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# Long-term soil water content database, Reynolds Creek Experimental Watershed, Idaho, United States

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**Abstract.** We describe long-term soil water data collected at the Reynolds Creek Experimental Watershed (RCEW). Data were collected for 10–25 years at 18 sites representing different climatic regimes and soils in the RCEW. Soil profile data are also available. High correlation between neutron probe and lysimeter measurements are the basis for assessing the accuracy of neutron probe–measured changes in soil water content. 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

Storage of water in the soil is an important component of the water balance affecting infiltration, runoff processes, plant growth, and the energy balance. Soil water has been part of the data collection efforts at the Reynolds Creek Experimental Watershed (RCEW) nearly since the project's inception. Several projects have been undertaken that examine soil water dynamics in the RCEW [e.g., *Rawls et al*., 1973; *Stephenson and Zuzel*, 1981; *Seyfried*, 1998]. Since 1970, there has been a sustained effort to monitor soil water content at specific locations in conjunction with the meteorological and hydrological monitoring networks.

The data described were measured with neutron probes. The neutron probe was first developed in the 1950s [*Gardner and Kirkham*, 1952] and has been a well-accepted method for measuring soil water content for many years [*Chanasyk and Naeth*, 1996]. There are a variety of references that specifically address the neutron method in principle [e.g., *Greacen*, 1981; *Gardner*, 1986]. There are limitations to the neutron probe that are both inherent in its mode of operation and dependent on the specific methodology and circumstances involved. In this report we describe how the data were collected and assess the measurement accuracy.

## 2. Data Collection Methodology

Data described were collected from 18 access tubes at five locations ranging in elevation from 1190 to 2101 m. General site locations are illustrated by *Slaughter et al*. [this issue], and specific tube locations are presented in Table 1. In all cases, neutron access tubes are located within ~100 m of precipitation gauges and in reasonable proximity to climate stations. Individual access tubes are labeled using the six-digit nomenclature described by *Seyfried et al*. [2000b]. Detailed soil descriptions are available for each of the access tube locations and are supported by laboratory analysis at most sites.

The vegetation at all five sites is dominated by different subspecies of sagebrush. Plant community distributions are described by *Seyfried et al*. [this issue (a)]. A more detailed description of the plant communities is given by *Seyfried et al*. [2000b]. At the Flats, Quonset, and Nancy Gulch sites the dominant plant community is Wyoming big sagebrush, which grows to a height of 0.30–0.60 m. Plant cover, including understory grasses and forbs, is generally <50% of the soil surface. At Lower Sheep Creek the dominant plant community is low sagebrush, which usually grows to a height of ~0.30 m. Ground cover of plants is a little greater than at the lower elevation sites, ~50% of the soil surface. At Reynolds Mountain the dominant plant community is vaseyana (or mountain) big sagebrush, which typically grows to a height of 0.45–0.60 m. Plant ground cover is greatest at this site, ~60%. One tube at Reynolds Mountain, number 176006, is located in an aspen grove.

The length of record and number of readings taken varies for different sites (Table 1). The main data collection effort was initiated between 1970 and 1973 using 48 mm diameter aluminum access tubes installed to varying depths. The holes were excavated using a "Houston" rotary core drill using air pressure. This was essential for most sites because of the high rock contents common in RCEW soils. It was generally felt by early investigators that the sample volume probably changed slightly shortly after tube installation as the soil settled around the tubes.

Measurements at all tubes were made at a depths of 0.15 and 0.305 m followed by readings at 0.305 m intervals to the bottom of the tube, which ranged from 0.61 to 2.74 m. Except where noted, 30 s counting times were used. Readings were made at approximately biweekly intervals with ~20 readings per year. The data record for 1996 for all tubes is very sparse because of a combination of equipment failure and personnel changes. A tube was installed in each of the four RCEW lysimeters. The two tubes in the Reynolds Mountain lysimeters were not monitored when there was significant snow cover because they were intended to track growing season soil water use.

Five different neutron probes were used over a 26 year period. From 1970 to 1979, two probes manufactured by Troxler were used (492 and 152); these were replaced with two probes manufactured by Campbell Nuclear Pacific (606 and



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**Table 1.** Site Information for Neutron Probe Data

| Site | Tube | Record Years | Location, UTM Easting | Location, UTM Northing | Depth, m | Soil Description[a] |
|---|---|---|---|---|---|---|
| Flats | 057896 | 1973–1996 | 521491 | 4785951 | 1.22 | S 81ID-073-003 |
| Flats | 057C96 | 1971–1996 | 521526 | 4785956 | 1.22 | S 81ID-073-003 |
| Flats | 057H96 | 1986–1996 | 521386 | 4786029 | 0.91 | S 81ID-073-004 |
| Quonset | 076059 | 1981–1996 | 520388 | 4783423 | 1.22[b] | not available |
| Quonset | 076159 | 1987–1996 | 520372 | 4783418 | 0.91 | S 81ID-073-004 |
| Nancy Gulch | 098697 | 1971–1996 | 523367 | 4779370 | 1.22 | S 81ID-073-009 |
| Nancy Gulch | 098897 | 1973–1996 | 523347 | 4779303 | 1.22 | S 81ID-073-009 |
| Nancy Gulch | 098F97 | 1973–1996 | 523448 | 4779559 | 0.61 | S 81ID-073-009 |
| Lower Sheep Creek | 117079 | 1972–1996 | 521595 | 4776403 | 0.91 | S 81ID-073-003 |
| Lower Sheep Creek | 117186 | 1973–1996 | 521599 | 4776514 | 2.74[c] | S 81ID-073-003 |
| Lower Sheep Creek | 117287 | 1973–1996[d] | 521759 | 4776439 | 2.13 | S 81ID-073-004 |
| Lower Sheep Creek | 127707 | 1974–1993 | 521743 | 4776182 | 0.91 | S 81ID-073-008 |
| Lower Sheep Creek | 127807 | 1970–1993 | 521741 | 4776182 | 0.91 | S 81ID-073-008 |
| Lower Sheep Creek | 127907 | 1970–1996 | 521738 | 4776184 | 1.82 | S 81ID-073-008 |
| Reynolds Mountain | 176006 | 1973–1996 | 520077 | 4768151 | 1.22 | RM1 |
| Reynolds Mountain | 176025 | 1977–1996 | 519715 | 4767899 | 0.91 | S 81ID-073-007 |
| Reynolds Mountain | 176125 | 1977–1993 | 519707 | 4767900 | 0.91 | S 81ID-073-007 |
| Reynolds Mountain | 176225 | 1977–1993 | 519710 | 4767896 | 0.91 | S 81ID-073-007 |

[a]See *Seyfried et al.* [2000a] for a detailed description of labeled soil profiles.
[b]Years 1981 and 1982 went to 0.91 m.
[c]Years 1979, 1980, and 1981 went only to 2.13 m.
[d]No data were collected from 1987–1989.

607). A different Troxler instrument was used briefly near the end of the study.

## 3. Calibration

All probes were calibrated in standard source material (polyethylene) manufactured by Troxler (part numbers 7328-1, 7328-2, and 7328-3) to simulate the following three water contents: 0.1096, 0.2121, and 0.3008 m$^3$ m$^{-3}$. Each calibration consisted of five measurements made for each simulated water content along with 5–10 standard counts, which were of longer duration. The measured count ratios were fit to a simple linear regression equation of the form

$$\theta = mC_r + K, \quad (1)$$

where $C_r$ is the count ratio (measured count/standard count), $m$ is the slope of the $\theta/C_r$ relationship, and $K$ is the value of $\theta$ when $C_r$ is 0.

All calibration data were strongly linear. Coefficients of determination ($r^2$) ranged from 0.995 to 0.999 [*Seyfried et al.*, 2000a]. No trend over time was discernable, so a single calibration equation was used for each instrument. The measurements at each simulated water content also had a high degree of precision. The standard deviation of a given reading will increase with the square root of the number of counts, which can be evaluated for specific readings. For the calibration data the 99% confidence interval for these instruments ranged from 0.008 to 0.014 m$^3$ m$^{-3}$ for the highest water content and from 0.003 to 0.009 m$^3$ m$^{-3}$ for the lowest. This high precision was also evident in field measurements. For example, for 208 measurements made between September 2, 1986, and November 14, 1995, in tube 098897 at Nancy Gulch, a wetting front was not apparent at depths either immediately above or below 0.91 m (Plate 1). The measured mean $\theta$ at 0.91 m was 0.230 m$^3$ m$^{-3}$ with a 99% confidence interval of 0.0015 m$^3$ m$^{-3}$.

The problem with the calibration approach used is that to the extent that the standards do not represent the field soil, bias was introduced. In addition, because the sampling volume of different neutron probes varies, there is a potential for significant instrument-induced effects. This would be most evident where there is strong soil horizonation or a sharp wetting front.

## 4. Instrument Effects

Previous work by *Reginato and Nakayama* [1988] demonstrated that it is possible to cross calibrate probes of like manufacture using calibration standards. It is not clear how well that applies to probes of different manufacture because the sampling geometry may vary. This was tested in the field in the spring of 1979 using the four primary probes. Seven access tubes at four locations and four dates were used. On each date the four probes measured $\theta$ at the same depths at approximately the same time.

The correlation among instruments was high, with $r^2$ values ranging from 0.968 to 0.995. In general, differences increased with water content such that estimates were within 0.01 m$^3$ m$^{-3}$ for low $\theta$ (0.10 m$^3$ m$^{-3}$) and increased to 0.02 and 0.03 m$^3$ m$^{-3}$ when $\theta$ was $>$0.30 m$^3$ m$^{-3}$. The differences were almost entirely between the units of different manufacture, with the Troxler units reporting the greater values [*Seyfried et al.*, 2000a]. These differences would not necessarily be the same at all sites and depths because of the effects of soil layering interacting with the different sampling geometries.

These data indicate that the calculated $\theta$ should have decreased when probe 607 replaced 492 in January of 1979. Field data indicate that this did occur at some locations, but the effect was not consistent. For example, for access tube 098897 (Plate 1), there appears to be a drop at the 0.61 m and possibly the 1.22 m depth, but the effect is not clear at other depths at the site nor at some of the other sites. Therefore we have not

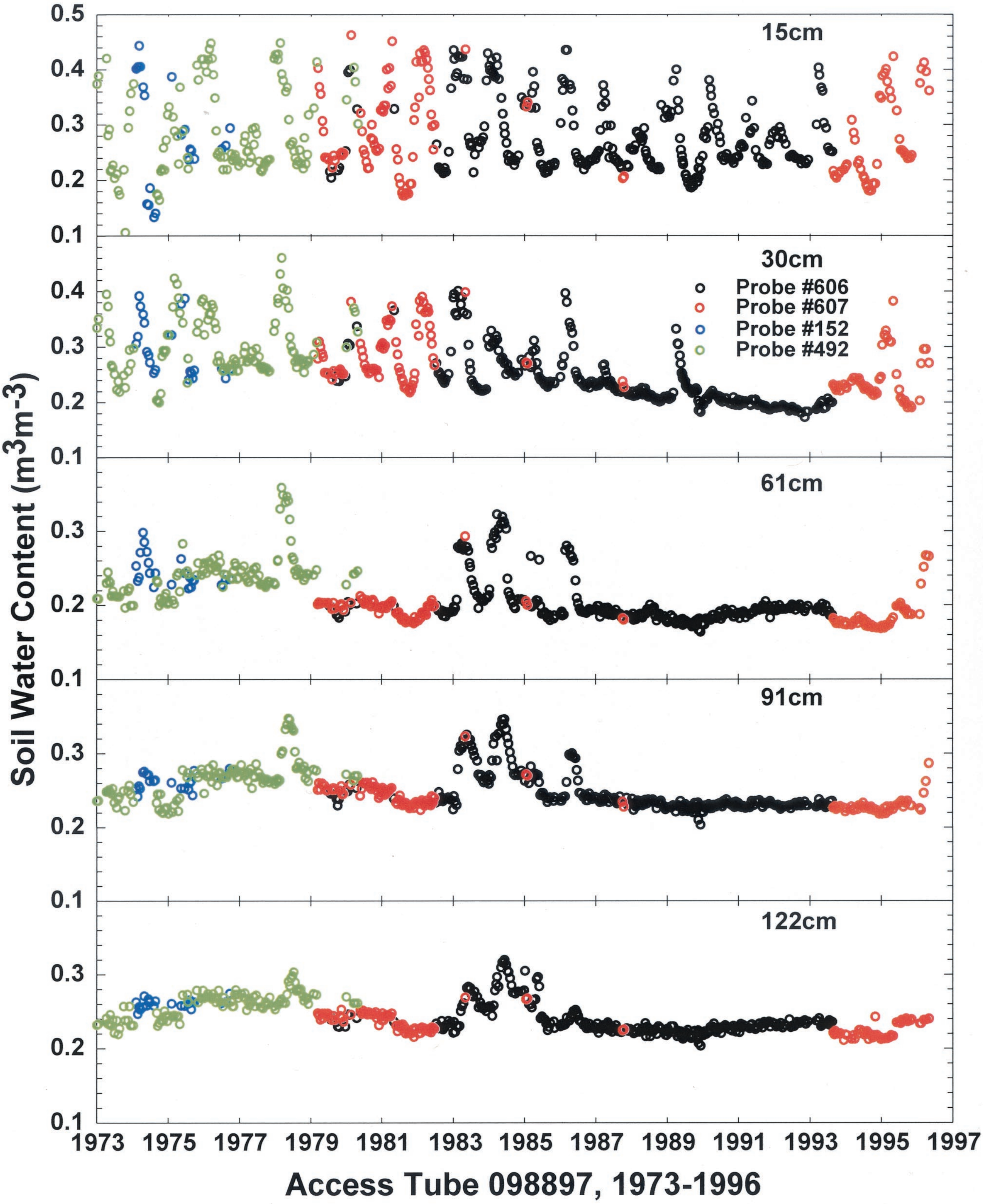


**Plate 1.** Soil water content at multiple depths over a 23 year period at access tube 098897 at Nancy Gulch.

corrected for this "instrument effect" in the database, although users of these data should be aware of this potential effect.

## 5. Water Content Change Measurement Accuracy

We used complimentary lysimeter data at Reynolds Mountain and Lower Sheep Creek described by *Seyfried et al.* [this issue (b)] to estimate the accuracy of neutron probe–measured changes in soil water content. Since lysimeters provide information only on the change in the total soil profile water storage ($\Delta W$ in millimeters), we converted measured $\theta$ into $\Delta W$ assuming that each neutron probe reading represented a specific depth increment of soil. Thus the 0.15 m reading represented

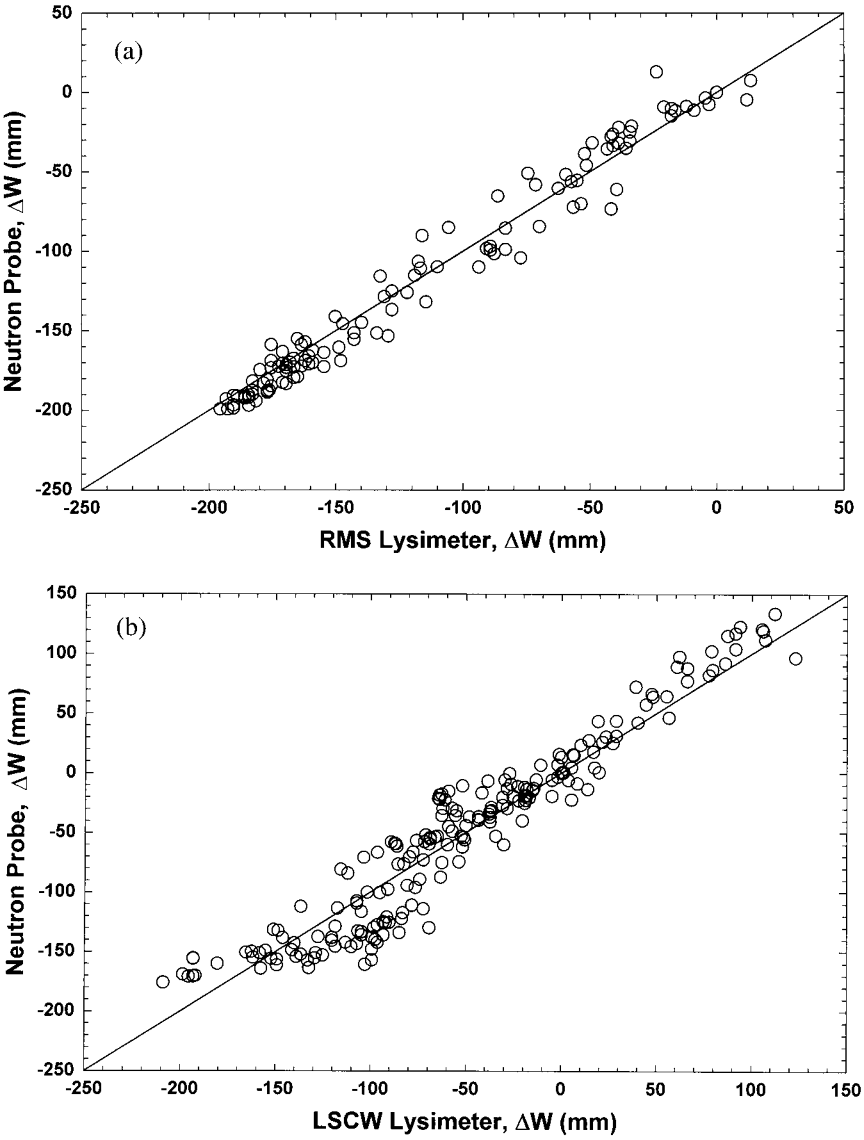


**Figure 1.** Comparison of neutron probe–calculated and lysimeter-measured $\Delta W$ over the measurement period (see Table 1) for the (a) Reynolds Mountain south (RMS) lysimeter and (b) Lower Sheep Creek west (LSCW) lysimeter. Neutron probe data are the average of the two access tubes at each site.

soil water from 0 to 0.230 m, the 0.31 m reading represented the 0.23 to 0.46 m depth increment, the 0.61 m reading represented the 0.46 to 0.75 m depth increment, and the 0.91 m reading represented the 0.75 to 1.06 m depth increment. Values for $\Delta W$ were then calculated relative to the first recorded readings of the calender year.

There was close agreement between the probe-calculated and lysimeter-measured $\Delta W$ at both sites. Using the 128 neutron probe measurements taken between 1980 and 1992 at Reynolds Mountain (Figure 1a), the linear correlation between the two methods was strong ($r^2 = 0.98$) with very little bias (slope = 1.03, $Y$ intercept = 0.23). Similarly, the correlation calculated from the 218 neutron probe readings made between 1976 and 1992 (excluding 1977 and 1978) and the lysimeter measurements at the Lower Sheep Creek lysimeter (Figure 1b) was also linear ($r^2 = 0.92$) and only slightly biased (slope = 1.04 and $Y$ intercept = 0.003). Since $\Delta W$ calculated from two independent sources are in close agreement, we conclude that they are both reasonably accurate and that the standard-derived calibration slopes (not necessarily the $y$ intercept) of the neutron probe calibration curves must be accurate.

Some of the scatter in the lysimeter–neutron probe relationship are inherent in the methodology. Of particular concern is the fact that surface dynamics are not well measured. On the other hand, for purposes of $\Delta W$ calculations the neutron probe has an inherent advantage over other instruments in that measurement volume, typically about a 15 cm radius, is relatively large. Another advantage of the neutron probe is that, unlike most other instruments, it is not affected by soil freezing.

## 6. Absolute Calibration

The analyses presented indicate that (1) the calibrations are highly precise; (2) the data are reasonably self-consistent with some small bias introduced by the different instruments used; (3) the measurements are highly reproducible; and (4) the calibration slopes, as inferred from the lysimeter data, are approximately correct. This all indicates that these data can be used to accurately calculate changes in $\theta$ but not necessarily the actual value. This is not unusual for neutron probe data. As *Williams and Sinclair* [1981, p. 40] noted, "Attempts to estimate bias in the neutron method are conspicuous by their absence from the literature." Attempts to check the calibrations with gravimetric sampling were inconclusive because of high variability of $\theta$. This high variability, the typically high coarse fragment content, and strongly contrasting soil horizons provide considerable obstacles for absolute neutron probe calibration for the RCEW soils.

## 7. Other Considerations

The data have been checked for unreasonable values. In most cases those resulted from transposition errors. However, this checking was done to different standards by different individuals over the years, so some "bad" values may persist, especially prior to 1975. It was noted that some of the cable stops that were set to establish the measurement depths slipped slightly with time, so that after a few years the measurement may be 0.02–0.03 m deeper than reported. This would not be critical in many soil profiles, but where there are abrupt soil boundaries, it might be. Thus we sometimes observed either upward or downward changes in $\theta$ when probes were changed from probe 606 to probe 607, which have the same measurement geometry.

## 8. Data Availability

Data from the 18 neutron access tubes described and an electronic copy of the more detailed description of the RCEW soil water data [*Seyfried et al*., 2000a] 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 is presented by *Slaughter et al*. [this issue].

## 9. Examples of Data Use

These data may be used for a variety of applications related to the description and modeling of the spatial and temporal distribution of soil water content, evapotranspiration, and groundwater recharge. *Rawls et al*. [1973] examined soil water content trends at three of the sites ranging in elevation from 1285 to 2097 m to establish moisture availability and rate of use at different sites. They found that the annual peak in soil water contents at the lower-elevation site was in February, about 3 months prior to the peak at the higher-elevation location. They estimated that the average loss of water from the lower site was 1 mm $d^{-1}$, was 1.8 mm $d^{-1}$ at the midelevation site, and was 2.5 mm $d^{-1}$ at the upper site. Similar data are presented by *Seyfried et al*. [this issue (b)].

*Stephenson and Zuzel* [1981] used water content profiles to infer patterns of groundwater recharge. They observed water table rises at some locations even though soil water content did not increase at depths of 210 cm. This, along with other data collected, leads to the conclusion that the groundwater was recharged at specific, shallow soil areas. An example of that kind of data is presented for Nancy Gulch (tube 098897) in Plate 1. Between January 1, 1973, and December 30, 1996, 526 readings were taken at five depths. The 0.15 m water contents are the most dynamic, showing a pronounced annual cycle which peaks in late winter to early spring. At increasing depth the amplitude of the cycles is reduced, and many peaks disappear entirely, indicating that the annual wetting front failed to arrive at that depth. The observed peaks are also displaced to the right with increasing depth. Thus, while the 0.15 m depth peak for 1978 is in February, the peak at 1.22 m is about 3 months later.

**Acknowledgments.** Ultimately, the key to this data collection program was the individuals who did the fieldwork. Many individuals were involved in this task but none more than Delbert Coon. In addition to maintaining a regular schedule visiting each site at least biweekly, year round, he helped install the neutron access tubes, served as the nuclear safety officer, and generally maintained data continuity. Others who have contributed many hours to this database include Dave Robertson and Sue Stillings.

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