DISCUSSION OF PROBLEMS IN MEASURING PRECIPITATION IN MOUNTAINOUS AREAS
(key paper)

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SUMMARY

Precipitation measurement deficiencies, which are a function of many variables, exist in nearly all precipitation measurements and much effort and research has been devoted to the problem of minimizing these measurement errors. Papers which deal with the general problem of improving precipitation measurements and which were presented in this particular session of the symposium are reviewed. Specific areas of concern that are touched upon include evaporation losses in seasonal storage gauges, wind effects on gauge catch, horizontal versus sloping orifices, and precipitation measurements by radar.

RESUME

Les mesures des précipitations souffrent presque toutes d'imperfections, qui dépendent de très nombreuses variables; or des efforts soutenus et de nombreuses études ont été consacrés à la recherche d'une solution qui permette de réduire ces imperfections au minimum. L'auteur passe en revue les communications qui traitent du problème général de l'amélioration des mesures des précipitations et qui ont été présentées au cours de cette séance du colloque. Les problèmes particuliers qui sont abordés comprennent les pertes par évaporation dans les pluviomètres totalisateurs fonctionnant durant certaines saisons, les effets du vent sur les quantités d'eau recueillies par les pluviomètres, les avantages respectifs des instruments à orifice horizontal et des instruments à orifice incliné, ainsi que les mesures des précipitations par radar.

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Introduction

Hydrologists have long recognized that deficiencies exist in precipitation measurements, especially those for snowfall. Errors in precipitation data account for a large portion of the inaccuracies in precipitation-runoff and other hydrological relations. For this reason, considerable effort has been devoted to the development of techniques and instrumentation for the improvement of precipitation measurements. The need for improved knowledge of the amount and distribution of the actual precipitation, rather than an index of the amount, has greatly increased with the advent of conceptual hydrological models for simulation of streamflow.

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Kurtyka /1/ and Israelsen /2/ have presented reviews of the various instruments and techniques that have been developed during the past one hundred years to measure precipitation. The recent WMO/IHD Report No.16 "The Precipitation Measurement Paradox - The Instrument Accuracy Problem" by Rodda /3/ contains a comprehensive review of the many problems associated with precipitation measurement methodology. These authors agree that the deficiency in a precipitation measurement is normally much greater for snowfall than for rainfall and in general more difficult in mountainous areas. It is also generally accepted that standard gauges record less than the true precipitation under most conditions and that the deficiency in catch is primarily the results of wind action and resulting turbulence around and over the orifice of the gauging instrument.

Many different types of gauges and protection devices have been developed to minimize the adverse effects of wind but none are entirely acceptable under all conditions and for all types of precipitation. For rainfall there is fair agreement that a pit gauge adequately protected from splash-in by the use of a grid of vertical strips of metal, provides reasonably accurate measurements /4/. The pit gauge cannot be used for snowfall because of the redistribution of snow that occurs after it reaches the ground.

It is not the intent of this paper to review the many techniques and instruments for measuring precipitation that have been proposed or that are in use. The papers which are to be presented at this session include many of the major problem areas and propose some new approaches for minimizing the most serious causes of deficiency in precipitation measurements. Those problem areas of measuring precipitation that are covered in these papers will be discussed. These are:

1. Evaporation losses in seasonal storage gauges.
2. Wind effects on precipitation gauge catch.
3. Horizontal versus sloping orifices.
4. Measurement by radar.
5. Analysis of snow cover.

In keeping with the theme of this symposium, the following comments will be directed primarily to problems associated with measurement of precipitation in mountainous areas, especially those pertaining to measurement of snowfall.

<u>Evaporation losses in seasonal storage gauges</u>

Evaporation losses in precipitation gauges have been reported as being only a relatively small percentage of most measurement errors for daily precipitation but such errors in seasonal storage gauges assume more importance. Mr. Sevruk's paper "Evaporation Losses from Storage Gauges" discusses what can occur when a too thin film of oil (less than 5 mm) is used to prevent evaporation losses in seasonal gauges. A recent study by the National Weather Service of the United States /5/ verifies Mr. Sevruk's contention that the amount of oil required is more than that which is used in some countries. In fact, a depth of 7.6 mm (0.3 inch) was recommended for maximum effectiveness. The National Weather Service study also found that the type of oil is very important since several oils, including transformer and silicone oils, were not effective in retarding evaporation even using the recommended depth. The viscosity of some oils was found to be too high for use in a gauge and in some cases the oil became almost solid at minus 20 degrees centigrade.

<u>Wind effects on precipitation gauge catch</u>

The long history of the development of windshields to reduce the adverse effects of wind on precipitation gauge catch has been well documented in the literature. Mr. Kirigin's paper "A Contribution to the Problem of Precipitation Measurements in Mountainous Areas" reinforces the fact that windshields are generally effective in reducing the wind-caused errors. The use of windshields will result gauge catch which is normally greater than that without a windshield and is there assumed to be nearer the true precipitation. However, as reported by Mr. Kirigin and others, the relative catches among different gauges varies with the type of precipitation and also seasonally. This has been observed for gauges with and without windshields.

The purpose of the windshield is to reduce or eliminate the eddies and updrafts induced by the fact that the gauge is an obstruction in the windstream. Other studies have demonstrated that the use of windshields does increase gauge catch but there has been only very limited work to evaluate the effectiveness for measuring true precipitation, especially snowfall. A major reason for this has been the inability to accurately measure the true precipitation.

The paper by Messrs. Green and Helliwell entitled "The Effect of Wind on the Rainfall Catch" is an excellent contribution to the literature on this subject. The wind tunnel tests show the relative increase in wind speed above the gauge orifice even with relatively low wind speeds. Because of the limitations in simulating natural turbulent conditions in wind tunnels, their study, as with most studies of this kind, has been limited to modelling only the effect of horizontal, nearly turbulent free wind movement. For all but the most ideal of sites, air motion at the orifice of a gauge is seldom if ever truly horizontal. This is especially true for gauges in mountainous regions.

Figure 1 shows simplified illustrations how wind flow may vary in the vicinity of a gauge [6]. Figure 1a is an example of the classic diagram used to illustrate the effect of increased wind over the gauge resulting from horizontal wind movement. Figures 1b and 1c have been included to indicate that turbulence induced by roughness in the area of the gauge can result in upflow or downflow at the gauge orifice. A shift in the wind direction and/or speed could result in a change in the direction of the vertical flow over the top of the gauge. In addition, variations in flow at the gauge are also induced by the natural eddies in the lower atmosphere. Sudden changes in the rate of precipitation that is observed during convective type storms (as evident by the rapid changes in the amount of water on a windshield of a car when one drives through a heavy rain area) illustrates how severe the eddies may be and how effective they can be in concentrating the precipitation and in transporting the drops or snowflakes in irregular patterns. Downdrafts in such convective storms are often quite strong. Green and Helliwell reported that the data from their study indicates that raindrops do not fall at their terminal velocities in the lower layers of the atmosphere. From personal observation in the field it is felt that the strong downdrafts in convective storms may occasionally cause raindrops to arrive at the orifice of the gauge at speeds greater than their terminal velocities. The downward movement of the downdraft must be added to the fall velocity of the drop with respect to the air in which it is falling. Field results showing fairly large differences in catch for identical gauges with apparently similar exposure tends to support the fact that there are large unexplained differences in the amount of turbulence and consequently results in one area may not be applicable to other areas.

Because of the wide variations in natural conditions (i.e. gauge location, wind speed and direction, precipitation type, etc.) as well as gauge configurations (gauge type, shielded or unshielded, heated or unheated, height of orifice above ground and in respect to the top of the windshield, etc.) and also because of the inherent difficulties in obtaining reliable data for these events, it will no doubt be a long time before field tests can be used to definitely answer the questions pertaining to gauge catch efficiency.

The exposure or the degree of protection from adverse wind movement afforded the gauge by the surrounding objects is the most important factor relating to the

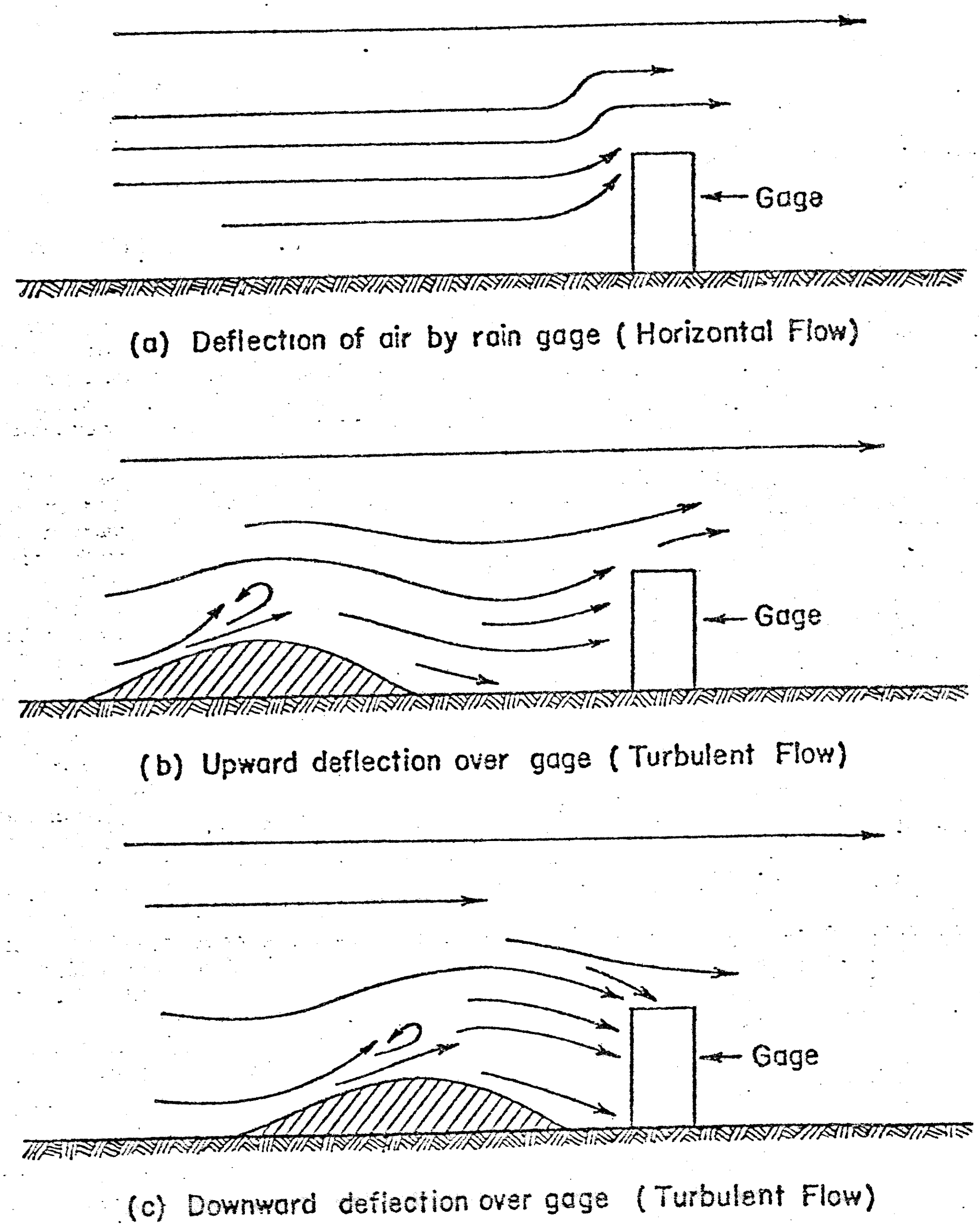

Figure 1: Variation in airflow over precipitation gage.

accuracy of the gauge in measuring true precipitation. Mr. Lee's paper "An Optographic Technique for Evaluating the Exposure of Precipitation Gauge Sites in Mountainous Areas" is a major step in providing an objective means of evaluating the exposure of a site. Such measurement could be used to develop improved objective techniques for defining exposure such as the method which has been proposed by Blust and DeCooke /7/. In the Blust and DeCooke technique a numerical value for exposure is determined from the horizontal and vertical angles from the top of the gauge to surrounding objects. Objective information on the immediate surrounding as provided by the globoscope would be of use in evaluating the effectiveness of the gauge in measuring true precipitation. However, additional research would be required since other factors such as the thickness of the objects and the effect of large-scale topographic features cannot be measured from the photographs.

Some investigators believe that well-protected sites such as small openings in large coniferous-type forests can provide a fair indication of the average snowfall in the area /8/. A subjective classification system based on the degree of protection afforded by nearby objects and a knowledge of the general terrain has been used to some extent in the United States /9/.

In mountainous areas, especially above the timberline, well-protected sites are generally not available and at such locations there is often considerable wind during periods of snowfall. Unfortunately it has been shown that windshields presently in use become less effective with increasing wind speed. Therefore, in order to accurately measure snowfall at such poorly exposed, windy locations, new instruments and/or techniques will be required. The paper by Mr. Ermini entitled "Significance of the Duration of Snow Precipitation at High Altitudes" proposes the technique of utilizing the average hourly rate of precipitation from lower altitudes to apply to the length of time that precipitation occurs at higher altitudes to arrive at an estimate of the amount of precipitation at the higher altitude. This is an interesting technique and in those locations where the occurrence of precipitation is observed, such as at ski resorts, but not the amount, fairly reliable estimates of the total precipitation could be obtained. A factor that should be considered however is the large variations in the distribution of precipitation that occurs with different types of storms. The use of storm typing therefore may be a useful parameter in improving the estimating procedure.

The proposals in the papers by Messrs. Rechard and Hamon utilize regular gauges to record the amount of precipitation but new approaches to determining the ground true precipitation. The dual gauge approach proposed in Mr. Hamon's paper "Computing Actual Precipitation" assumes that the wind movement on a pair of adjacent shielded and unshielded gauges is essentially the same and that the true precipitation can be computed using a relation involving the ratio of the catches in the two gauges and the catch in the unshielded gauge. This technique has the unique advantage in that the reduction in catch by the wind is used to advantage instead of being the cause of the major source of error. The relation may not hold for each individual storm, but it does hold great promise for obtaining realistic values for true precipitation on a longer term basis for locations at which it has been difficult to obtain reliable measurement in the past. The technique also has the advantage over some methods of calculating the true precipitation in that wind speed and temperature data are not required for the calculations.

Professor Rechard's paper "Winter Precipitation Gauge Catch in Windy Mountainous Areas" is basically a new approach for the use of snow fences to protect a precipitation gauging site rather than the gauge so that well-protected sites could be constructed at any location. Although Professor Rechard's investigations are continuing, present indications are that the blow fence gauge configuration may provide a relatively constant index of the true precipitation for all wind speeds. As with Mr. Hamon's approach the installation would be more expensive than a single shielded gauge installation. The improvement in precipitation measurement for windy locations should justify the additional cost of one of these techniques.

Horizontal versus sloping orifices

Two papers will present information on the general subject of the use of standard versus stereo and tilted gauges. Some investigators feel that data from gauges installed with their orifices parallel to the ground surface are well correlated with hydrological parameters in small watersheds. Another reason why some have considered the use of sloping orifices to be advantageous is that their catch on windward slopes is generally larger than for gauges with horizontal orifices. This increase in catch does tend to offset the deficiency in gauge catch due to wind action. This is not a valid reason however for selecting either the tilted or stereo gauge. On leeward slopes the sloping gauge often records less precipitation than one with a horizontal orifice.

The basic question is to determine what we really wish to measure. If the data are to be used to compare the precipitation between different locations or for use in constructing precipitation maps, then the meteorological precipitation or that amount which passes through a horizontal plane near the surface of the ground should be measured. If an estimate of the hydrological precipitation, or that amount which falls on a unit area parallel to the surface of the ground is of value then the use of a tilted or stereo gauge may be justified for research purposes. For national networks only gauges with horizontal orifices should be utilized.

It is felt however that most applications of stereo or tilted gauges are t result of a tendency to attribute a portion of the precipitation measurement error the increased angle of incidence of the precipitation particles themselves. It ma appear that as the angle with the horizontal of an idealized precipitation partic pathline reduces from 90 degrees (i.e. no wind) to something less than 90 degrees (i.e. increasing wind speed) there is also an increase in the error in the precipi tion measurement just due to the angle of the precipitation itself. This general co cept, however, is not correct in that no direct error in precipitation measurement results from the angle of inclination of the particle pathlines per se if the defin- ition of precipitation is based on the amount of water passing through a given horiz ontal surface.

Figure 2 shows idealized pathlines of falling precipitation for situations i a hypothesized precipitation event. Situation 1 is where an assumed random distribution of two populations of precipitation particles are not subject to wind effects. The pathlines intersect a horizontal plane (i.e. the plane containing the gauge orifice) at a distance apart of say X_1. If these same particles are then subjecte to a horizontal wind and if we assume the effect of wind on each population is the same, then we have situation 2. The particles approach the gauge at an angle of α with the horizontal but even though the perpendicular distance between pathlines i compressed, the horizontal distances between particles is still X_1. The idealiz gauge at situation 2 then will intersect the same number of particles pathlines a in situation 1 if the orifice is horizontal. Thus no error due to the inclinati of the pathlines themselves would result in the precipitation measurements between situations 1 and 2 in the idealized situation.

Mr. Sevruk's paper "Precipitation Measurements by Means of Storage Gauges with Stereo and Horizontal Orifices in the Baye de Montreux Watershed" presents additional data of interest on the comparison of catches with horizontal and stereo gauges. The differences in catches for the data reported between the two types of gauges are related to the exposure, or windiness, of the gauge sites. If a gauge is located where it has reasonably good protection from adverse wind effects, there will be only a small difference between the catch in a stereo gauge and in a gauge with a horizontal orifice. An example of how the exposure, or the windiness of the location, is important in respect to the difference in catch between the two types of gauges may be seen in Figure 3 from a report by the University of Stellenbosch, South Africa [10]. In this case the trees surrounding the gauge grew taller over a

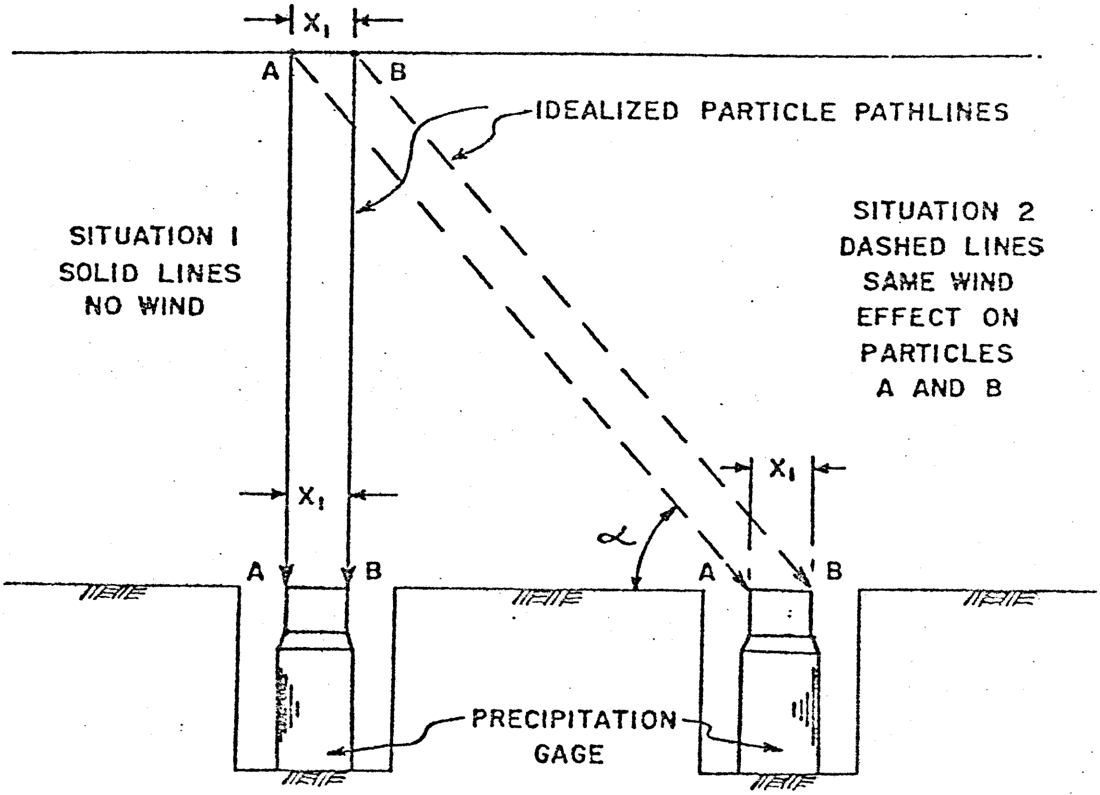

FIGURE 2.-IDEALIZED PATHLINES OF PRECIPITATION PARTICLES.

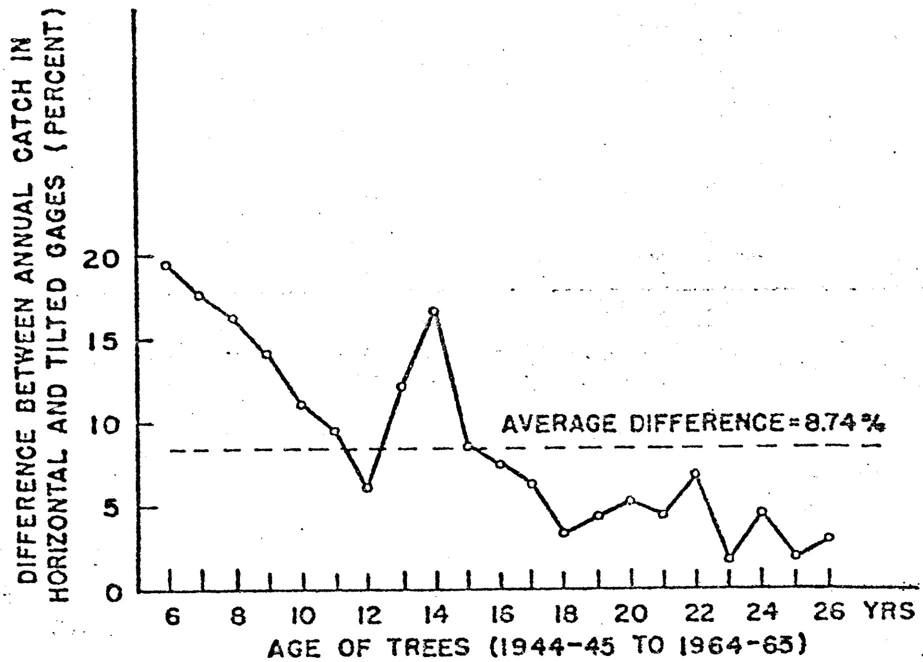

FIGURE 3.-PROGRESSIVE DECREASE IN DIFFERENCE OF HORIZONTAL AND TILTED GAGES SURROUNDED BY GROWING TREES

period of 26 years and gradually provided more protection from the wind movement. The differences in the recorded catch between the two types of gauges are plotted with time in Figure 3. The difference decreased from approximately 20 per cent when the surrounding trees were small to only about 3 per cent when the trees provided considerable protection near the end of the 26-year period.

The paper by Mr. Haupt entitled "Improved Instrumentation for Measuring Melted Precipitation on Windswept Topography" also raises the question of the use of tilted or stereo gauges for measuring precipitation. Mr. Haupt indicates that the lysimeter with its top parallel to the ground will partially solve the problem of inaccurate measurement of precipitation. However, in his conclusion he states that terrain locations where abnormal drifting occurs should be avoided when selecting the instrument site. If the instrument can be only used in well protected sites, it therefore cannot solve the problem for the areas where the need for improved measurements is the greatest. In addition, drifting of snow may occur with wind speeds as low as 2 metres per second /11/ and therefore it is questionable if the lysimeter can be considered as a reliable gauge for precipitation measurement. However, if the lysimeter is properly attended it should provide valuable data for snowmelt research.

Measurement by radar

The possibility of avoiding the many problems associated with gauge measurement of precipitation and the difficulties in determining areal average values from point observations is of major interest to the hydrologist. The paper by Messrs. Harrold, Bussell and Grinsted on "The Dee Weather Radar Project" describes an approach to attain this goal. Interestingly enough a similar project called the digitized radar experiment of D/RADEX is now being conducted in the south central plain states of the United States /12/. The many previous studies attempting to develop methods for using radar to measure precipitation have not attained general acceptance. Improvements in the radar systems in the past few years and the development of digitizing techniques have materially enhanced the possibility for greater success. There are still many problems associated with the measurement of rainfall by radar. Additional problems can be foreseen in using radar to measure snowfall. The Dee weather radar programme is rather ambitious but the results should be of considerable help in defining the value of radar as a tool for measuring the areal average precipitation. For ultimate utility, such an approach should include the use of meteorological measurements of stability and other physical properties to improve the relations such as has been accomplished to some extent by the use of storm typing.

Analysis of snow cover

The paper "Analysis of Snow Cover Distribution from Aerophotography Data Over Experimental Mountain Basin of Varzob River" by Abaljan brings out the high variability in the distribution of snow cover. The second paper "Snow Survey and Methods for Snow Storage Estimation in Mountain River Basins of the Soviet Union" by Komarov, Kharshan and Muchin points out the need for measurements at as many altitudes as possible in order to obtain a good estimate of the total snow cover from precipitation or snow survey data.

Comments

In an effort to compensate for the many errors in precipitation measurements, hydrologists will often adjust the data before using it in operational forecasting procedures. This adjustment or correction usually takes the form of simply multiplying the gauge readings by a factor greater than unity. In some instances this adjustment factor is considered to be a constant while in other instances it is taken to be a function of other variables such as wind speed and gauge configuration. The need for these many and varied adjustment procedures points out the fact that most people involved in hydrological work have a lack of confidence in the basic precipitation data. This is probably well justified and is one of the most perplexing and serious problems facing us today in the whole field of hydrology. It is hoped that radar will provide a means of obtaining improved measurements of the areal precipitation when it is in the form of rain and over non-mountainous areas. For snow and in the more rugged mountainous areas it appears that radar will not provide satisfactory solutions for some time to come. The techniques proposed by papers in this session hold some promise of obtaining more reliable point measurements in windy locations. However, it is certain that many if not most installations will continue to use present type gauges. Development of an objective exposure index could provide the necessary information to evaluate the effectiveness of these gauges to measure true precipitation.

It is realized that the required accuracy of precipitation data is highly dependent upon the intended use. In some areas of interest, the present methods and equipment may be adequate. It is generally agreed, however, that much remains to be done in most areas of precipitation measurements, especially in the measurement of solid precipitation, measurements in mountainous areas, measurements in windy areas, etc. In general, the authors in this session are to be congratulated for their contributions on this subject of precipitation measurement but considerably more research will be required and the necessary changes made in the field before the hydrologist will have adequate information on such questions as the amount and distribution of precipitation from mountainous areas.

Summary at close of session

A question has been raised as to the need for improving the accuracy of precipitation measurements. A report by Walter Wilson [13] in the Monthly Weather Review presented an excellent case for the value of improved measurements. His report clearly demonstrated that precipitation data from stations with good exposures, i.e. protected from strong wind movement, had a much better correlation with hydrologic parameters than did data from stations that were poorly exposed. In empirical relationships, therefore, higher correlation coefficients between hydrological parameters and precipitation data can be obtained from a small number of well-exposed stations rather than using records from many stations having poor exposure. When using hydrological conceptual models it is difficult to obtain a best fit if precipitation data does not represent the true amount of input into the basin. The observed data should represent the actual input to the system in order to simulate both the movements and amount of water in the entire system.

A second question that was raised was which windshield is the most satisfactory. This question is difficult since we hydrologists do not have definite research results available to support our views. Most research in this area tends to show that gauge shields do improve precipitation measurements. In general, some hydrologists prefer the Alter type windshield while others use a shield with the leaves in a fixed position. The Nipher or solid type of windshield has proven to be good for rainfall but it has definite drawbacks for snowfall measurement because of orifice capping. A compromise of the fixed leave version and those with free swinging leaves might be of value. The leaves could be free with a ring to prevent the leaves from being lifted more than 20 to 30 degrees. The blow fence gauge discussed by Professor Rechard has been designed using field test information and wind tunnel tests to determine the configuration which provides the most laminar flow at the gauge orifice. The selection of windshield, and the type of gauge, is largely determined by the location or exposure of the site. The exposure of the site is much more important to the accuracy of the catch in relation to true precipitation than is either the type of gauge or windshield. In well-protected sites almost any gauge will provide a fairly good measurement. The dual-gauge approach described in Mr. Hamon's paper would be good for a windy site with a fairly level area. The blow fence scheme would probably be best for a non-level, windy location. For locations with moderate wind a Tret'yakov gauge corrected for wind velocity and air temperature as used in the Soviet Union [14] would provide a good estimate of the true precipitation. Thus the question as to which is the best windshield does not have a simple answer. The site exposure, type of gauge, and the ultimate use of the data are probably the most important factors to consider.

The question of the value of comparison tests for precipitation instruments has also been raised. Reviews of many such studies indicate that the physical placement of the equipment probably introduced interactions among gauges that greatly affected the results. It is extremely difficult to achieve ideal exposure conditions for comparing the relative accuracy of various gauges. In the past we have relied on average values from large numbers of paired installations. The results might be more conclusive if they were obtained from a few well-designed installations operated under rigorous criteria, especially with respect to exposure.

Exposure of gauges has been a subject of considerable interest during the session. For maximum use of our precipitation records information on the exposure of each gauge is required. Published data often are taken under widely differing exposure conditions and, therefore, do not necessarily represent the same relative amount in relation to the true precipitation. Many users assume that data collected and published by a national agency are collected under standard conditions which is not true for exposure. Publication of information on the history of each precipitation station with particular emphasis on the exposure of each location would greatly enhance the value of the published records. Objective techniques for defining the exposure, especially with respect to windiness of sites, would also help in this regard. The use of the globoscope, as proposed by Dr. Lee, would be of value for this purpose. This information will not answer the questions as to the importance of variations in nearby relief on the representativeness of the catch at any one point, but it would be a first step in developing techniques for evaluating the exposure of gauges.

The studies on the use of radar by Dr. Harrold are very interesting and the results indicate that radar can be used to measure areal average rainfall for the limited area that they are working with. Additional work of this quality is needed to develop methods for measurement of snowfall and rainfall when the bright band effect is observed.

Based on the material presented and the discussions during the session, recommendations for the future should include:

1. Continued research for improvement of point measurements of precipitation, especially snowfall.

2. Emphasis should be given to development and improvement of techniques and instrumentation to measure the areal distribution of winter snowfall and snow cover. These should include:

    a. Radar
    b. Aerial gamma radiation techniques
    c. Techniques applicable for satellite use (microwave, multispectral, etc.)

3. Encouragement for meteorologists to work on multi-discipline approaches to compute areal averages and distribution.

4. Increased emphasis on network design studies, especially for the improvement of input data as required by conceptual hydrological models.

5. Operators of national precipitation networks should develop techniques for evaluating the exposure of gauge sites and to publish whatever information is available so that users may be able to assess the relative usefulness of published records.

6. Installation of gauges used for comparison studies should be installed and operated under rigorous criteria, especially with respect to exposure.

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