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Hydrometeorology

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Abstract

The paper presents a review of the activities of the Hydrology Committee of the AMS. In addition, recent progress and areas needing additional research and development in the field of hydrometeorology are discussed.

1. Introduction

Hydrometeorology is the study of the atmospheric and the land phases of the hydrological cycle, with emphasis on the interrelationships involved (WMO, 1974). Since this area encompasses both the fields of hydrology and meteorology, there are relatively few individuals with sufficient training in both to be knowledgeable in all areas of hydrometeorology. In most cases, practicing hydrologists are engineers, foresters, agriculturists, environmentalists, or others who have had training in water resources, and they have to rely on meteorologists to provide most of the inputs (meteorological measurements), as well as many of the techniques, for their studies. Besides meteorologists, the practicing hydrologists working in the area of hydrometeorology must interface with scientists of many other physical disciplines, as well as with sociologists and economists.

Recognizing the importance of meteorology in the field of hydrometeorology, the American Meteorological Society in 1973 established a Hydrology Committee. The general purposes of this committee are to stimulate research in hydrology—especially in relation to meteorology—and to encourage the exchange of ideas and information. In this brief report, I would like to discuss the actions taken by the committee to achieve these aims and to inform the Society of the progress, problems, and opportunities that exist in the field of hydrometeorology. I hope this will stimulate some to give increased attention to important areas of research and development that are urgently needed to improve the usefulness of meteorology in solving some of the practical problems confronting hydrologists.

2. Hydrology Committee activities

In April 1976, the Hydrology Committee cosponsored the First Conference on Hydrometeorology in Ft. Worth, Tex. (AMS, 1976). Those who organized the conference wanted it to serve many purposes. One was to have it serve as a means of increasing communication between practicing hydrologists and those who develop and design new tools, techniques, and remote sensing measurement methods. This first conference was not successful in bringing practicing hydrologists to meet with those scientists and researchers who normally attend national meetings of the AMS.

The Second Conference on Hydrometeorology was held a year and a half later in Toronto, Canada, in October 1977 (AMS, 1977). This time, the Hydrology Committee increased its efforts to ensure the attendance of those who are users of new developments and techniques. Several organizations whose memberships include practicing hydrologists were invited to cosponsor the conference. These organizations included the American Geophysical Union, the American Society of Civil Engineers, the American Water Resources Association, the Canadian Society for Civil Engineering, and the Canadian Water Resources Association.

Representatives of the cosponsoring organizations were given the opportunity of presenting the needs of practicing hydrologists, including those who work in operational hydrology, water supply and power generation, design engineering, urban hydrology, and environmental engineering. In response, federal representatives from Canada and the United States reported on what meteorologists could do for hydrologists. Other scientists reported on new models, techniques for use in operational hydrology, and hydrological design. Considerable attention was also given to problems in snow and ice hydrology and on the status of remote sensing for providing areal measurements. The important achievements were the large attendance of many hydrologists, engineers, and others who work directly in hydrology and water-related areas and the successful transfer of information.

3. Progress in hydrometeorology

The hydrologist is interested in obtaining a qualitative understanding of the hydrologic cycle and measuring the quantities of water in transit in this cycle. He must be able to understand the interrelations among the various factors so he can accurately predict the influence of man-made works on these relations. He must also be concerned with the frequency with which various extremes of the cycle may occur, for this is the basis of economic analysis, which is an important determinant

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for all hydraulic projects (Linsley *et al.*, 1975). Hydrometeorology may be viewed as applying the science of meteorology in the solution of hydrologic problems.

Many disciplines have contributed to the development of the science of hydrology. Meteorology is one of the most important contributors, and a total review of the entire general field of hydrometeorology would be a major undertaking. For the purpose of this discussion, the comments will be limited to those aspects dealing with the design and use of hydraulic structures, water resources planning, operational hydrology (the forecasting of water supply, rivers, floods), and related water management.

During the past 20 years, major changes have taken place in hydrology. One has been the development and introduction of improved transfer function techniques for relating meteorological inputs to streamflow. Deterministic approaches have included the Stanford (Crawford and Linsley, 1966), Sacramento (Burnash *et al.*, 1973), and SSARR (U.S. Army, 1972) models for simulating continuous hydrographs. Other operational models have included those to use meteorological data to predict snow accumulation and ablation (Anderson, 1973). These physically based conceptual models are replacing the index models used in operational hydrology since the early 1940s.

Other models for various uses have included the development of spectral regression and statistical-mathematical methods (Box and Jenkins, 1970). Stochastic methods are primarily in the research stage, with limited practical use (Yevdjevich, 1963). Deterministic and stochastic models provide a basis for maximizing the usefulness of meteorological inputs for all areas of hydrology, which was not possible with the early index approaches.

Remote sensing has greatly improved the ability to observe and identify severe storms and the occurrence of extreme precipitation. Satellite and radar information is being used to warn of potential flash floods (Davis, 1976; Griffith and Woodley, 1977) and has been especially of value in estimating rainfall from hurricanes (Oliver and Scofield, 1976) and extratropical storms. New techniques are emerging for improving the use of radar for estimating rainfall (Cain and Smith, 1977). Other uses of satellite imagery are also being applied in routine hydrologic forecasting, such as determining the extent of the snow cover for seasonal water supply and snowmelt flood forecasts. No adequate method has been developed for measuring from space the water equivalent of the snow cover, but techniques using low-flying aircraft measuring the natural gamma radiation of the earth are being used (Peck and Bissell, 1973).

Quantitative precipitation forecasts (QPFs) for various periods up to 3 days have also improved. These now include daily precipitation probability forecasts for 267 locations using output from numerical models and statistical methods (Lowry and Glahn, 1976).

Fine-mesh numerical models that provide improved forecasts for local areas have also been developed (Gerrity, 1977). A movable model using initial conditions from the large-scale national models has provided improved forecasts of precipitation from hurricanes. Fine-mesh models have also been developed to use in predicting precipitation in mountainous areas but have not yet been put into operational use (Rhea, 1977).

Long-range weather forecasting (from 10 days to several months) is now showing some skill. However, these weather forecasts are still of very limited use for hydrologic forecasting. Technology for using such forecasts in long-range hydrological forecasting is available. At the present time, climatological data are used in place of long-range forecasts to produce probabilistic forecasts for future streamflows (Twedt *et al.*, 1977). Such forecasts were used for the recent droughts in California and in the Potomac River Basin near Washington, D.C.

A statement of needs in hydrology was published in 1964 by a special committee of the AGU (Linsley, 1964). For many of the items pertaining to hydrometeorology, there has been considerable progress and major developments during the ensuing 12 years. However, it is clear that there are still many needs that have not been met.

Advances have been made in the development of both data analysis and techniques useful for hydrologic design and planning. These include a method for predicting the probability of wind-induced storm surges on the Atlantic and Gulf coasts (Myers, 1970). Considerable progress has been made in providing analysis of the time distribution of precipitation (Frederick, 1973). Detailed isohyetal maps of seasonal and annual precipitation for the mountainous West have been of value for design and planning of water resources development (NOAA, 1977).

4. Areas needing additional research and development

In many areas of science, it is difficult for graduate students to identify specific problems suitable for individual research for use in fulfilling their research requirements for advanced degrees. This is not a problem for those working in the field of hydrometeorology. The research of the past 20–30 years, although extensive and of considerable value, has served primarily to open new avenues for research and new approaches to use meteorology in the field of hydrology.

A major deficiency is the inability to describe the natural variability of precipitation in space and time as a stochastic process. This ability is required as a basis for generating inputs to hydrologic models for extented streamflow prediction. They could also be used as inputs to the same hydrologic models for estimating flood frequency of ungaged areas or judging the reliability of complex water resources systems, such as the California water plan.

The ability to determine more accurately the temporal and spatial distribution of precipitation in real time for mountainous areas is needed for use in operational hydrology.

Network design to provide for improved measurement of precipitation and other parameters has been limited (Lenton and Iturbe, 1974). Progress on improvement in observing networks has been delayed to some extent because of the potential overlap from direct and remote sensing approaches. It is important that the capability of each observing method be evaluated for use in the development of combined networks. For example, for precipitation, one must consider the combined use of rain gages, pulse and Doppler radar, satellite observations, and other techniques for determining the network required to meet the needs of meteorologists, climatologists, as well as hydrologists. Continued development of networks without such consideration is wasteful. Included in the development must be the need for real time use of data, as well as the value of storing data for other purposes.

Flash floods are now the number one killer of all weather-related disasters in the United States (AMS, 1978). Property damage from such floods now averages about $1 billion a year. Present forecasts are limited to warnings of the possible occurrence over large areas. More knowledge about the space-time variation in precipitation for small areas is needed to understand the limits of predictability of extreme amounts and would be of value in developing guidance for forecasting and predicting the locations of such extreme events.

Forecast of precipitation for small areas is a real challenge. The present use of infrared and other satellite imagery for estimating present rainfall is very encouraging. However, the errors in mean areal precipitation for even medium size river basins (400 km^2) are large even from the current rain gage data network. These are small, however, when compared to QPF errors.

Temperature forecasts for use in snowmelt forecasting also need improvement.

At the present time, there are no operational methods for measuring or adequately forecasting the actual evapotranspiration from a river basin. Hydrologists use estimates of potential evaporation from shallow water surfaces together with model calibration to account for actual evapotranspiration in hydrologic simulation. Research to provide for measurement or methods for estimating actual evapotranspiration is needed.

The joint use of deterministic models of physical properties of river basins and stochastic models of measurement errors, model errors, and natural variation of meteorological parameters would povide the basis for improved estimates of the hydrologic system at any time and for improving the accuracy of predictions for the future. Estimation theory (space-state models, Bayesian theory, etc.) has proven useful in other disciplines for similar purposes. Researchers are investigating the possible use and are developing procedures for applying estimation theory in hydrology. However, its practical use is limited until more is known about the uncertainty of the measurement and the natural variability of meteorological and hydrological parameters.

Long-range hydrologic forecasts could also be improved with additional knowledge of the interrelationships of the hydrologic cycle. For example, it is well known that precipitation is influenced by the surface temperature of the oceans and the associated general circulation patterns. Research relating surface water temperature of the oceans with seasonal precipitation is encouraging but needs additional attention. Seasonal forecasts of temperature and precipitation by the NWS using numerical models are showing some skill but also need improvement to be of value to operational hydrology.

A major need for hydrologic design is improved knowledge of storm processes to develop a sounder basis for estimation of extreme precipitation (probable maximum precipitation) and snowmelt events. Information as to how close these events can occur in time is also an important need to improve the ability to safely compute the design floods for hydrologic structures. There is a need for improved techniques to use our knowledge of the physical processes while also accounting for the uncertainty in these processes. Some work has been done on stochastic models (Schaake *et al.,* 1972).

Of special interest to hydrologic engineers is the potential value of climatic models for use in design and planning for water resources projects. Mandelbrot and Wallis (1968) have introduced Biblical history to describe the two major climatic events. These are the "Joseph event," indicating long periods of time when precipitation or streamflow is either well above or well below normal, and the "Noah event," for those times when precipitation can be very extreme. Kilmartin (1976) presented a very interesting review of the work that has been accomplished to develop climatic models to adequately describe these major climatic fluctuations. Development of climatic models and the identification of the anomalies in the atmospheric circulation that accounts for such fluctuations would be a major contribution to hydrology and of value to design and planning engineers. The use of improved models of climatic variations would help prevent the failure of future hydraulic structures. Many of the extreme precipitation occurrences that have been associated with the major flash floods in the past 2 years have been referred to as having a frequency of occurrence of once in 500 or 1000 years. Our limited knowledge of and ability to describe the climatic variability for specific time periods makes it impossible to make a realistic statement about such recurrence intervals. The apparent unusual number of major flash flood occurrences (such as those that occurred at Johnstown, Pa., Big Thompson, Colo., Kansas City, Mo., and Rapid City, S.Dak., to mention the best known of more than 1000 that have occurred since 1971) gives us concern about possible shifts in the climate that may indicate continued increase of such storms in the future without the ability to assess the potential.

Last and not least, we need to continue and increase the research to determine the effects of man on the climate and thus on hydrology. This research should encompass many areas such as inadvertent modification, the effect of urbanization, as well as the effects of man's activities on changing the general climatic patterns.

5. Conclusion

Hydrometeorology is a marriage of the techniques and methods for using meteorological data and analysis in the area of hydrology. It has been impossible to cover all uses of meteorology for hydrological application, and many research activities and many procedures in use have not been mentioned.

Approximately 13 years ago, I presented a paper at the Western Snow Conference entitled "The Little Used Third Dimension" (Peck, 1964). The title was intended to indicate that hydrologists were not making maximum use of meteorological measurements to help determine the distribution of precipitation in mountainous areas. Although there has been considerable progress during the intervening years, I believe it is still pertinent to state that there is still limited use of the science of meteorology in the field of hydrology. For example, there have been very few attempts to use stability, vorticity, moisture, and other parameters from the upper air to help solve the problem of determining the distribution of precipitation in mountainous areas (Elliott, 1977). In many cases, the hydrologist does not know what information might be of value, and therefore the responsibility for accomplishing much of the required research and developing techniques lies with those in the field of meteorology.

The next major crisis to follow the present energy crisis in the United States may well be a water crisis. Meteorologists could make a major contribution in helping to provide hydrologists with additional tools to help solve some of the pressing needs in hydrology.

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