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Precipitation

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Increasing concern about the environment has resulted in a greater need for improved knowledge of precipitation for the solution of water resources problems. A specific example of such a need is the recent world-wide research in development of hydrologic models for continuous synthesis of streamflow, the success of which will be ultimately limited by the reliability of the primary input function, precipitation. Much of the precipitation research during the 1967–1970 period has been concerned with errors in measurement and development of better methods for measuring areal and temporal distribution of precipitation.

Measurement

Israelsen [1967] prepared an excellent summary of the literature dealing with the reliability of can-type precipitation gages, an extension of the earlier work of *Kurtyka* [1953]. More recently, investigations have been conducted to determine the relative effectiveness of different gages in measuring solid and liquid precipitation [*McGuinness*, 1966; *Morgan and Lourence*, 1969]. *Jones* [1969*a*] evaluated the effect of gage shape on catch and concluded that the sloping portion of the gage housing was a cause for catch reduction in some gages. *McGuinness and Vaughn* [1969] found that there was a seasonal variation in the relative catch between the standard straight-sided 8-inch gage and the digital gage of the National Weather Service (formerly the U.S. Weather Bureau). Their report indicated that the 8-inch standard gage caught more precipitation in summer and less in winter. Studies by *Parmele* [1970] and *Hoehne* [1968] on comparison of gage catch for the same instruments do not support the findings of *McGuinness and Vaughn* [1969]. The results are not sufficient to establish coefficients for relating catches between these gages for either rainfall or snowfall or to evaluate properly the effect of the shape of gage housing.

Research has continued on the development of measuring techniques to prevent the deficiencies of present can-type gages. *Duncan* [1966] developed an airborne foil impactor to measure shower-type rainfall, and *Bradley and Martin* [1967] have reported on an airborne precipitation collector. Measurement of precipitation by attenuation of electromagnetic waves has been reported by several investigators [*Warner and Gunn*, 1969]. The electromagnetic attenuation approach holds promise for improvement in the measurement of snowfall. Efforts are also being made to improve the value of regular gages for snowfall measurement. *Hamon* [1970] has reported on the use of dual gages, shielded and unshielded, as a means of determining true snowfall. *Rechard and Larson* [1970] are attempting to develop protection for the gage site from adverse wind effects by the use of snow fences.

Electrical gages for sensing rainfall rate have been developed and reported by *Semplak* [1966] and *Morgan* [1968]. A new instrument to sense or detect the presence of dew, frost, drizzle, rain, or snow has been developed by *Peck* [1968].

Radar Measurement

The possibility of using weather radar to measure precipitation has been discussed and studied for many years. Recent electronic and engineering developments have permitted the digitizing of radar estimates of rainfall from operational weather radars (WSR-57) of the National Weather Service. *Kessler and Wilk* [1968] reported on the use of radar measurements of precipitation for hydrologic purposes. *Atlas* [1968] presented a review on the use of radar for measurement of precipitation. *Flanders and Bigler* [1970] have reported on the history and development of automatic weather radar data processing at the World Meteorological Organization Technical Conference of Hydrological and Meteorological Services. An operational field test of digitizing weather radar data is being conducted by the National Weather Service [*Bigler et al.*, 1970]. The accuracy of measuring rainfall by radar still presents a problem. *Huff* [1967] used rain gage data to calibrate the radar. *Wilson* [1970] has extended these studies and introduced the concept of using the spatial variability indicated by radar as a parameter for further improvement. Techniques for

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direct application of the radar information for operational hydrologic analyses are being developed by *McCallister and Teague* [1968], *Hudlow and Clark* [1968], and *Grayman and Eagleson* [1970].

Other studies are being continued on the use of the standard Z–R (rainfall rate–radar reflectivity) relation [*Stout and Mueller*, 1968; *Cataneo*, 1968; *Environmental Science Services Administration*, 1966; *Carlson*, 1968]. Many radar precipitation studies fall in the realm of meteorology rather than hydrology, but these studies are pertinent to the measurement of precipitation. Some of these are studies by *Jones* [1969], *Mueller and Sims* [1969], *Environmental Science Services Administration*, [1967*a*], *Runnels* [1967], *Boston* [1968], *Bridges and Feldman* [1966], and *Runnels et al.* [1968].

Network Design

The design of precipitation network remains a problem area that has received relatively little attention. *Eagleson* [1967] approached the problem of determining optimum density of rainfall networks by the application of the sampling theorem. He also used the concepts of distributed linear systems to study the sensitivity of peak catchment discharge to the characteristic spatial variability of convective and cyclonic storm rainfall.

To obtain information on storm morphologies, dense networks of recording and/or nonrecording rain gages have been installed in a number of countries over the years. In the United States, almost 30 such networks are reported by *Tucker* [1969] as being currently operated by major federal, state, academic, and private research organizations, and a fairly large number of other networks are in existence in many cities.

Most of the analyses of data collected in these networks have been concerned with the representativeness of point values in the definition of total storm precipitation volume patterns [*Hershfield*, 1968; *Delaine*, 1969; *Reich*, 1966; *Snyder and Courtney*, 1967].

Temporal and Spatial Distribution

Studies on the dynamics of storm distributions at ground level are comparatively new. In recent years, thanks to the accumulation of data gathered in dense networks and also to the availability of meteorologic radars, these investigations are beginning to bear fruit.

Amorocho and Brandstetter [1967] developed a method for the three-dimensional representation of storm fields that is suitable for use in connection with distributed hydrologic models in the analysis of individual flood events. *Amorocho et al.* [1968] presented an analysis of the sensitivity of simple hydrologic systems to the time and space variations of precipitation intensities. Other spatial and temporal distribution studies of rainfall have been made by the Illinois State Water Survey [*Huff*, 1968; *Huff and Shipp*, 1969], by *Environmental Science Services Administration* [1967*b*], by the Agricultural Research Service [*Nicks*, 1966; *Drissel and Osborn*, 1968; *Osborn*, 1968], and by others [*Brooks and McWhorter*, 1968; *Collinge and Jamieson*, 1968; *Austin and Houze*, 1970].

Because of the importance of precipitation as a water resource at higher elevations, many investigators are studying the influence of topography in relation to precipitation distribution. Recent studies relating seasonal precipitation and elevation have been reported for numerous locations [*Walkotten and Patric*, 1967; *Cooper*, 1967; *Sarker*, 1967; *Schermerhorn*, 1967; *Mueller et al.*, 1968; *Dickison*, 1968]. Large-scale (1–500,000) seasonal and annual isohyetal maps, similar to those previously prepared for Utah [*Peck and Brown*, 1962], have been published by the National Oceanic and Atmospheric Administration (NOAA) for the mountainous states of Arizona, Colorado, and New Mexico. Reviews on the variation of precipitation in relation to elevation, aspect, and forest canopy in forested mountainous areas were presented by *Hoover and Leaf* [1967] and by *Meiman* [1970].

Researchers at Colorado State University are continuing to study the statistical aspects of precipitation and in general have found that precipitation can be represented as a random process [*Todorovic and Yevjevich*, 1969; *Llamas and Siddiqui*, 1969]. Others have applied Monte Carlo methods to prepare precipitation frequency analyses [*Wiser*, 1966].

Frequency Studies

The frequency of occurrence of large amounts of precipitation is useful in many investigations. The National Weather Service has prepared a series of maps [*Miller and Frederick*, 1966] that depict the normal number of 24-hour periods with precipitation equal to or greater than 0.50, 1.00, 2.00, or 4.00 inches.

A series of precipitation frequency maps is being prepared by NOAA for the western United States. These maps show point values for the 6- and 24-hour durations for return periods from 2–100 years. Large working scale maps have been completed for some western states.

The National Weather Service has published many reports concerning probable maximum precipitation (PMP) and related topics. *Myers* [1967] presented a series of lectures at Bangkok summarizing the approaches used by the National Weather Service. Special attention has been given to the areal and time distribution of rainfall associated with hurricanes [*Goodyear*, 1968]. Generalized estimates of PMP were developed for the Mekong drainage of Southeast Asia by using observed typhoon rainfalls in the basin supplemented by record typhoon rainfalls from other parts of the world [*Environmental Science Services Administration*, 1970]. The record breaking rains of Hurricane Beulah in 1967 and Camille in 1969 were subjects of special reports [*Reidel*, 1970; *Schwarz*, 1970].

Environmental Effects

Changes in the environment that may be induced by man's activities are now receiving increased interest. It is evident that air pollution does result in the inadvertent modification of the atmosphere [*Barrett et al.*, 1970]. The evaluation of suspected changes in precipitation

...ngnes has been the objective of recent analyses [...haefer, 1969; *Warner*, 1968; *Ogden*, 1969; *Changnon*, 1969; *Stidd*, 1968]. In some cases, the findings have been questioned by those who believe the analyses were inconclusive [*Holzman and Thom*, 1970]. *Eichenlaub* [1970] has investigated the lake effect on snowfall to the lee of the Great Lakes and concludes that the snowfall has been significantly increased during the past few years and that there is a likely chance that this increase resulted from a general cooling during the winter.

The rapid growth in metropolitan areas and the associated increase in the percentage of impermeable drainage area has greatly enhanced the flood damage potential for such locations. Detailed studies on precipitation characteristics for urban areas are being conducted [*Fieg*, 1968; *Changnon*, 1969]. Much more research will be required to provide the information necessary for adequate evaluation of the increased flood hazard in metropolitan areas.

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