MONITORING A RAIN-ON-SNOW EVENT

By

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INTRODUCTION

A large portion of the flooding and erosion damage in the Pacific Northwest and Intermountain areas of the United States arises from a mix of rainfall, snowmelt, and frozen soil, in the transient snow zone. A study of flooding in the northwest by Johnson and McArthur (1973) concluded that; "In general, the most severe floods occurred from December through March. The usual antecedent conditions on flood source areas were persistent periods of extreme cold, which froze the soil to considerable depth, and a shallow snow cover. Warm, moist, unstable air masses, accompanied by strong southwest winds, produced rain and caused rapid melting of the snow on frozen ground. The amount and intensity of the rainfall, the amount of snowmelt, and the imperviousness of the frozen soil combined to affect the flood severity."

A recent report from a more detailed study on small plot areas in northeast Oregon found that; "frozen soil, snowmelt, and rain on snow were key mechanisms in observed soil loss events. Because the infiltration capacity of these soils was severely curtailed or non-existent when frozen, nearly all surface water ran off" (Zuzel, Allmaras and Greenwalt, 1982).

Although the transient snow zone has been found to produce the most severe flooding and soil loss, to date major efforts in modeling snow accumulation and melt have emphasized deep or continuous snowpacks. Therefore, this method of determining the impact of various designs of conservation practices on runoff and erosion in the transient snow zone has not reached fruition, and more costly and time consuming field trials have been necessary.

This study was initiated to determine the water balance of the transient snow zone, and thereby gain an understanding of the conditions necessary for the rain-on-snow events to produce significant flooding and erosion. A secondary purpose of this study was to monitor the dynamics of the water and temperature systems prior to, during, and after an event.

DESCRIPTION OF STUDY SITE AND EQUIPMENT

The site selected for this study is a sub-watershed of the Reynolds Creek Experimental Watershed located in southwestern Idaho (Robins, et al. 1965). The site, called Nancy Gulch, was selected because of data availability, and because it represents "typical" rangeland sites found in the western United States that lie within the transient snow zone, that being between about 1200 to 1700 meters elevation in this area. The site consists of a 1.3 ha watershed instrumented with sensors and facilities to obtain precipitation, runoff, air temperature, soil temperature at five depths, and wind run on a continuous basis. A photographic record of conditions on the watershed (including snow cover) is obtained every three hours (or less during events) and snow cover and depth observations are recorded weekly. Soil frost is determined from a tube-type frost gage and temperature block measurements on a weekly basis and soil moisture is obtained using a neutron probe on a biweekly schedule. Humidity and solar radiation are monitored continuously at a nearby site. Runoff from two new plots consisting of a $0.9m^2$ metal pan and a $0.9m^2$ border enclosing a natural plot are also recorded continuously (Figure 1). As noted in Figure 2, these plots provide estimates of the water balance components of infiltration into the soil with or without frost, and evaporation from the snow surface.

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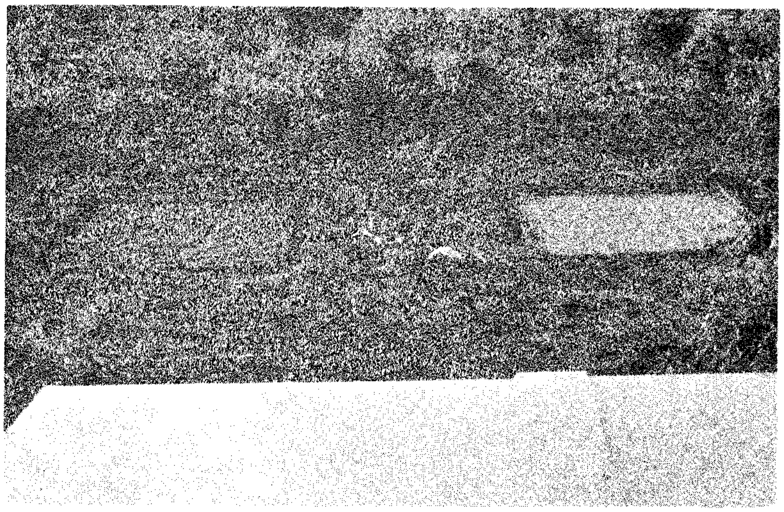

Figure 1

Nancy 0.9m^2 water balance study plots - bare soil plot on the left and metal pan plot on the right

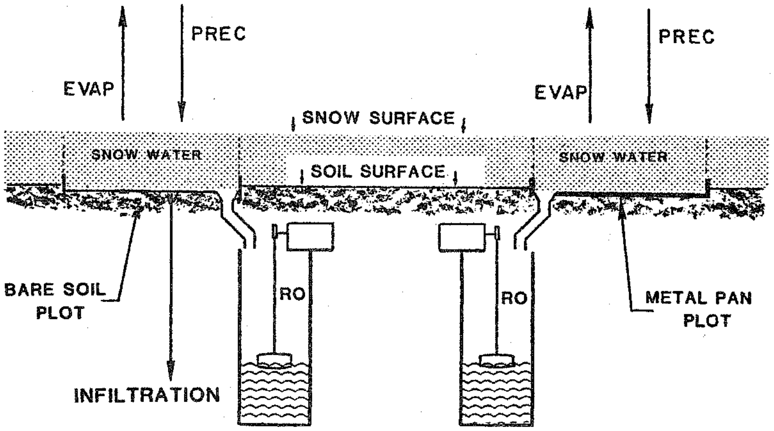

Figure 2

Water balance components for bare soil and metal pan plots, and water level recording system

The procedure for determining the water balance of a transient snow event is to monitor precipitation, runoff from rain or snowmelt, evaporation from the snow as a residual determined from precipitation minus runoff on the metal pan but assumed to be the same from both plots, and infiltration as determined by a comparison of runoff from the metal pan and the natural plot. The dynamics of the system are determined by using the above determined water balance components in association with measurements of the other parameters discussed.

RESULTS

Components of the water balance from six snow periods are presented in Table 1. A snow period is defined here as the period from the time snow starts to accumulate on the ground until it melts and the ground is again bare. A seventh period occurred and is listed along with cumulative precipitation, but this event contained more water in snow water storage and rainfall than the system was designed to accommodate at that time, thus overfilling at least one of the runoff tanks. In addition, some equipment malfunctions occurred, thus the numbers except for precipitation are meaningless and data are not included. However, counting this event it can be seen that three to four such events occur at this site during a winter season.

Table 1

Water Balance Components for Periods of Snow Accumulation and Melt
on Small Impervious and Bare Soil Plots

Period Dates	Period (Days)	Cumulative Precip. (mm)	Metal Pan Runoff (mm)	Evaporation (mm)	Evaporation (%)	Bare Soil Runoff (mm)	Infiltration (mm)	Infiltration (%)	Avg. Wind Run (km)
11/17/81-12/21/81	35	65.5	66.5	-	-	.3	66.2	99.6	10.8
12/22/81-2/17/82	59	79.4	Good snow event, but data lost due to equipment problems[1]						
2/18/82-3/12/82	23	11.9	11.9	-	-	0	11.9	100	8.4
11/20/82-12/6/82	17	23.9	25.4	-	-	.8	24.6	97	11.1
12/12/82-12/21/82	10	27.9	29.5	-	-	.8	28.7	97	13.4
12/22/82-1/8/83	18	17.3	15.5	1.8	10	19.8[2]	0	0	8.7
1/19/83-2/13/83	26	40.4	35.3	5.1	13	30.2	5.1	13	11.4

[1] Essentially all water in snow storage and precipitation did appear as runoff based on estimates of collection tank volumes.

[2] There may have been some snow left on the bare soil plot from the previous period.

Runoff from the metal pan matches very closely the precipitation recorded for the periods. The difference is probably due to measurement errors and drifting when runoff exceeds precipitation, however, as noted, the differences are small and never exceed 1.6 mm. In theory the difference between precipitation and metal pan runoff would be evaporation from the snow surface. In this study only on two occasions was runoff less than precipitation, and these differences are labeled as evaporation. In both cases the evaporation component is small and averages less than .2 mm per day, which is about the same order of magnitude as presented in other studies (Hutchison, 1966; West, 1962; Zuzel and Cox, 1978). Several factors could cause runoff from the metal pan to be greater than precipitation, these being: 1) wind distorting the catch in the precipitation gages, however, a dual gage system (Hamon, 1970) is used to account for this factor, 2) wind causing drifting on the metal pan thus increasing snow water equivalent above the average for the entire watershed, 3) splash onto the pan during periods of rainfall, or 4) runoff from the watershed above the pan overtopping the rim and running onto the pan. Since rainfall events produce essentially the same amounts of both precipitation and metal pan runoff, it seems most likely that drifting of snow on the pan is the cause of the slight increase in runoff from the metal pan over that recorded as precipitation. Drifting does occur and can be seen in Figures 3 through 5.

The infiltration component, which is the main factor affecting flooding and erosion, is seen to vary from essentially zero to 100 percent of precipitation. This means that depending on the soil conditions, all of the water stored as snow on the surface and occurring as rainfall can either be infiltrated into the soil, or appear as runoff.

Figures 3 through 5 show conditions on the watershed prior to a rain on snow event, during the event, and near the end of the event. The time between commencement of rainfall and removal of the snow cover depends on the initial snow cover, temperature, humidity, wind, and amount of rainfall. At this site this length of time was generally on the order of one to three days, thus it does not generally produce flashy type runoff, but rather runoff that builds up over a few days time. Average wind conditions were not drastically different for the six periods of complete data shown in Table 1, although winds during the melt period could be different, thus affecting melting time.

The influence of frozen soils on infiltration has received considerable attention at a number of locations within the United States (Mace, 1968; Trimble, et al., 1958; Pierce, et al., 1958; Willis, et al., 1961). All of these investigators noted that infiltration approached zero as a layer of concrete frost formed near the soil surface. The occurrence of concrete frost appeared to be a function of the soil type, vegetative cover, snow cover, temperature, and soil moisture. The factors affecting the occurrence of concrete frost at our study site are shown in Figures 6 and 7. During the two winters of observation at this site (1981-82 and 1982-83), infiltration was inhibited by soil frost on three occasions as noted in Table 1 (See footnote No. 1 at bottom of Table). In all three cases there had been a period of at least eight or nine days of below freezing average daily air temperatures, a 100 to 130 mm layer of snow on the soil surface, and the soil moisture in the top 230 mm had increased from about 40 mm in the fall to 80 mm or more when the critical freezing winter temperatures occurred. High soil moisture values have been identified by other researchers as being necessary to the formation of concrete frost and restricted infiltration (Kane, 1980).

The effectiveness of a snow layer in insulating the underlying soil against rather large air temperature fluctuations is also depicted in Figures 6 and 7. As shown the 100 mm depth soil temperature fluctuates considerably in response to air temperature changes when the surface is void of snow, but changes very little when 100 mm layer of snow is present.

Runoff from the bare soil and metal pan plots along with precipitation and average hourly air temperature are plotted in Figure 8 for the event of February, 7-13 1983. In this

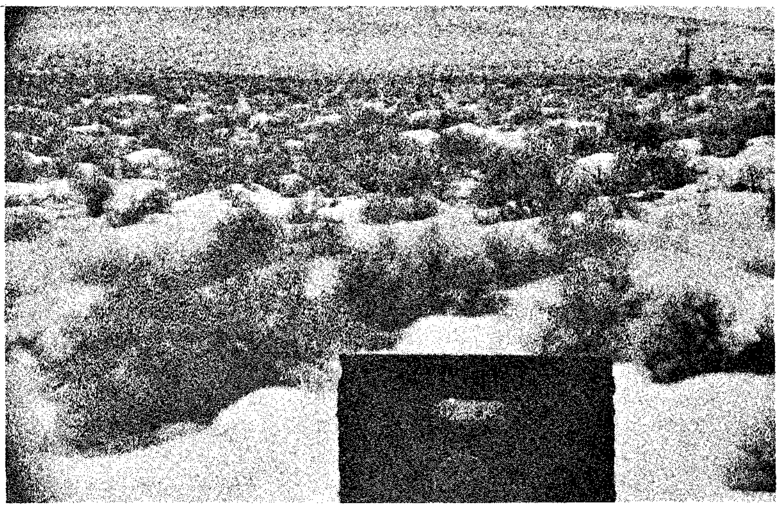

Figure 3

Snow cover of approximately 150 mm, as indicated on the pole marker at Nancy Watershed at 8:40 a.m., February 13, 1982

Figure 4

Partial snow cover after commencement of a rain on snow event at Nancy Watershed at 8:30 a.m., February 14, 1982

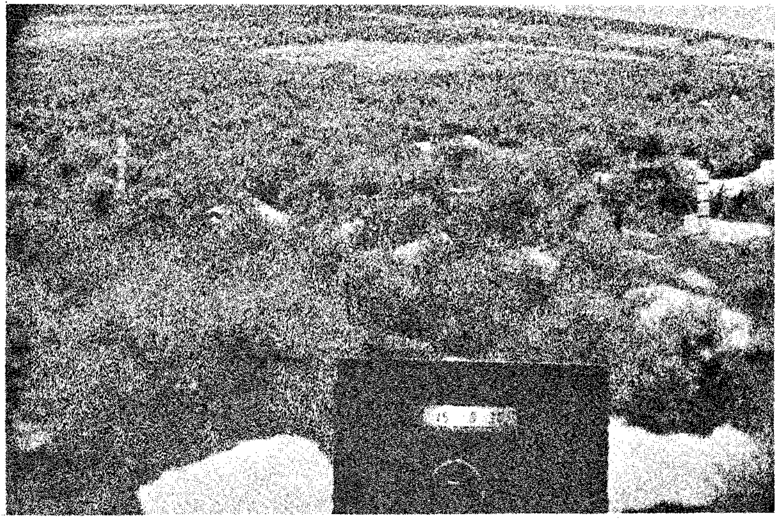

Figure 5

Isolated snow drifts during latter portion of a rain on snow event at Nancy Watershed at 8:30 a.m., February 15, 1982

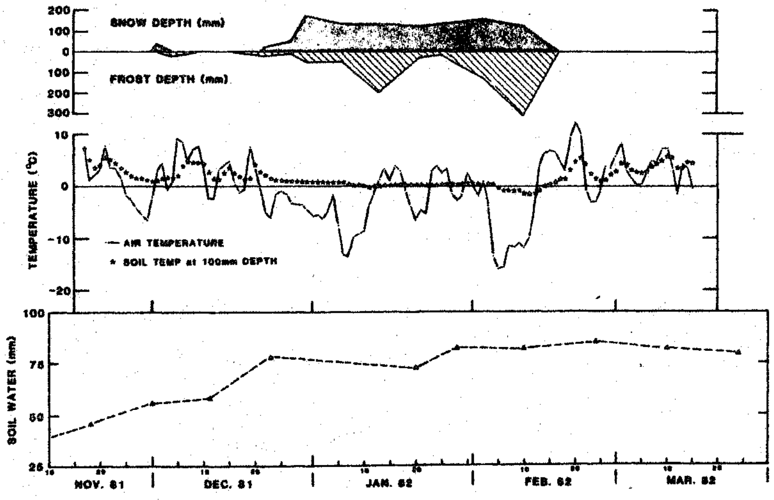

Figure 6

Air temperature, 100 mm depth soil temperature, soil moisture in the top 230 mm layer, soil frost and snow cover at the Nancy Watershed site for the winter of 1981-82

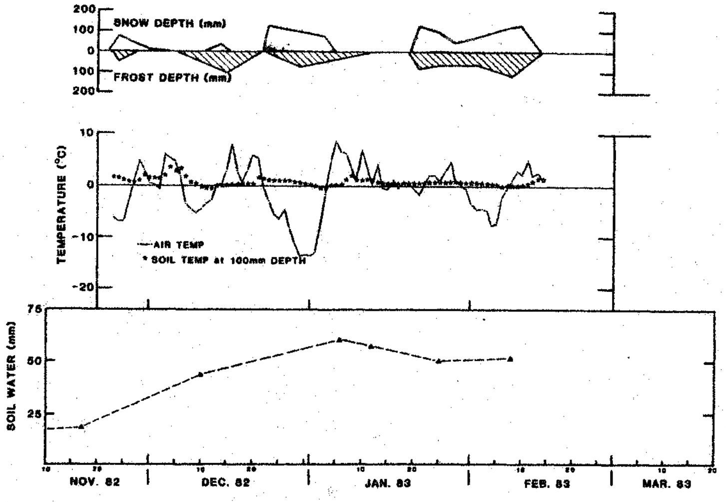

Figure 7

Air temperature, 100 mm depth soil temperature, soil moisture in the top 230 mm layer, soil frost and snow cover at the Nancy Watershed site for the winter of 1982-83 case, snow had accumulated from storms that occurred between January 19 and February 6 when temperatures had been near or below freezing, and snow water storage on the plot was measured at 22 mm and 21 mm on the bare and metal plots respectively. Precipitation in the form of rainfall on February 9 and 10 at slightly above 0° C initiated runoff from the plots, but the major portion of the runoff occurred in the afternoon of February 11 when temperatures increased a few more degrees. By the time more rainfall occurred on February 12 and 13, all snow water from the bare plot had been removed as runoff, however, some snow water was still stored on the metal plot and this water along with the additional rainfall continued to run off until rainfall ceased. This phenomenon occurred during all three events, that is, runoff from the bare soil plot was more rapid than that from the metal plot. A possible explanation for this phenomenon, although measurements are not available, is that the metal pan stays cooler than the bare soil, thus slowing snowmelt and subsequent runoff.

CONCLUSIONS AND DISCUSSION

Water balance components determined for six rain-on-snow events indicated that evaporation losses were generally small, and that infiltration values could range from 0 to 100 percent of rainfall and snow water storage. The infiltration component was greatly influenced by temperature and the amount of soil moisture in the upper 230 mm of soil. If the upper 230 mm of soil contained more than 80 mm of soil water and air temperature stayed below 0° C for periods of at least eight days infiltration was 13 percent of rainfall and snow water storage or less, for the six cases observed. In all other cases observed infiltration approached rainfall plus snow water storage, whether the soil was frozen or not.

The system of photographic equipment, standard meteorological recorders, and measurements from bare soil and impervious plots provided adequate information for determining the water balance components involved in all but one event, during which runoff exceeded design capacity. More intense monitoring of some variables would provide a more continuous record for determining the physical processes involved.

Further studies will be conducted to determine physical properties such as surface temperature and roughness of the bare soil plot during runoff from rain-on-snow in an attempt to explain the rapid melt and runoff, not observed on the metal pan plot. Observations of runoff from the 1.3 ha watershed will also be used to extrapolate results from the plots to field size areas.

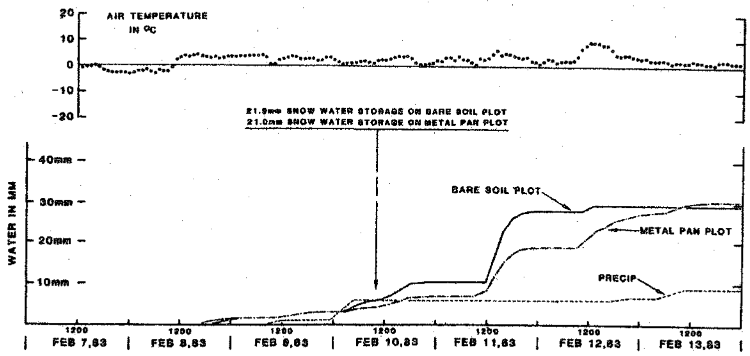

Figure 8

Average hourly air temperature, accumulated runoff from the bare soil and metal pan plots, and accumulated precipitation for a rain on snow event February 7-13, 1983

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