

[a]LSC refers to Lower Sheep Creek.
[b]RM refers to Reynolds Mountain.

7. Data Availability

Data from both lysimeters in this report and an electronic copy of the more detailed description of the RCEW soil climate data [*Seyfried et al.*, 2000] are available from the anonymous ftp site ftp.nwrc.ars.usda.gov maintained by the U.S. Department of Agriculture, Agricultural Research Service, Northwest Watershed Research Center in Boise, Idaho, United States. A detailed description of data formats, access information, licensing, and disclaimers are presented by *Slaughter et al.* [this issue].

8. Examples of Data Use

These data can be used to compare the ET regimes for different environments in the RCEW or for testing and/or parameterization of rangeland ET models. Estimation of ET on rangelands is complicated because a significant bare ground component is present (often ~50%), ET is routinely limited by soil water availability, and numerous plant species are present at a given site. This is further complicated within the RCEW by

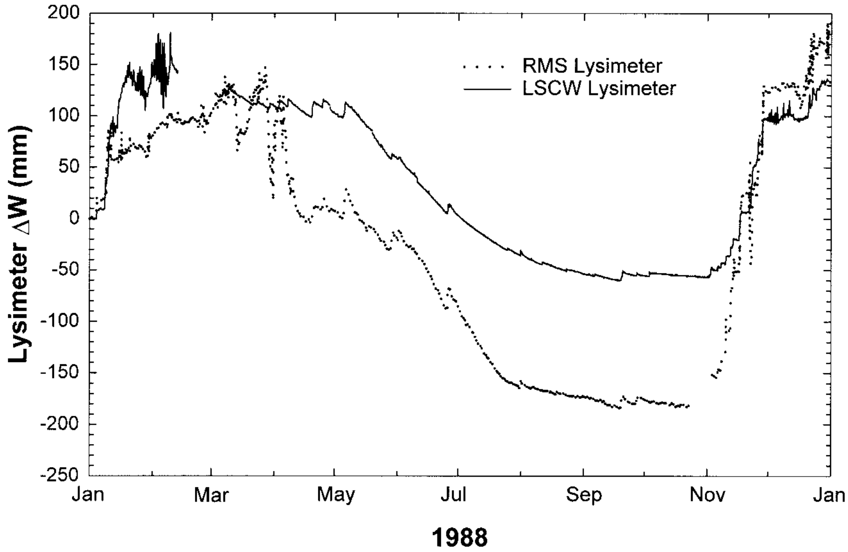

Figure 2. Comparison of ΔW dynamics at the Reynolds Mountain south lysimeter (RMS) and the Lower Sheep Creek west lysimeter (LSCW) during 1988.

the high degree of spatial variability introduced by the wide range of climate and soil conditions in relatively short distances.

Typical hourly data, collected at the RMS and LSCW lysimeters in 1988, are presented in Figure 2. The relatively noisy data early in the year at both sites is indicative of snow cover, which had melted by March 1 at LSCW and by mid-April at RMS. The sharp decline in weight at the time of snowmelt observed at RMS is also common. Net water loss occurred more gradually at LSCW. It had lost about one third of its total water by June 1 and about two thirds by July 1, while at RMS the net loss was less than one tenth on June 1 and was still less than one half on July 1. Maximum ET rates were considerably greater at RMS, where maximum LAI, available soil water, and atmospheric demand are in closer synchrony than at LSCW. During late June to the end of July, when there was practically no rainfall, the LSCW lysimeter lost 40 mm of water ($\sim$1.3 mm/d), and the RMS lysimeter lost 80 mm of water (2.7 mm/d). Essentially all available water was transpired from both lysimeters by the end of summer, as is expected in this climate.

Three ET models were evaluated by *Wight et al*. [1986] using the lysimeter data from Lower Sheep Creek. Despite the environmental complexity, results from the simplest model, Ekalaka Range Hydrology and Yield Model, compared as well or better to the lysimeter data as the other two models tested. Following Wight et al., *Wight and Hanson* [1990] used the lysimeter data from Lower Sheep Creek and other locations to examine the transpiration of rangeland vegetation relative to reference potential ET calculations. They found consistent results across different sites in South Dakota, Wyoming, and the RCEW.

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