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INSTITUTE OF HYDROLOGY

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REPORT ON PRECIPITATION

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A 'state of the art' report prepared on behalf of the Committee on Precipitation of International Association of Scientific Hydrology, for the Moscow General Assembly, August 1971.

1. INTRODUCTION

'What happens to the rain' is without a doubt the shortest definition of the science of hydrology. 'The rain and what happens to it' is probably more apt and a definition that demonstrates better the importance of this flux. This importance is, of course, generally recognised, both nationally and internationally. Apart from the work of the International Association of Scientific Hydrologists and its Committee on Precipitation, there are those activities stemming from the several resolutions adopted by the Coordinating Council of the International Hydrological Decade. Some of these resolutions have been taken up by the World Meteorological Organisation which has working groups of its own that are active on a variety of problems concerned with precipitation. National IHD programmes include studies of precipitation, measurement, network design, frequency of intense rainfall and assessment of probable maximum precipitation. Outside the IHD, work on precipitation is being carried out in a variety of disciplines; ecologists are studying the nutrient supply in rain, the occurrence of heavy rain during the sheep breeding season is of interest in animal husbandry studies, hail and its supression are vital to viticulture, while communications engineers are investigating how precipitation interferes with the propogation of microwaves. The field is vast and not one that can be covered adequately in a few pages, hence this report concentrates on subjects that are considered most central to hydrology. Topics of a specialised nature, or ones involving an allied discipline, are not included, such as radar measurement of rainfall (Kessler and Wilk 1968), rainfall stimulation (Neiburger 1969), time series analysis (Sneyers 1964), rainfall simulation (Grace and Eagleson 1966, Raudkivi and Lawgun 1970) and inadvertent rainfall regime modification (Changnon 1969).

2. MEASUREMENT AT A POINT

Although the subject of precipitation measurement has a long history and a voluminous literature (Kurtyka 1953, Israelsson 1967), awareness of the significance of the conventional type of instrument's shortcomings has grown only during recent years. It is now being recognised that measurements of precipitation, particularly rainfall, are neither reliable nor accurate and that hydrologists have been misled in assuming that they are.

2.1 RAINFALL MEASUREMENT

Large numbers of comparisons of different types of raingauge have been undertaken at various sites (Poncelet 1959a, Jaquet 1960, McGuinness & Vaughan 1969) and there has also been an international comparison based on the interim reference precipitation gauge (Poncelet 1959b, WMO 1969). Different sizes of gauge (Kalma *et al.* 1969) and different shapes (Maidens 1965) have been tested. Raingauge readings have been compared with lake level measurements (Harbeck & Coffay 1959, Kkarbaum & Klinker 1966) and lysimeter records (McGuinness 1966) and have been found too low. However, recognition that the chief source of error, namely wind, causes the normal type of elevated gauge to under-register in a systematic fashion has led to the use of the pit gauge (Struzer *et al.* 1965, Rodda 1967). This instrument, which is particularly suited to the measurement of rainfall is being used in a new WMO international programme of raingauge comparisons.

2.2 SNOWFALL MEASUREMENT

The effect of wind on a gauge is even larger in the case of snowfall, resulting in greater difficulty in obtaining more nearly true measurements of snowfall than rain. It has been estimated from the water balance in one region where snow is a very important component of precipitation, that there is a systematic annual error of about 20% in the assessment of precipitation (Findlay 1969). Snow gauges in sheltered surroundings are employed as reference instruments in some countries (Uryvaev *et al.* 1965), while the profile method, which uses pairs of gauges at different levels, one shielded and the other unshielded, has been tried in others (Hamon 1970). Measurement of snow on the ground is of course much simpler than catching snow as it falls, but this too has its problems (McKay 1968). The use of snow courses and the sampling of cores are well known techniques, as are devices like snow platforms and snow boards. Radioisotope gauges have been employed in remote areas and these are often telemetering, while neutron scatter devices have been employed for snow density determinations (Danfors *et al.* 1962). The technique of measuring the attenuation of the natural radioactivity of the soil by the snow lying on it has been developed for determination of snow depth (Zotimov 1965) and now aircraft are being used for these surveys (Dahl and Odegaard 1970, Peck *et al.* 1970). The snow pillow, despite its draw-backs (Beaumont 1968), seems to be the instrument that provides the best information on the timing and amount of snow and is now in use at a number of sites (Engman 1966, Tollan 1970), some with telemetering facilities (Shannon 1968). A possible alternative is the snow melt lysimeter. An instrument for snow, equivalent to the pit gauge, has yet to be devised however, while techniques for the measurement of hail (Voronov 1967), dew and the other minor forms of precipitation have to surmount even more difficult problems.

2.3 SOURCES OF ERROR

Aerodynamically designed gauges (Poncelet 1962), some developed from wind tunnel tests (Robinson & Rodda 1969), are a possible alternative to pit gauges, but there is the problem of how to obtain a performance that is reasonably constant for all combinations of turbulent wind flow with different drop size spectra. There are, of course, other sources of error that affect a gauge. Splash-in has been investigated (Struzer & D'jackova 1966, Struzer *et al.* 1968) together with the lateral travel of splashes determined in the field (Green 1969, Green 1970). The loss due to wetting of the funnel of certain types of gauge has also been assessed (Necaev 1965) and a correction made for evaporation of the collected water (Golubev 1960).

2.4 CORRECTING FOR ERRORS

As a consequence of these studies of gauge errors, some countries have adopted a new type of gauge for their national networks (Beaak 1945, Struzer 1965b), while countrywide maps have been constructed to show how the difference between precipitation at gauge height and at ground level is distributed (Struzer *et al.* 1968, Rodda 1970). Few attemps have been made to assess the precipitation over the world's oceans, regions where gauge errors would probably be even greater than for the most difficult land areas.

2.5 AUTOMATIC AND OTHER INSTRUMENTS

A number of new types of recording raingauges have been devised such as the one with a measuring chamber drained by a magnetic valve (Karkunen 1965) and instruments are available commercially that record on punched paper tape or magnetic tape. In addition, vecto-pluviometers continue to be employed at a number of sites (Meyburgh

& Wicht 1966), while more specialised devices have been produced, such as the one for determining raindrop size (Joss & Waldvogel 1967). Some indirect methods of measurement of precipitation have also been devised, such as by use of optical attenuation (Warner & Gunn 1969) and by capacitance changes (Semplak 1966), but their weakness is that they rely on bucket-type gauges for their calibration.

3. NETWORKS

The majority of precipitation networks have developed in a haphazard fashion and few are adequate in terms of density of instruments and length of records. There was, however, a symposium on the Design of Hydrological Networks in Quebec in 1965. There are also available a number of comprehensive reports on networks such as those published by WMO (Kohler 1958, Rodda *et al.* 1969) and a number of accounts of the design and operation of networks in individual basins (Hamilton 1954, Wicht *et al.* 1969). Although some papers deal with network design for snow depth determinations (Hegedus & Szesztay 1967, Orstrem & Stanley 1969), the majority are concerned with rainfall. Naturally there are differences between network designs according to objectives, for example, flood warning as opposed to surveying water resources. Most networks, however, must be classed as multipurpose, but whichever objective is paramount, the problems of design are similar. These problems may be stated as follows:

i. How many stations are required?
ii. Where are the stations to be located?
iii. How long should they operate?

There are a number of objective methods of answering the first question, fewer ways of replying to the second, and hardly any means of deciding when stations should cease operating. In addition there is the need to translate the information content of the data into its economic worth - a subject rarely treated.

3.1 NUMBER OF GAUGES

There are various methods of analysing the rainfall records from a network to derive a parameter, such as the variance, then relating that parameter to the number of gauges, and the required accuracy of estimate of the mean (Rycroft 1949, McCulloch 1961, Panchang and Narayanan 1962, Sutcliffe 1966, Stephenson 1967, Herbst & Shaw 1968). A variant of this approach is to 'saturate' a basin with gauges and to compute the error that results from employing only a small number of the gauges (Huff & Neill 1957, McGuinness 1963, Nicks 1965). This approach assumes, of course, that the true mean basin rainfall is given by the dense network - a questionable assumption.

3.2 SPACING OF GAUGES

The spacing or location of raingauges is dealt with in other papers, the use of correlation analysis being favoured recently, (Hershfield 1967, Holland 1967). Networks in different areas and different periods of observations in the same network have been investigated in terms of the decay of correlation between gauges. Factors other than distance between gauges, such as altitude differences, have also been considered (Hutchinson 1969). The use of primary and secondary stations is advocated as a method of establishing spatial patterns more readily and the optimum duration for secondary stations has been assessed (Langbein 1960). It has been postulated however, that some of the apparent variability of rainfall across small areas may be due to the exposure of raingauges (Hamilton 1954) and to faults in the performance of the gauges themselves (Rodda 1970). The various mathematical models of basins that have been developed to predict runoff might be optimised on the hydrological network rather than on the runoff, particularly the rainfall network, so that the minimum error would result. Alternatives are the use of spectral analysis (Eagleson & Shack 1966) and sampling theory (Eagleson 1967). Another approach is to calculate the standard error of the mean basin rainfall using a covariance factor amongst raingauges, to use a Lagrangian multiplier technique to minimise the variance and to optimise allocations of gauges (Sun Fu Shih *et al.* 1970). However, all these methods require data from networks of gauges that have been in existence for some time. No method has yet been devised that will permit determination of the number of gauges required for a basin which has no records.

3.3 SPECIAL NETWORKS INCLUDING THROUGHFALL NETWORKS

Basin scale and countrywide networks are not the only ones that have received attention; there are the special purpose networks covering small areas that are designed for sampling the variations in the chemical composition of rainfall for example, Andersson 1969, while throughfall networks are an integral part of studies of the distribution of interception. The following extract from a review of the subject by Leyton and Rodda (1970) covers many of the important points.

"The problem of sampling a variable throughfall is discussed in some detail by Reynolds & Leyton (1963) and Leyton *et al.* (1967), (1968). The aim is usually to obtain a reasonably reliable estimate, generally one with a mean standard error of about ± 5% with a minimum number of measurements. The need for some statistical measure of the reliability of these measurements has not always been appreciated so that many of the results that have been quoted for interception are of questionable reliability. Various types of collecting gauges have been used ranging from large troughs to small standard type raingauges. The theoretical advantage of troughs is that because they sample more of the throughfall fewer are needed. Eidmann (1959) and others used very long narrow troughs capable of sampling below the crown spread of adjacent trees; Stalfelt (1963) preferred triangular troughs. Reynolds & Leyton (1963) have described automatic recording techniques based on

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