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SNOW MONITORING AT THE REYNOLDS CREEK EXPERIMENTAL WATERSHED, IDAHO, USA

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ABSTRACT

Snow is the dominant form of precipitation in the Reynolds Creek Experimental Watershed (RCEW). Annual average precipitation varies from 236mm at the driest lower elevation site, to more than 1100mm at the wettest site in the higher elevations. Based on dew point temperature during storms, 15-55% of the lower elevation precipitation falls as snow, and 60-90% of the higher elevation precipitation falls as snow. Water from snowmelt is critical to the ecosystems and resources in RCEW because the water stored in the seasonal snow cover is the primary source of spring and summer soil moisture and streamflow. Snow water equivalent (SWE) has been measured at eight locations in RCEW every two weeks throughout the snow season (Dec.1 to June 1) for 35 water years (1962-1996). SWE was continuously monitored at one reference site for 14 water years (1983-1996). The measurement sites are described, the methods used are presented and discussed, and these data are summarized. A description of the files and instructions for accessing these data is given.

Key words: snow deposition, snow properties, water resources

1. INTRODUCTION

Water from melting snow is a critical resource in the western U.S., Canada, and other similar regions of the world. This is particularly true in the arid watersheds of the interior northwest such as the Reynolds Creek Experimental Watershed (RCEW). In RCEW the storage of winter precipitation in the seasonal snowcover for release during spring and early summer is critical to sustaining the basin's vegetation and ecosystems.

When the northwest Hydrology Research Watershed was authorized by congress in 1959, and located in the Reynolds Creek basin in the Owhyee Mts. of Idaho in 1960, five essential measurements were defined [Robins, et al., 1965]. One of these was snow:

- *Snow deposition and melt as related to the nature of snowfall, shifting by wind, vegetation, topography, and meteorologic factors.*

To satisfy this requirement, a series of intensive investigations of snow deposition and melt patterns, and of snow measuring techniques were undertaken to improve understanding of snow deposition patterns, physical changes after deposition, and variable rates of snowmelt related to the topographic structure of the watershed, climate conditions, and vegetation. To support these investigations, the USDA Agricultural Research Service initiated a detailed snow monitoring and measurement program early in the development of the Reynolds Creek Experimental Watershed (RCEW). This snow measurement program has continued to the present and is still in operation. This effort has provided over 35 years of detailed data on snow deposition, density, and depth over RCEW that are presented in this paper.

2. MEASUREMENT SITES

Seven snow course sites were established in 1961, and one additional site was added in 1970. A snow pillow is located at the Reynolds Mtn. Snow Study Site (176x07); watershed locations are referenced to an arbitrary grid described by Seyfried et al. [2000]). All sites are located in the high elevation southern extent of the basin, where snow accumulation is greatest (Figure 1). Table 1 gives the site ID numbers, period of record, and a general description of the layout of these sites.

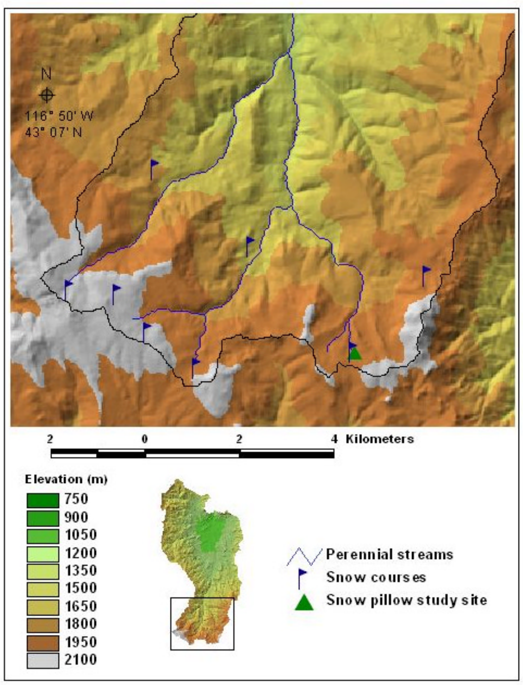

Figure 1. Map showing locations of snow courses and snow study plot in the Reynolds Creek Experimental Watershed. Watershed outline and perennial streams are shown. Snow courses are indicated by red flags, and Reynolds Mtn. Snow Study site is indicated by a green triangle.

Table 1: Snow Measurement Site Description

Site #:	Record:	Description:
144x62	1961-96	Site is in the Dobson Creek drainage about half way between the confluence with Reynolds Creek and the headwaters of Dobson Creek. Snow course was originally located to the north and northeast of a very dense stand of mature fir trees. In the summer of 1991 the site was harvested (clear-cut) so the snow course is currently in an open, fairly flat area.
155x54	1962-96	Site is located about one half mile above Democrat (old stage stop from the1880's). The snow course is at the southern edge of an open mountain meadow that extends up from main Reynolds Creek. Due to its relatively close proximity to Reynolds Creek the snow course is considered in a canyon setting with mountains on all sides except downstream to the north. Snow course is very near the lower boundary of continuous winter snow cover.
163x20	1961-96	Site is located at the headwaters of Dobson Creek. Snow course is at the lower edge (northwest) of a dense stand of Douglas Fir, not far from the ridge line boundary of the watershed.
163x35	1969-96	Site is located on the divide between Dobson Creek and the west fork of West Reynolds Creek. Snow course is located in a clearing of a sparse stand of Douglas Fir with the southern ridge line of the watershed about 400 meters to the south.
163x98	1961-96	Site is located near the headwaters of the West Fork of Reynolds Creek in a small opening in a dense stand of Douglas Fir. Snow course is just a short distance to the north from a large snow-drift accumulation area.
167x07	1961-96	Site is located on the east side of Reynolds Creek Watershed at Bull Meadows near the headwaters of Slacks Creek on the north side of Slacks Mountain. Snow course is at the north edge of a sparse stand of Fir and Mountain Mahogany that breaks away to a large mountain meadow which is very near the eastern ridge line boundary of the watershed.
174x26	1961-96	Site is also located near the headwaters of the West Fork of Reynolds Creek but near the east side of the drainage. Snow course is at the north edge of a small stand of Douglas Fir that is situated on the lee side of the ridgeline boundary of the watershed.
176x07	1961-96	Site is located near Reynolds Mountain in an instrumented 40.5 hectare sub-watershed near the headwaters of Reynolds Creek. This site is the Reynolds Mountain Snow Study Site, which includes the snow pillow that has operated continuously since 1983. Snow course is situated in a sparse Aspen grove bordering a sparse stand of Fir to the south, about 90 meters north and about 250 meters to the east of a snow-drift accumulation area.

The Reynolds Mtn. Snow Study Site (176x07), has been used to conduct detailed experiments on snow measurement techniques, instrumentation, and modeling. In 1970, an eighth site (163x35) with additional instrumentation similar to site 176x07 was established in an effort to extend detailed snow studies in RCEW. This site was maintained for several years, until it was established that there was very little difference between snow and climate conditions between 163x35and176x07. The additional instrumentation was then discontinued, and only the snow course at site 163x35 was continued.

Table 2 presents specific information on the location and characteristics of the sites. Eastings and Northings are UTM, Zone11, using NAD 27 and Clarke 1866. All elevations, Eastings and Northings are in meters. Both a GPS-measured elevation, and a DEM-derived elevation are presented. These sites were selected to represent as full a range of snow conditions found in RCEW as possible. Elevations of snow measurement sites range from1700m to 2200m, and are distributed throughout a full range of exposures to represent a variety of conditions. Sites 163x20, 163x35, 163x98, and 174x26, and 176x07 all lay above 2000m. Sites 163x20,163x35, 163x98, and 174x26 are shaded, high deposition sites facing northeast. Site 176x07 has a northern exposure, and receives slightly less snowfall than the other high elevation sites and site 167x07 faces west in a slightly drier location. Sites 144x62 and 155x54 are lower elevation locations that are on the edge of the continuous snowcover in RCEW. While snow does occur in other portions of the watershed, it is generally more ephemeral, and is unlikely to persist throughout the winter.

Table 2: Snow Measurement Site Elevation, Easting, & Northing

Site #:	GPS Elev: (m)	DEM Elev: (m)	UTM Easting, Northing (m)	(m)
144x62	1808	1816	515864	4771970
155x54	1743	1733	517892	4770341
163x20	2167	2159	514041	4769438
163x35	2147	2153	515042	4769342
163x98	2125	2119	515687	4768520
167x07	2010	2009	521613	4769718
174x26	2078	2072	516719	4767777
176x07	2061	2058	520055	4768117

3. METHODS

3.1. Snow Course Measurements

Snow water equivalent (SWE), depth, and density have been sampled at multiple locations in RCEW since 1961. These data have been collected using standard snow tube methods that have been described by the U.S. Soil Conservation Service [1972], the Atmospheric Environment Service [1973], the World Meteorological Organization [1974] and Goodison, et al., [1981]. These methods are generally considered the standard for manual measurement of snow depth, density, and SWE. At the time the RCEW snow courses were being established, a number of investigations were underway to evaluate errors associated with snow sampling [see: Bindon, 1964; Work et al., 1965; and Goodison, 1978]. The USDA Agricultural Research Service (ARS) and National Resource Conservation Service (NRCS - formerly the Soil Conservation Service (SCS)) were involved in testing and evaluating snow samplers. A transition from the Standard Federal Sampler to the Rosen sampler was begun in 1966, because the Rosen sampler showed consistently less over sampling (2.9% vs. 10.2% as reported by Work et al., 1965). The Standard Federal Sampler was replaced with the Rosen sampler in 1968.

RCEW snow courses were designed after the procedures described by the U.S. Soil Conservation Service [1972], and the Atmospheric Environment Service [1973]. Each RCEW snow course is approximately 15m in length with five sampling points separated by about 3m. Plate1 shows the layout of a typical snow course in RCEW.

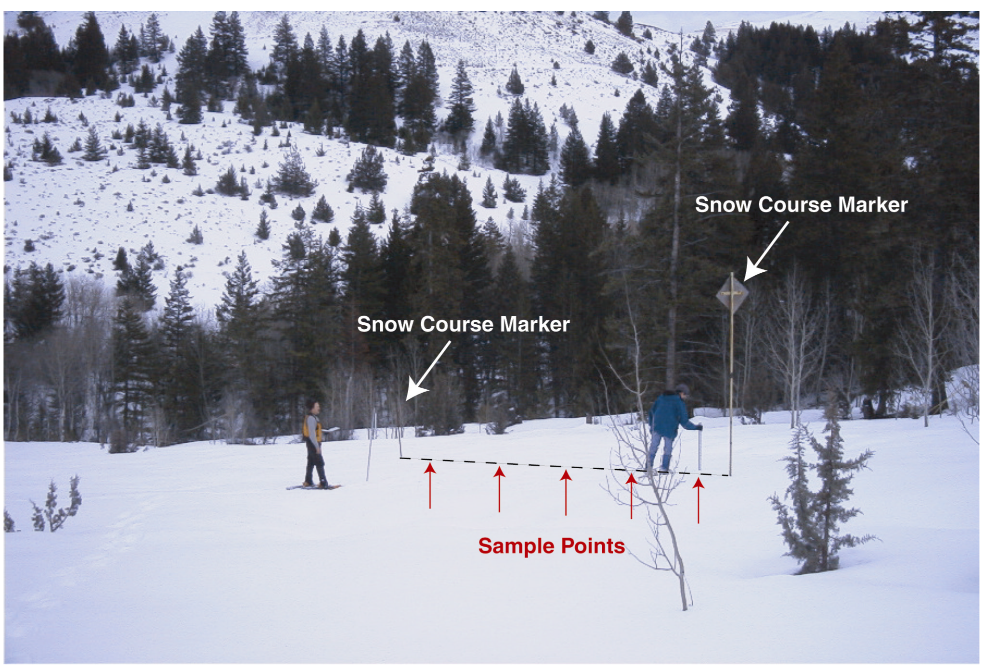

Plate 1. Snow course at site 155x54. This is the typical layout of the RCEW snow courses: five samples taken at approximately 3m intervals between two permanent markers.

3.2. Continuous Measurement of SWE with a Snow Pillow

SWE has been continuously monitored at site 176x07 using a snow pillow since late 1982. A pressure snow pillow gauge is a device similar to a large air or water mattress filled with antifreeze. As snow is deposited on this gauge, the pressure increase is related to the accumulating mass and thus to snow water equivalent (SWE). Such devices have been in use since the early 1960's, but have been considered generally reliable only since the late 1970's or early 1980's. A description of early designs for snow pillows and the problems associated with their use was presented by Beaumont [1965], and a general description of snow pillows, their operation and installation, and the evolution of various designs was presented by Goodison, et al., [1981].

In 1964 one of the first snow pillows was installed at the Reynolds Mtn. Snow Study site 176x07. During the late 1960's and 1970's extensive experimentation was done in RCEW on the reliability and accuracy of various snow pillow designs, including various pressure transducers, installation configurations, and types and concentrations of antifreeze [see Mayo, 1972; Davis, 1973; Barton, 1974; Cox, et al., 1978]. By the early 1980's researchers had found the butyl rubber snow pillow to be the most reliable and accurate. Though research is still underway to evaluate new snow pillow designs, the 3m diameter butyl rubber pillow is now considered the standard and has been in continuous operation at site176x07 since late 1982.

3.3. Measurement Uncertainty

A standard deviation (SD) and coefficient of variation (CV) was computed for the five individual samples from each of the 388 bi-weekly snow course measurement dates at site176x07 to assess within-course variance. As expected, the standard deviation within each set of samples had a corresponding increase with the mean of sampled SWE (Figure 2a). The average SD taken from all 388 courses was 35.5mm, and the average CV over the period of record was 10.4%. In shallow snowpacks, the range of observed CVs was high and indicated that confidence intervals about the mean could be quite wide (Figure 2b). In general, outliers shown in Figures 2a&b occurred during late spring (May or June) when the snowcover was relatively thin and discontinuous. As the amount of measured snow increased, the range of observed CVs decreased leveling out at approximately 8-9%.

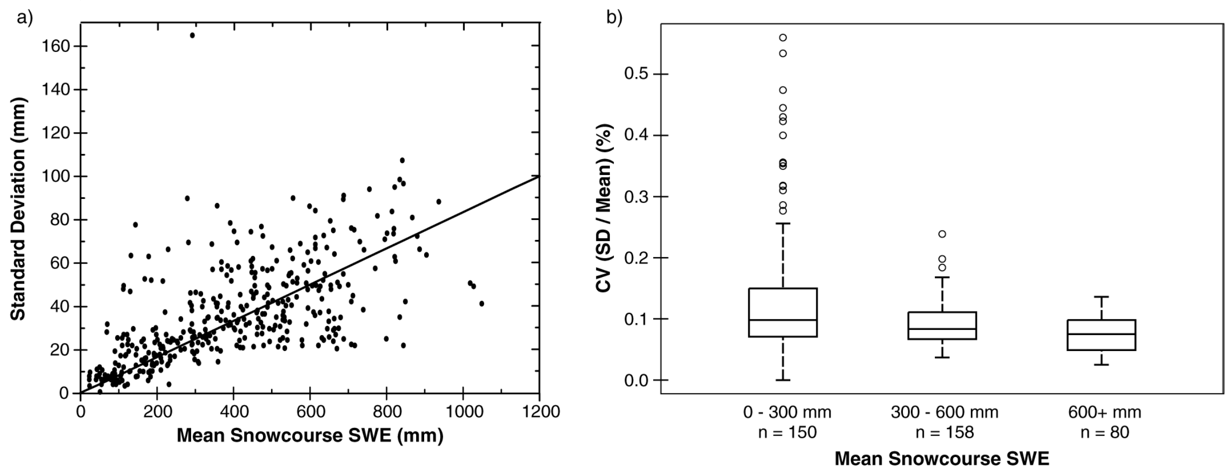

Figure 2. Standard deviation (SD) and coefficient of variation (SD/mean) for the five individual samples from each of 388 bi-weekly snow course measurement dates for site 176x07.

4. SNOW DATA

4.1. Snow Course Data

Snow course data were collected at seven sites beginning in1961, with the addition of an eighth site in 1970. Prior to the1970 water year, data were not collected on a specific schedule, and not all sites were visited on the same day, or the same number of times. Beginning with WY 1970, data have been collected approximately every two weeks starting December 1, and ending on May 15, at all eight sites, for at least 12 data values for each site for each water year. Figures 3 & 4 present data only for the 27 water years (1970–1996) for which snow courses were sampled at regular intervals.

Figures 3a,b,&c show the 27 year average snow water equivalent (SWE), depth, and density for each scheduled measurement date. The SWE and depth data show that the snow courses are separated into two groups. Five snow courses (163x20, 163x35, 163x98, 174x26, 176x07) are high deposition sites, and three snow courses (144x62, 155x54, 167x07) are low deposition sites. Average snow density shows only a small difference between sites (10-15%), though there is some separation between high and low deposition locations. Note that measurement of snow density using a snow tube when the snowcover is thin is unreliable.

All of the high deposition snow courses are high elevation sites, ranging from 2061m to 2167m. Site 163x20 (2167m) is the highest elevation, and shows the most snow deposition. Sites 163x35 (2147m), 163x98 (2125m), and 174x26 (2078m) show nearly identical deposition over the 27-year averaging period. Site 176x07 (2061m) shows less deposition throughout the year, but is still clearly part of this group of snow courses.

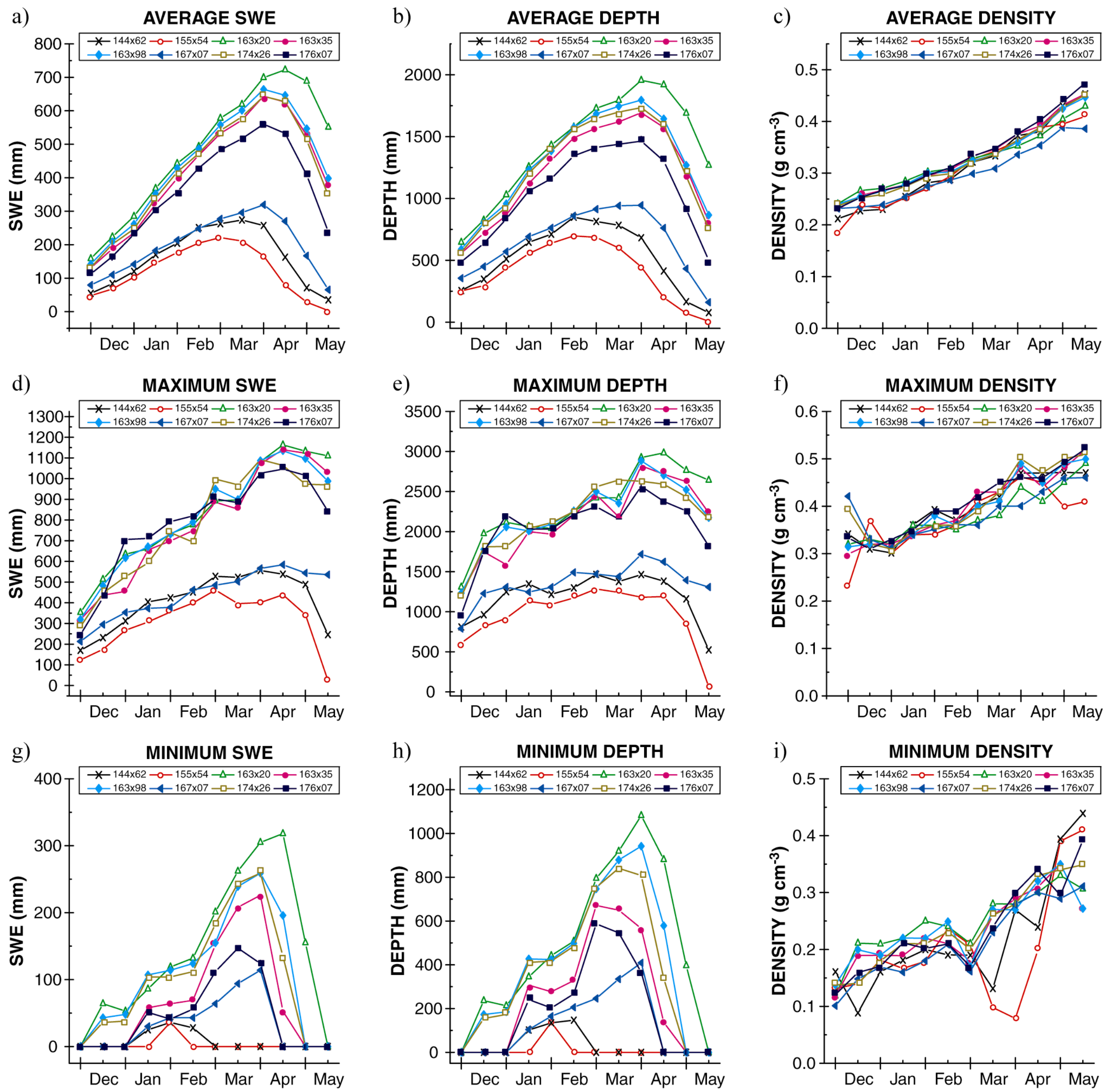

Figure 3. Average, Maximum, and Minimum snow water equivalent (SWE), snow depth, and snow density for the 27 year period when snow courses were sampled at regular bi-weekly intervals from December 1 to May 15 (water years 1970–1996). (Note: only 1970–1996 water year data is used because prior to 1970, sampling was not done at regular two-week intervals.

Of the low deposition sites, 144x62 (1808m) and 155x54 (1743m) are lower elevation, while 167x07 (2010m) is at an elevation similar to the high deposition sites. The two low elevation sites are near the end of continuous snowcover and we would expect them to show less snow. From Figure 1 we can see that site 167x07 occupies a western exposure that creates a much drier location for that elevation than the more northern exposures of the other high elevation sites.

Figure 3a also shows that the seasonal peak SWE occurs earlier at the two low elevation sites (March 1 for site155x54 and March15 for site144x62) than at the higher elevation sites (April1 for all remaining sites except 163x20 which is April 15). This indicates that the differences between the low elevation, low deposition sites and the high deposition sites is caused by both lower snowfall rates and warmer temperatures. Differences between the high elevation, low deposition site (167x07) would be attributed to lower precipitation rates only, because peak SWE occurs at the same time as the other high elevation sites.

Figures 3d,e,&f show the 27 year maximum SWE, depth, and density for each measurement date. The maximum SWE and depth data show the separation of the high and low deposition snow courses that the average SWE and depth did, and there is a small density difference (10-15%) between sites until spring, when the snowcover begins to thin at the low elevation sites. Figures 3g,h,&i show the 27 year minimum SWE, depth, and density for each measurement date. Separation of the high and low deposition sites is evident, but is not nearly as clear as it was for the average and maximum SWE and depth. While there is some density difference between sites, most of this is caused by the inherent difficulty measuring snow density when the snowcover is very thin, or discontinuous. It is noteworthy that the maximum SWE and depth are nearly twice the average (894mm vs. 456mm, and 2263mmvs.1296mm respectively), and minimum SWE and depth are about half the average (175mm vs.456mm, and 594mm vs.1296mm respectively) when all sites are averaged.

Figures 4a-h compare the largest snow season (WY1984) to the smallest snow season (WY 1992) in the 35 year period of record for each of the snow courses for each measurement date. During the 1992 snow season, the low elevation snow courses (144x62, 155x54) show a minimal snowcover (less than 100mm SWE), and are snow free by March 1. The high elevation snow courses also show a minimal snowcover during the 1992 snow season (generally less than 200mm SWE), with 167x07 and 176x07 snow free by April 15, 163x35, 163x98, and 174x26 snow free by May 1, and 163x20 snow free by May 15. During the 1984 snow season, the low elevation snow courses show a more substantial snow cover, but are close to snow free (144x62) or snow free (155x54) by May 15. In contrast the high elevation snow courses not only show a substantial snowcover during the 1984 snow season, but 60-85% of that snowcover was still present on May 15.

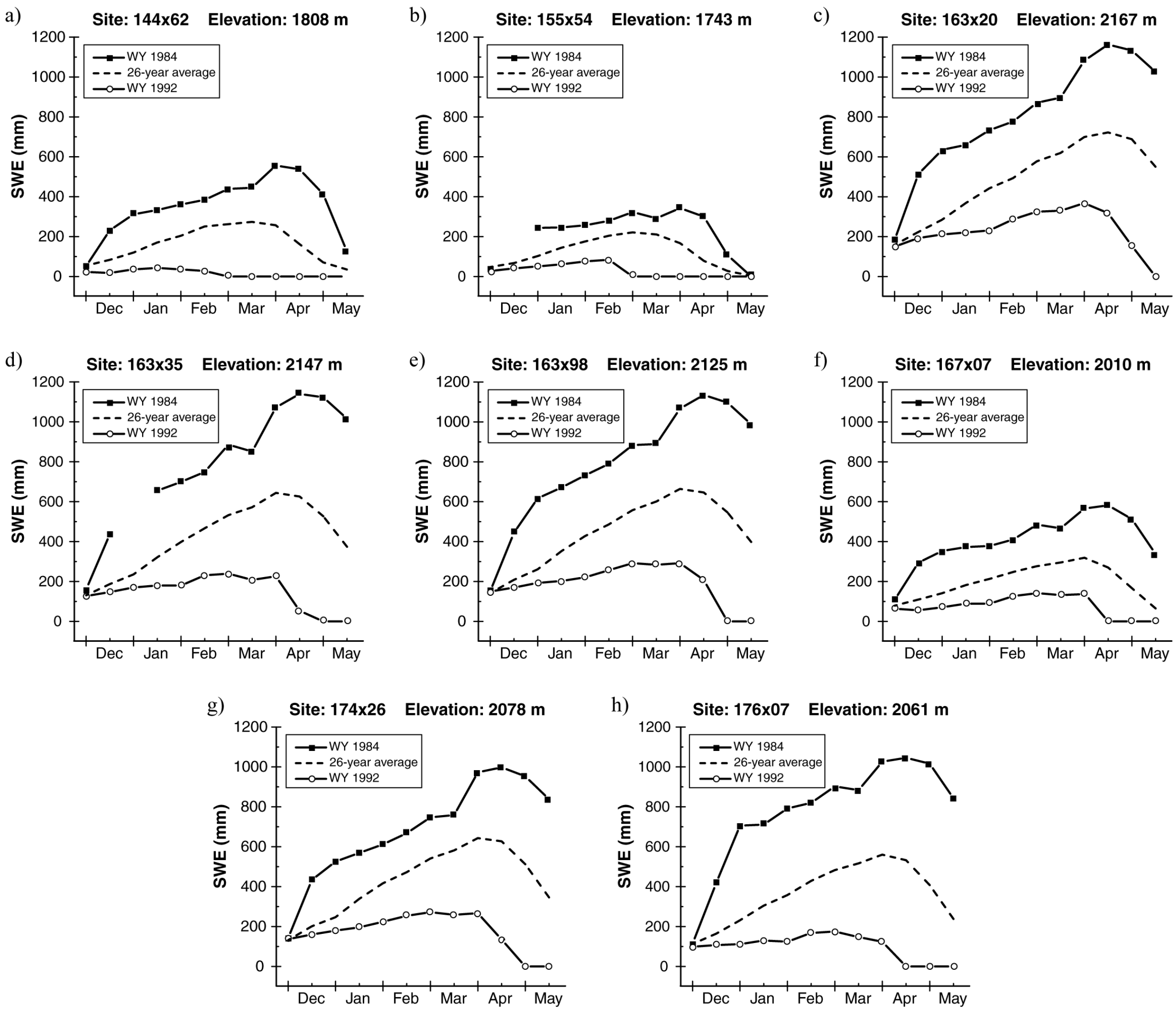

Figure 4. Bi-weekly snow water equivalent (SWE) for the largest snow season (water year 1984), and the smallest snow season (water year 1992). WY 1984 was the largest precipitation year on record, and WY 1992 was the smallest in the 35 year record (WY 1962–1996).

Figures 5a-h show the annual maximum SWE for each year in the 35 year record. Again, these data show a clear separation between the five high deposition sites (163x20,163x35, 163x98, 174x26, and 176x07) and the three low deposition sites (144x62, 155x54, and 167x07). Figures 5a-h also show the strong relationship between the seasonal snowcover and stream discharge in RCEW as presented by Pierson et al. [2000].

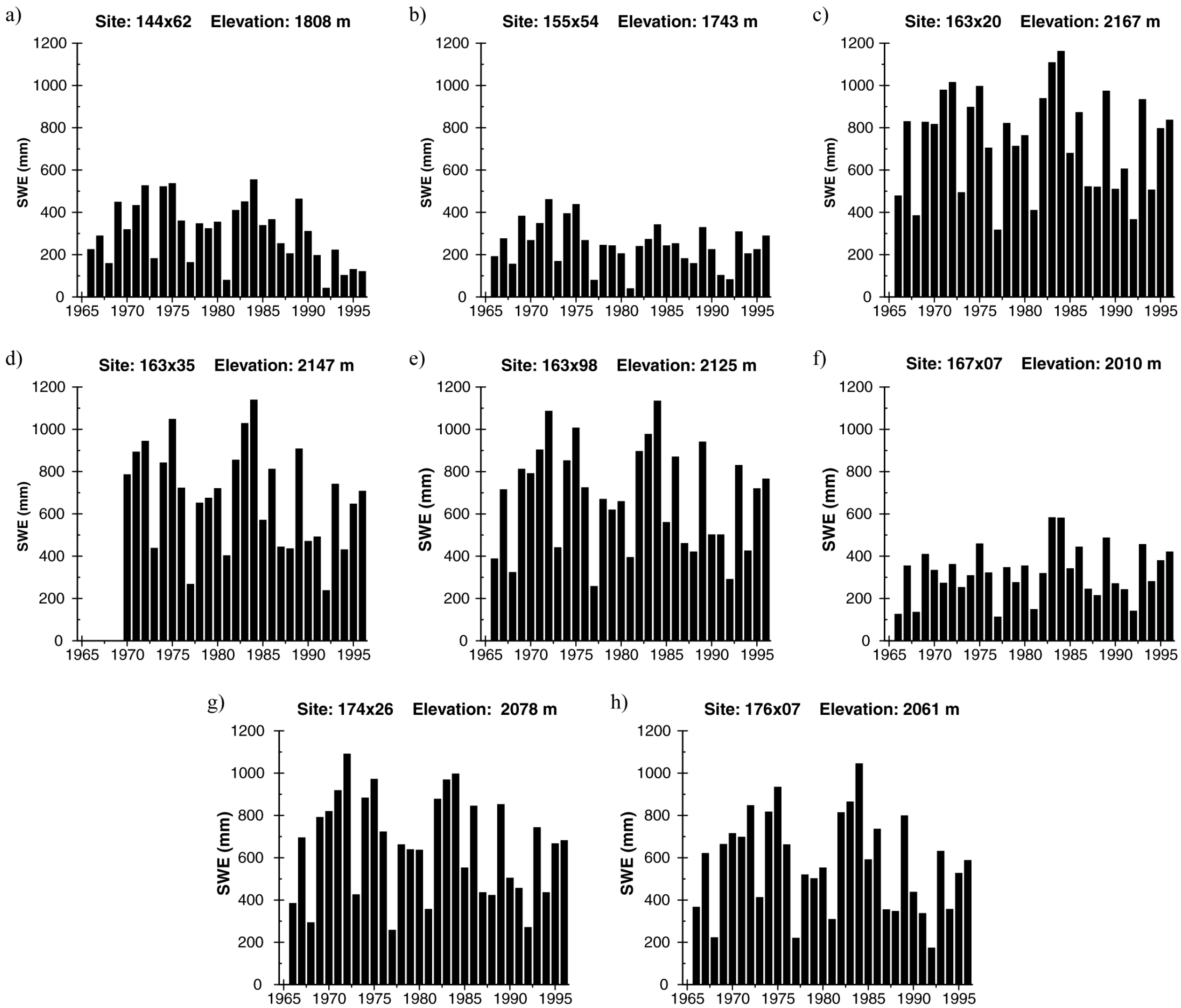

Figure 5. Observed snow course maximum for each year of record (WY 1962–1996).

4.2. Snow Pillow Data

Though various snow pillows have been operated at the Reynolds Mtn. Snow Study Site (176x07) since1964, snow pillow data have been considered part of the standard snow monitoring program at RCEW only since the early 1980's. Figure 6 presents 14 years of hourly SWE measured by the snow pillow at site 176x07. Figure 7 presents hourly snow pillow and bi-weekly snow course data for the1984 and 1992 snow seasons at the same site. During the1984 snow season, snow course data are greater than pillow data until mid-April, and then match the pillow data through melt-out. During the 1992 snow season, snow course data and pillow data are in close agreement. Differences between the snow course and snow pillow during the 1984 snow season can be attributed in part to over-sampling by the snow tube

[Work et al., 1965], bridging over the snow pillow with cold conditions during development of the snowcover in December and January [Beaumont, 1965], and actual differences in SWE along the snow course relative to SWE over the snow pillow.

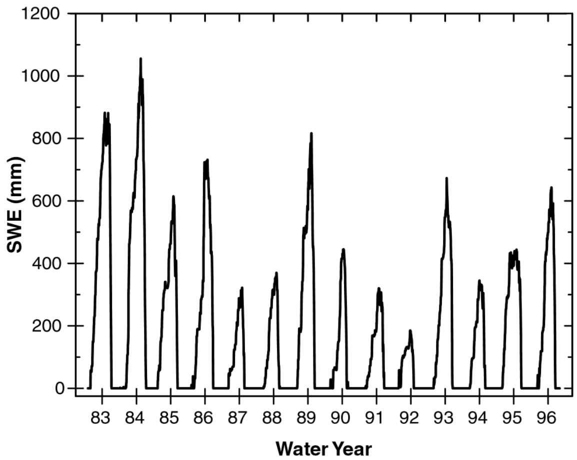

Figure 6. Hourly snow pillow data (SWE), 1983 – 1996 water years.

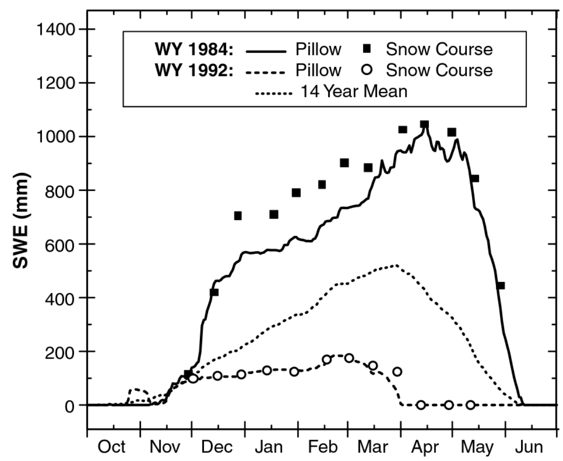

Figure 7. Snow pillow and snow course data (SWE) comparison for the 1984 and 1992 water years

5. DATA AVAILABILITY

Data from the eight snow courses and the snow pillow at site 176x07 are available from the anonymous ftp site ftp.nwrc.ars.usda.gov maintained by the USDA Agricultural Research Service, Northwest Watershed Research Center in Boise, Idaho, USA. Data are located in the directory publicdatabase/snow, in ASCII files that have been compressed using a "zip" utility. Each file has a 26-line ascii header providing brief information on file contents, file completion date, location (Easting and Northing, UTM zone11), both the GPS elevation and the DEM elevation (see Seyfried et al., this issue), time format, and period of record, column contents and units, missing data key, contact information, citation information, and disclaimer. An ASCII README file in the same directory gives a detailed description of the file format and contents. The interval snow course data are in eight separate files (one for each snow course) identified by the snow course site ID (eg.: "snowcourse144x62.txt"). Each file consists of a line containing month, day, year, SWE (mm), and snow depth (m) for each snow course sampled. The hourly snow pillow data are in a separate file identified as "pillow.txt", consisting of a line containing month, day, year, hour, minute, SWE (mm) for each hour from October, 1,1982, through September 30,1996 (14 water years).

Any publications which are generated from these data should cite this publication, and acknowledge the

USDA-ARS Northwest Watershed Research Center as the source. In addition we request that you notify NWRC of all publications, including theses and dissertations, which use or refer to these data. Citations may be sent by email to: publicdatabase@nwrc.ars.usda.gov or by mail to: USDA-ARS Northwest Watershed Research Center, 800 Park Blvd., Suite 105, Boise, ID 83712-7716. Your cooperation in this matter will promote further research and cooperation, help to validate the usefulness of the ARS experimental watersheds and data collection activities, and influence agency policy regarding future data collection.

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