Antecedent Moisture Condition Probabilities for Selected Indiana Stations

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Introduction

The prediction of the volume of direct runoff resulting from a particular storm rainfall is among the central issues in hydrology. Abstractions such as interception, depression storage, and soil moisture storage cause direct runoff to be less than storm rainfall. The complexity and intrawatershed variability of these abstraction mechanisms has led to the adoption of simplified descriptions in many practically important runoff models. But even the most elementary models usually incorporate the observation that the direct runoff from a given storm normally increases with increasing moisture content of the watershed at the start of the storm.

A common scheme to account for the dependence of abstractions on initial watershed moisture is to define several discrete Antecedent Moisture Condition (AMC) classes based on the total precipitation during a specified period of time preceding the storm of interest. The model parameters which determine the abstractions are varied depending on the AMC class. It is easy to apply such schemes when calculating the runoff from historical storms if the appropriate antecedent rainfall data are available. To treat hypothetical or design storms, the analyst must postulate appropriate AMC classes, considering both the purpose of the calculations and the local climate. This paper provides a rational basis for such choices in Indiana by reporting the actual percentage of time spent in the various AMC clases of two widely used runoff models: the Soil Conservation Service Curve Number method and the Illinois Urban Drainage Area Simulator (ILLUDAS).

The Curve Number (CN) method is a simple empirical technique developed by the Soil Conservation Service (SCS) to calculate the direct runoff volume caused by a given depth of rain (12,14). The CN method applies to both rural and urban watersheds (15) and has been used around the world (7). It has been recommended for the calculation of excess rainfall in several unit hydrograph techniques (4, 8, 10, 13, 15). Hawkins (7) has provided a critical discussion of the theoretical basis of the CN method.

The heart of the CN method is the SCS Runoff Equation, a simple algebraic formula relating the direct runoff volume to the total rainfall volume and the Curve Number. The Curve Number reflects the hydrologic abstractions of the watershed. Using data from field experiments, the SCS has determined CN values for many combinations of soil type and artificial or natural cover (12, 15). These tabulated CN values are for an intermediate Antecedent Moisture Condition (AMC II). They must be decreased for drier soil (AMC I) or increased for wetter soil

(AMC III) in accordance with an empirical conversion table provided by the SCS (12, 15).

ILLUDAS is a non-proprietary Fortran program developed by the Illinois State Water Survey (18) to aid in the design or evaluation of storm sewer systems. Given the layout of an existing or proposed storm sewer network and an arbitrary rainfall hyetograph, the program calculates direct runoff hydrographs at each junction and specifies the necessary commercial pipe diameters. ILLUDAS is widely used in urban hydrology and its performance has been studied by the present authors (1, 2, 3) as well as by others.

ILLUDAS determines the direct runoff from grass covered areas by comparing the intensity of rain at each time step to the infiltration capacity predicted by Horton's empirical equation (9). Among the parameters in this equation are the initial and ultimate infiltration capacities. Different initial and ultimate infiltration capacities are specified for each of the 4 SCS soil types. The effects of antecedent moisture are modeled by defining 4 AMC classes with corresponding initial infiltration capacities for each soil type. A higher AMC class implies a wetter soil with a reduced initial infiltration capacity.

In the CN method and in ILLUDAS, the AMC for a given day is determined by the total rainfall on the 5 preceeding days. Table 1 lists the class limits used in this study. The dormant and growing season criteria for SCS AMC I, II, and III were established by the SCS (12). AMC IV was defined by the authors to quantify the percentage of time for which the CN method is invalid because the ground is frozen or snow covered. The originators of ILLUDAS established the limits for AMC 1, 2, 3, and 4 (18). AMC 5 was added by the authors. In the documentation for ILLUDAS, no distinction is made between the dormant and growing seasons. The authors believe that the infiltration capacities used in ILLUDAS are not valid during the dormant season in Indiana. For this reason the ILLUDAS criteria were applied only during the growing season. The operational definition of the growing season is discussed in the next section.

TABLE 1. *Antecedent Moisture Condition Criteria.*

AMC CLASS	TOTAL 5-DAY ANTECEDENT RAINFALL (INCHES)	
	Growing Season (April 1 - October 31)	Dormant Season (November 1 - March 31)
SCS AMC I	less than 1.4	less than 0.5
SCS AMC II	1.4 to 2.1	0.5 to 1.1
SCS AMC III	over 2.1	over 1.1
SCS AMC IV	Frozen soil or snow cover*	Frozen soil or snow cover*
ILLUDAS AMC 1	0	NOT APPLICABLE
ILLUDAS AMC 2	0 to 0.5	
ILLUDAS AMC 3	0.5 to 1.0	
ILLUDAS AMC 4	over 1.0	
ILLUDAS AMC 5	Frozen soil or snow cover*	

*The frozen condition is assumed to occur whenever the average daily air temperature is less than 32° F or whenever there is measurable snow on the ground.

Data and Analysis

This study was undertaken to provide Hoosier hydrologists and drainage engineers with occurrence probability estimates for SCS and ILLUDAS AMC classes. To accomplish this it was necessary to analyze long series of reliable daily rainfall and temperature observations from stations throughout the state. After consultation with State Climatologist Dr. Lawrence A. Schaal, the 10 stations listed in Table 2 were selected for analysis.

TABLE 2. *Seasonal AMC Occurrence Probabilities Expressed as Percentages.*

		SCS Growing				SCS Dormant				ILLUDAS				
Station	County	I	II	III	IV	I	II	III	IV	1	2	3	4	5
Berne	Adams	88	8	4	0	27	10	13	50	20	39	20	21	0
Mt. Vernon	Posey	86	7	6	0	35	13	19	33	27	34	16	23	0
Paoli	Orange	85	8	6	0	30	14	20	37	24	34	18	24	0
Rockville	Park	86	8	6	0	33	11	14	41	26	34	18	22	0
Rushville	Rush	87	7	5	1	29	10	14	47	25	34	19	21	1
Spencer	Owen	85	8	6	0	29	12	16	43	23	36	19	22	0
Valparaiso	Porter	85	8	6	0	23	8	11	57	19	38	20	22	0
Vevay	Switzerland	86	8	6	0	37	15	16	32	23	38	17	22	0
Waterloo	Dekalb	89	6	4	1	23	10	11	57	25	38	19	18	1
West Lafayette	Tippecanoe	86	7	6	1	27	9	10	54	22	37	18	22	1
Indiana average		86	8	6	0	29	11	14	46	23	36	18	22	0

Entries may not total 100% due to rounding.

Two magnetic tapes which contain all of the daily weather observations for every station in Indiana through 1977 were purchased from the National Oceanic and Atmospheric Administration. The daily record for each station used here includes the water equivalent precipitation, maximum and minimum air temperatures, and the depth of snow on the ground at the time of observation. These were the data used to determine the AMC for each day.

The most straightforward way to determine if the ground was frozen would be from actual soil temperature measurements, but these are available at only 12 sites in Indiana and begin in 1960 (16). Among the 10 stations selected for this study, only West Lafayette reports such measurements. In addition, soil temperature depends strongly on the depth of measurement and on the soil type. For these reasons it was not practical to use soil temperature to establish the occurrence of SCS AMC IV and ILLUDAS AMC 5.

McGarrahan and Dale (11) have investigated the accuracy of regression equations for the prediction of soil temperatures from air temperatures, but their results did not seem to warrant incorporating such a procedure in this work. Therefore, for the purpose of this study, "frozen ground" was deemed to occur if the average of the maximum and minimum air temperatures was less than 32.0°F. If this occurred or if there was more than a "trace" of snow on the ground at the time of the observation, the day was counted in SCS AMC IV and ILLUDAS AMC 5. The water equivalent of all precipitation falling during a series of "frozen ground" days (regardless of length) was accumulated and counted as rain on the last day of the series. This treatment neglects the possibility of gradual evaporation or melting, but it is no more arbitrary than any other scheme to account for snowfall using the available data.

A Fortran program was written which read the appropriate data, formed 5 day antecedent water equivalent precipitation totals, and assigned each day to the appropriate AMC class. Whenever any of the 4 observations was missing, that day and the next 5 days were not assigned to an AMC class. The ratio of the number of days in each class to the total provides an estimate of the probability of the occurrence of that class.

The definition of the dormant and growing seasons required judgement. Climatologists often define the growing season as the period from the last air temperature of 32°F in the spring until the first air temperature of 32°F in the fall. To implement such a definition would require checking all the minimum temperatures until the first fall freeze before the season could be defined. Since each year's growing season is then different, it would be impossible to state whether growing or dormant criteria should be used during the spring and fall. These problems could be overcome by using average growing seasons, but these differ among stations. Average growing seasons have been established for 7 of the stations used in this study and for stations close to the others (17). The average date of the last occurrence of 32°F in the spring ranged from April 9 to May 5 with a mean date of April 25. The average date of the first fall occurrence of 32°F ranged from October 9 to October 25 with a mean date of October 17. To avoid the inconvenience of splitting months between the seasons, the growing season was defined to last from April 1 through October 31 for every station in this study.

The selection of a period of analysis for any climatological study requires a compromise among the need for a long period to assure statistical significance, the requirement that the period be short enough to reduce the influence of climatic change, and the desire for a short period to reduce the computational expense. The entire record for Berne from 1910 through 1977 was analyzed, and it was found that the 30 year period used for most climatological calculations was satisfactory for AMC studies as well. The results for 7 of the stations in this study are based on the period from January 1, 1948, through December 31, 1977. The exceptions are Spencer (1950-1977), Vevay (1961-1977), and West Lafayette (1954-1977), which began reporting at later dates. The percentage of days which were not assigned an AMC due to incomplete data ranged from 13% at Paoli to 1% at West Lafayette. The average was 7% with most such days occurring in the dormant season. The total number of days assigned to an AMC class was 94116.

Results

The primary results of this study are the seasonal AMC probabilities presented in Figure 1 and Table 2 for each station and for the state. The Indiana average entries are not simple averages of the station probabilities but are based on the total number of days analyzed.

The SCS growing season probabilities are remarkable for their uniformity among stations and for the overwhelming predominance of AMC I caused by the high class limit of 1.4 inches of rain. The probability that any growing season day will be in AMC I is everywhere greater than 85%. It is clearly incorrect to consider AMC II as an average condition. SCS AMC IV has a probability of less than 0.4% during the growing season, as does ILLUDAS AMC 5.

The SCS dormant season results show far more variation among stations, especially in AMC IV, the frozen soil or snow cover class. This probability ranges

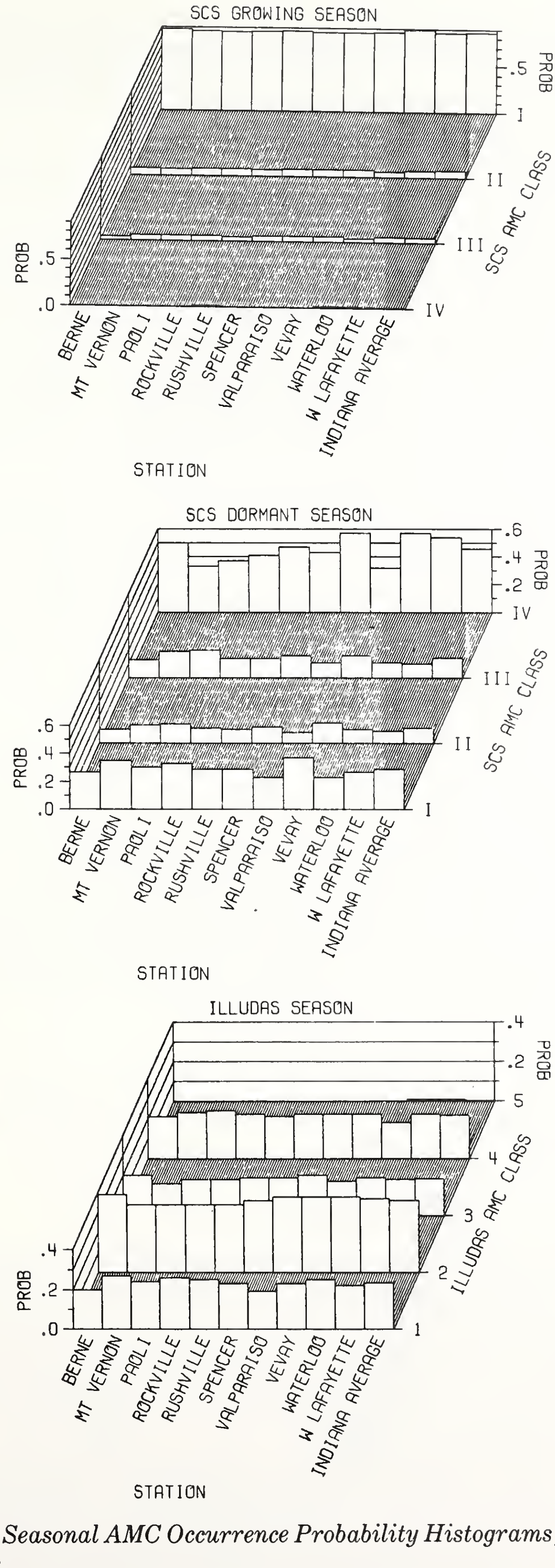

FIGURE 1. *Seasonal AMC Occurrence Probability Histograms for Each Station and for Indiana.*

from 32% at Vevay to 57% at Waterloo and Valparaiso. The trend correlates very closely with annual average temperature and with latitude, the colder stations having a greater AMC IV probability. The most important conclusion, however, is that the CN method is invalid for almost half of the dormant season for the state as a whole.

The ILLUDAS results, which refer to the growing season, show uniformity among stations and a fairly even distribution among classes. This makes the selection of a design AMC rather critical.

For some applications, monthly AMC probabilities are useful. Once again, the variations among stations are modest, except for SCS AMC IV during the dormant season which shows a marked increase with latitude. The Indiana average results are shown in Figure 2. The SCS growing season results vary slightly, with the probability of AMC I increasing from 84% in April to 90% in October. The AMC III probabilty ranges from 4% in October to 8% in June. The probability of AMC IV (and ILLUDAS AMC 5) is 1.7% in April, 0.4% in October, and 0% in the other growing season months.

During the dormant months, the probability of SCS AMC IV shows a definite seasonal trend with a maximum of 67% in January and a minimum of 19% in November. This variation occurs largely at the expense of AMC I, whose probability is least in January (15%) and greatest in November (23%).

The ILLUDAS probabilities show moderate variations. The probability of AMC 1 grows from a low of 13% in April to a high of 31% in October. The AMC 4 probability is greatest in June (27%) and least in October (15%).

Conclusions

The analysis of a total of 258 years of daily weather observations at 10 Indiana stations has provided reliable estimates of the probability of occurrence of the Antecedent Moisture Condition classes of the SCS Curve Number method and the ILLUDAS computer program. The uniformity of the probabilities across the state means that probabilities for any location in Indiana can be interpolated with confidence. The present results confirm and supercede the less statistically significant AMC probabilities published previously by Gray and his co-workers (5,6) for fewer Indiana stations.

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Literature Cited

1. BURKE, C.B. and D.D. GRAY, 1980. A Comparative Application of the Rational Method and the Illinois Urban Drainage Area Simulator to an Indiana Subdivision. Proceedings of the Indiana Academy of Science for 1979, 89: 191-203.
2. BURKE, C.B. and D.D. GRAY, 1981. Some Techniques for the Design of Subdivision Storm Drainage Systems, Water Resources and Land Use Management in Indiana, R.E. Warner and P.E. Clark, eds., Indiana Water Resources Association, Indianapolis, 141-155
3. BURKE, C.B., A.R. RAO and D.D. GRAY, 1980. Duration and Temporal Distribution of Storms in Urban Drainage Design. Prodeedings, International Symposium on Urban Storm Runoff, University of Kentucky, UKY BU121, 71-79.
4. DELLEUR, J.W., 1979. Unit Hydrograph. in "Urban Drainage Planning and

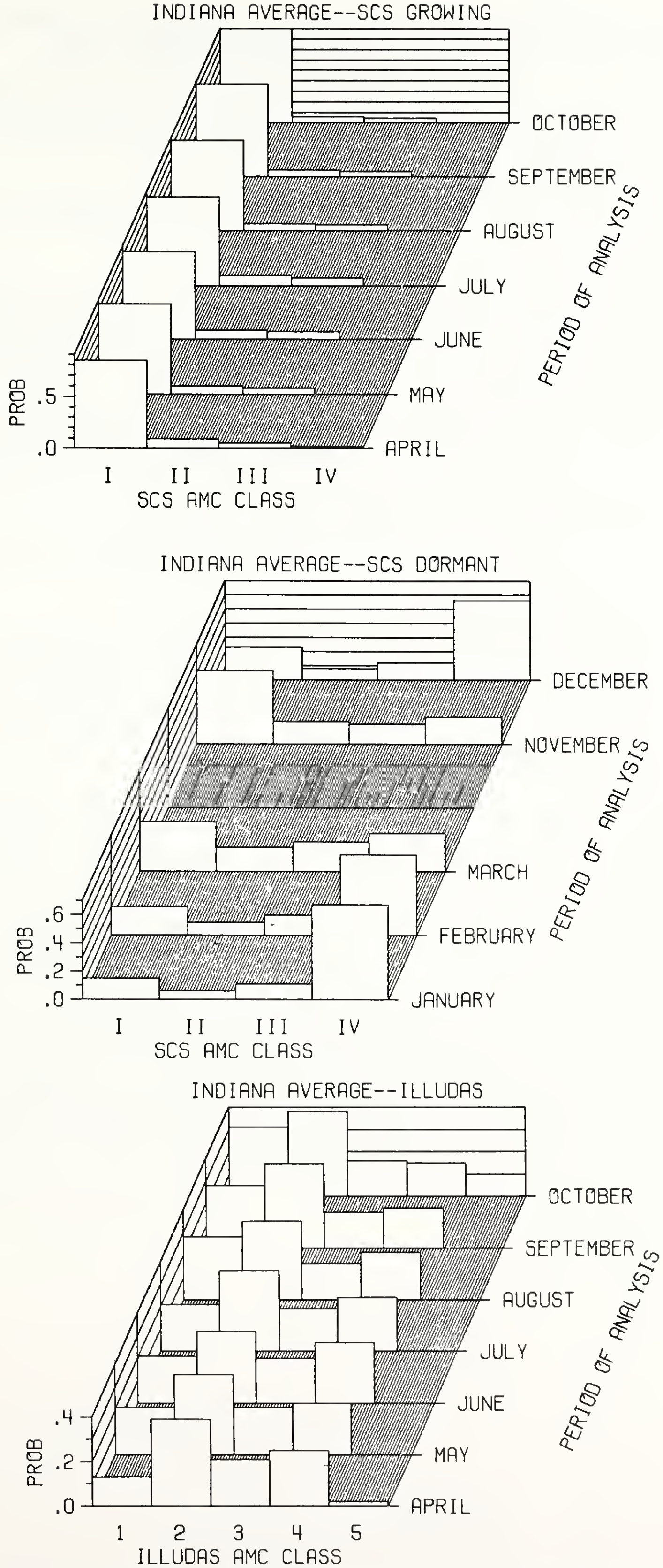

FIGURE 2. *Indiana Average AMC Occurrence Probability Histograms by Months.*

Design", notes for short course held June 4-6, 1979, Purdue University Water Resources Research Center, West Lafayette, Indiana, 59-87.

5. GRAY, D.D. and N.P. COGO, 1981. Antecedent Moisture Condition Probabilities in Tippecanoe County, Indiana. Water Resources and Land Use Management in Indiana, R.E. Warner and P.E. Clark, eds., Indiana Water Resources Association, Indianapolis, 157-176.
6. GRAY, D.D., P.G. KATZ, S.M. DEMONSABERT, and N.P. COGO, 1982. Antecedent Moisture Condition Probabilities. ASCE Journal of the Irrigation and Drainage Division 108: 107-114.
7. HAWKINS, R.H., 1978. Runoff Curve Numbers with Varying Site Moisture. ASCE Journal of the Irrigation and Drainage Division, 104: 389-398.
8. KENT, K.M., 1973. A Method for Estimating Volume and Rate of Runoff in Small Watersheds. Soil Conservation Service, SCS-TP-149.
9. LINSLEY, R.K., M.A. KOHLER, and J.L.H. PAULHUS, 1982. Hydrology for Engineers, 3rd ed. McGraw-Hill, New York, 237-239.
10. MCCUEN, R.H., 1982. A guide to Hydrologic Analysis Using SCS Methods. Prentice-Hall, Englewood Cliffs, New Jersey, 145 p.
11. MCGARRAHAN, P. and R.F. DALE, 1980. Predicting Soil Temperatures with Air Temperature and Soil Moisture; Proceedings of the Indiana Academy of Science for 1979. 89: 386-393.
12. MOCKUS, V.J., 1972. Estimation of Direct Runoff from Storm Rainfall. Chapter 10 of SCS National Engineering Handbook, Section 4—Hydrology, 10.1-10.24.
13. POPE, E.J., 1973. A Method for Determining Peak Flows and Detention Storage requirements in Urbanizing Areas. Soil Conservation Service, Indiana State Office, Indiana Technical Note—Engineering—2.
14. RALLISON, R.E., 1980. Origin and Evolution of the SCS Runoff Equation. Proceedings of the Symposium on Watershed Management 1980, ASCE, 912-924.
15. SCS, 1975. Urban Hydrology for Small Watersheds. Soil Conservation Service Technical Release No. 55.
16. SCHAAL, L.A., 1981. Climatology of Soil Temperatures in Indiana. Station Bulletin No. 307, Department of Agronomy, Purdue University, West Lafayette, Indiana, 87 p.
17. SCHAAL, L.A. and J.E. NEWMAN, undated. Determining Spring and Fall Frost-Freeze Risks in Indiana. Agronomy Guide (Weather) AY-231, Cooperative Extension Service, Purdue University, West Lafayette, Indiana, 8 p.
18. TERSTRIEP, M.L. and J.B. STALL, 1974. The Illinois Urban Drainage Area Simulator, ILLUDAS. Illinois State Water Survey, Urbana, Illinois, Bulletin 58, 90 p.