Representative and experimental basins

An international guide for research and practice

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A contribution to the International Hydrological Decade

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Thus to obtain the snow density the number of graduations of the weight scale should be divided by the reading of the cylinder scale multiplied by ten.

The instrumental error in measuring snow density by the weighing snow sampler is obtained by summing the error in measuring the snow depth (which may be estimated as 0.5 cm) and the error in taking readings by the balance scale (which may be assumed to be half a graduation or approximately 2.5 g). The greatest relative errors occur when the depth and density of the snow cover are small, and the smallest errors when the snow depth is equal to the height of the snow sampler and the snow density is above normal. When the snow depth is 50 cm and the density 0.40, for example, the relative error in measuring the density will not be more than $\pm$ 2 per cent.

In mountainous basins snow surveys are very difficult and sometimes dangerous for a snow surveyor. In areas with difficult access and considerable snow depth where long-distance methods of measuring are possible one of the simplest methods used is the installation of permanent snow scales with readings taken by means of optical devices.

Measurement of the water equivalent of snow in separate points can be made by an instrument based on the principle of counting gamma rays absorbed by snow. Cobalt-60 is used as a source of gamma radiation and a long-distance Geiger-Müller counter may serve as a detector (see section 4.11.3).

A device to measure the water equivalent of the snow cover, based on registration of the diminution of the natural radioactive radiation of the earth under the influence of a snow cover, is being installed in the U.S.S.R. The impulses of a medium radioactive background of the earth on a selected course before and after snowfall are measured by terrestrial or aerial survey [235].

4.2.2.1 Snowmelt

Data characterizing the intensity of snowmelt may be required in studying processes of spring floods caused by snowmelt in order to develop methods of calculation and forecasting of spring run-off.

The simplest methods are based on the relation between snowmelt and positive air temperatures. One of these methods consists of determining the dependence between a reduction of the water equivalent of the snow cover, obtained by snow surveys, and the sum total of the daily mean positive air temperatures.

Where research into snowmelt processes is to be done all factors affecting the snowmelt should be taken into account.

In the U.S.S.R. a special method, which is based on an inventory of all the energy-balance components of the snow pack has been developed. All the components of the radiation balance and of the turbulent heat and moisture exchange of the snow pack with the atmosphere are considered. With these investigations the water-balance method is usually applied using data from snow surveys, measurements of evaporation from the snow cover, precipitation observations and calorimetric estimation of the water-liquid phase in the snow pack.

Simplified versions of snowmelt-intensity calculations have also been used, Such methods are generally based on the use of climatological data such as wind velocity, total and lower cloudiness, vapour pressure and air temperature.

4.2.3 *Interception of precipitation by vegetation*

4.2.3.1 Interception of rain

4.2.3.1.1 FOREST VEGETATION

4.2.3.1.1.1 *General*

A large part of the rain falling upon forests is evaporated from the aerial parts of trees [87] and from the litter beneath them. Hydrologists disagree on the importance of interception as a water loss in excess of normal transpiration. Some reason that energy dissipated in evaporating intercepted water cannot be used for transpiration [34, 147,151]. Thus, they believe that evaporation of intercepted water results in lower transpiration rates. On the other hand, some [79, 199] suggest that sources of energy for transpiration and interception loss may not be the same. In fact, they have shown that interception loss during the dormant season greatly exceeds maximum potential evapotranspiration calculated by empirical formulas. Although the net effect of interception on the water balance of a forested catchment is not clearly understood, substantial interception differences between forest stands and species have been demonstrated. Because interception loss may affect total water yield from forest lands, hydrologists need estimates of these losses.

The objective of this section is to discuss the whole interception process, to recommend proven sampling techniques and instrumentation, and to present factors which will be useful in planning interception studies. For terminology, see section 1.5.

Gross rainfall, throughfall, and stem flow can be measured in the field. Litter interception presents a special sampling problem because it cannot be measured directly. After individual components of the interception process have been determined, total interception loss and net rainfall can be calculated by solving algebraic equations. Thus, total interception loss is calculated as

$$I_s = P_g - (Tf + Sf) + \text{Litter } I_s \tag{4}$$

and net rainfall is

$$P_n = P_g - I_s \tag{5}$$

where:

I_s = interception loss;
P_g = gross precipitation;
T_f = throughfall;
Sf = stem flow;
Litter I_s = litter interception loss;
P_n = net precipitation (see section 1.5).

4.2.3.1.1.2 *Variables*

A complete treatment of all variables affecting interception by forest vegetation is beyond the scope of this guide. The objective here is to review the variables known to affect interception and to discuss their relative importance in the interception process. For convenience, interception variables are classed as climatic factors or as stand characteristics.

Total rainfall and storm frequency are the two most important climatic variables. Analysing gross rainfall and interception factors by covariance techniques usually removes 95 per cent or more of the variation between individual measurements. Other climatic variables (i.e., rainfall intensity, wind speed and air temperature) are sometimes statistically related to interception factors, but their net effect is small [91].

With the exception of gross rainfall, stand characteristics such as type of stand (coniferous or deciduous) are usually more important sources of variation between stands than climatic variables. Interception loss in deciduous species is greater in the growing than in the dormant season, but the seasonal effect is less important in conifers [125, 158]. Canopy density (an expression of species, stand age, stocking, etc.) is directly related to interception loss [125,158]. Stem flow varies with bark roughness and branching characteristics, averaging 10 per cent of gross rainfall in beech [144], but stem flow is insignificant in mature Douglas fir [196].

4.2.3.1.1.3 *Methods and instrumentation*

4.2.3.1.1.3.1 *Gross rainfall.* Conventional rainfall-sampling techniques are discussed in section 4.2.1. These are applicable to the sampling of gross rainfall for interception studies. In some cases a sealed-surface technique is used instead of precipitation gauges.

4.2.3.1.1.3.2 *Throughfall.* Water filtering through the forest canopy varies from point to point by 100 per cent or more [98]. This large spatial variation has encouraged many investigators to use samplers with large receiving areas in attempts to reduce throughfall variation. Small cylindrical gauges are favoured because they are easily obtained and positioned in the field. Furthermore, because gross rainfall is sampled with round gauges, the use of round throughfall gauges avoids the problem of comparing data from different types.

Point throughfall amounts are directly related to distance from tree trunks [98, 188], but the correlation in closed forests is too weak to justify a stratified sampling scheme. If throughfall is measured in very open stands, stratification may be desirable. Sampling plots can be divided into homogeneous zones [126].

4.2.3.1.1.3.3 *Stem flow.* Stem flow is usually less than 10 per cent of gross rainfall and it is often omitted in interception studies. This omission leads to overestimates of total interception loss and stem flow must therefore be measured in any complete interception study.

Stem flow is sampled by sealing collars of copper or tin sheeting to trees to divert downflowing water into containers for measurement. The collar should project about 2.5 cm from the tree bole. Wider collars are sometimes used on rough-barked species, but these probably catch some throughfall in addition to stem flow [144].

The best method is to locate small plots randomly within the study area and to measure stem flow from all trees within these plots. Measured water volume is readily expressed in conventional depth units by dividing by plot area. Plots should be at least 1.5 times the crown area of the largest plot tree or 20 m² for very small trees [92]. Measured in this manner, the coefficient of stem-flow variation is a tenth to a twentieth of that of single-tree samples, or only slightly greater than that for throughfall.

4.2.3.1.1.3.4 *Litter interception.* During storms, some water is retained by the litter layer, where it is unavailable to plants but is subject to evaporation. Although throughfall and stem flow have been extensively measured, litter interception has rarely been studied. It may, however, account for as much as 10 per cent of the total interception loss, and no study should be considered complete unless litter interception is included.

The recommended method is based on the knowledge that litter interception is a function of the amount of litter on the forest floor, its moisture-holding capacity, and the local climate. Litter samples are collected from the undisturbed forest floor to establish wetting and drying curves and litter weight. It is then possible to estimate moisture fluctuations through time and to express litter interception losses in conventional depth units. Sampling under natural conditions is preferred because it ensures natural moisture drainage and natural drying [90].

4.2.3.1.1.3.5 *Sampling intensity.* Below is given an equation which is useful for determining the number of gross rainfall, throughfall and stem-flow samples needed to achieve a predetermined sample accuracy [208]. In the equation

$$n = \frac{t^2 \sigma^2}{d^2} \tag{6}$$

n is the number of samples needed, t is the tabulated value for the desired confidence level and the degrees of freedom, σ^2 is the population variance, and d is the maximum permissible difference between sample and population mean. Experience of other investigators is the best source of estimates on population variance; study objectives dictate sample accuracy.

Figure 4.5 shows the average coefficient of variation data of interception factors for some stand and climatic conditions in the eastern parts of the U.S.A. [91]. It shows that: (a) each factor in the interception process is a different sampling population; (b) the coefficient of variation is inversely related to the gauge catch until the latter reaches about 10 mm, but is independent for larger gauge catches; (c) throughfall variation is related to timber type and, for deciduous trees, to the season of the year; (d) stem flow measured on 40 m² plots is slightly more variable than throughfall. Data in the figure can be used as a first approximation of sampling needs for other studies. The standard deviation (σ) for a given storm size can be computed from Figure 4.5 by multiplying the coefficient of variation by the average gross rainfall, throughfall, or stem-flow gauge catch. With an estimate of σ^2 from Figure 4.5 and the proper t and d values necessary to meet study objectives, the number of samples needed can easily be calculated by solving equation (6).

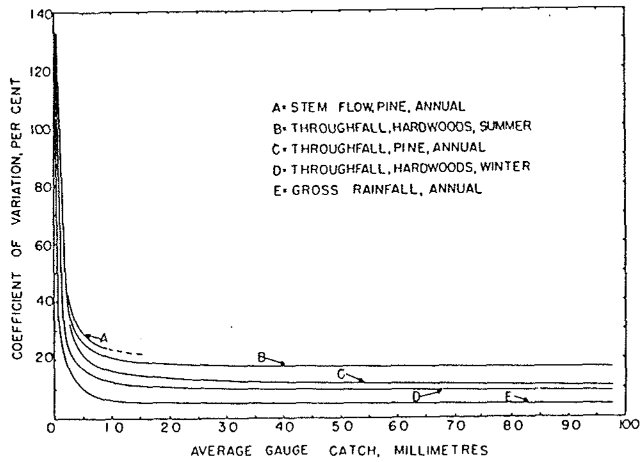

FIG. 4.5. The relation of coefficient of variation to selected interception-loss factors.

4.2.3.1.2 HERBACEOUS VEGETATION

4.2.3.1.2.1 *General*

Whereas forest and shrub communities have been widely studied, little research has been done into the measurement of interception loss in herbaceous communities [33]. Most work dates from 1940, although pasture grasses were considered earlier [100]. The lack of activity is attributable mainly to the difficulty of obtaining reliable measurements. The mechanical and spatial restrictions imposed by the reduced forms of herbs make the use of macro-sampling methods impossible. Micro-variations require refined and indirect measuring techniques.

4.2.3.1.2.2 *Sampling methods*

The variety of methods available makes it impossible to standardize sampling procedures. Because of difficulties in separating stem flow, throughfall and drip in the laboratory and the field, these parameters are normally measured as one.

The techniques considered are divided into two sections: gross interception loss and net interception loss. Early efforts generally measured gross interception loss while later techniques have attempted both. The more primitive methods are worth consideration as they may provide quick results for checking against more complicated but less mobile techniques.

A note of warning must be sounded here. The investigator must not rely too heavily on variance information from Figure 4.5 or from other studies. Such data provide a first approximation of sampling needs, but calculations of actual variance must be made as soon as enough data are available. For example, studies have been reported [115] in which throughfall variation was higher than expected and more gauges were required to meet study objectives. Too often variance is calculated after the study is closed and when it is too late to correct gauging intensity.

4.2.3.1.2.3 *Gross interception loss.* Some of the earliest attempts, where the height and density of the sward permitted, used standard precipitation gauges, placed 3 cm above ground level, amongst the growing vegetation. The throughfall thus collected was compared with precipitation catches on open ground [162, 181]. Others used test tubes flush with the ground to avoid disturbing the vegetation. [74] Results skewed by overland flow are a possibility in this method.

Others placed troughs in rows amongst the vegetation [10, 43]. Troughs integrate throughfall to a greater extent than gauges, although they do tend to overestimate the amount. They record the less dense outer portions of the canopy and do not measure stem flow.

Stem flow forms a significant proportion of the gross precipitation reaching the soil. Failure to record this value gives overestimation of the interception loss. Stem collars cannot be used and therefore the surface may be waxed under a sward in an effort to catch throughfall and stem flow [89]. This method has been refined by others [50], but even so its success in dense swards is doubtful.

The best method appears to be the cutting of specimens at ground level. They are then arranged on a screen, irrigated with a known quantity of precipitation and the throughfall collected [43, 134, 198].

These methods measure stem flow but introduce artificial arrangements in vegetative form. A test using a modified Northfork infiltrometer (Fig. 4.6) has been tried in dense rye dairy pasture. This method measures leaf-interception loss but does not accurately record the large quantity of moisture retained at the base of the stem. This moisture could be considered as surface detention. The method is satisfactory for low-growing and clustered plants.

4.2.3.1.2.4 *Net interception loss.* In some laboratory studies [34] samples grown in nutrient solutions were used. Paired samples on scales were irrigated to prove conclusively that leaf-surface evaporation reduces transpiration loss and increases net interception loss by the presence of dead matter. The system separated throughfall and stem flow, avoided the problem of taking soil-moisture measurements [207] and utilized plants growing in their natural position.

Other workers confirmed these results by extending this work and using floating lysimeters in a grassed field [151].

4.2.3.2 **Interception of snow**

The basic method for determining throughfall is a comparison of precipitation gauges and/or snow boards installed beneath the control gauges in adjoining clearings. If rainfall is absent, snow-pack measurements can be used. It may be necessary to measure stem flow, particularly during the thaw period and conventional collars are adequate.

Automation of sampling plots is complicated by the immobility of snow and by low temperatures. Sampling, phytomorphological and climatic requirements are the same as for rainfall.