Small Urban Watershed Use of Hydrologic Procedures

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The Federal Interagency Hydrology Subcommittee has published documents on flood frequency for gauged and ungauged watersheds. These documents include information on the preparation, dissemination, and results of a questionnaire sent to users of hydrologic methods. The questionnaire was circulated by a working group of the Hydrology Subcommittee and pertains to urban watersheds with areas of less than 30 mi^2. Respondents provided information relative to the physical and administrative factors influencing their use of specific hydrologic methods. Although respondents did not cite all available hydrologic methods, most commonly used methods were mentioned, even though some were not actually used during the period of usage about which the respondents were questioned. Results of the questionnaire indicated that 86 percent of studies performed by hydrologic methods were performed by one of four methods. More than half of the studies conducted during a 1-year period used the TR-55 computer model of the Soil Conservation Service (SCS). The other three methods in order of popularity were the rational method, TR-20 by SCS, and regression equations by the U.S. Geological Survey. The questionnaire displayed rather dramatically that users have been opting for less involved methods. The method selection process may be due to the fact that mutually accepted guidance on the priority of method use is unavailable. In addition to the results from the questionnaire, supplemental information is provided on the methods being used in state highway departments and the National Flood Insurance Program. Some current problems facing administrators regarding the proliferation of hydrologic models and rainfall data documents are also included.

Within the federal government lead responsibility for coordinating water data acquisition activities resides with the U.S. Geological Survey's (USGS's) Office of Water Data Coordination. The Interagency Advisory Committee on Water Data is composed of representatives of federal agencies and is divided into functional subcommittees (Figure 1). Among these subcommittees is the Federal Interagency Hydrology Subcommittee. Under the purview of the Hydrology Subcommittee is the coordination and the development of guidance for the application of hydrologic methods. Two important documents relating to hydrologic methods for flood frequency analysis were published in the 1980s by the Hydrology Subcommittee. The first document, *Guidelines for Determining Flood Flow Frequency, Bulletin 17B*, was published initially in March 1976 and most recently in March 1982 (*1*). These guidelines provided methods for obtaining the frequency of flood peak discharges for watersheds with gauged records of homogeneous data extending for 10 years or more. A follow-on publication, *Estimating Peak Flow Frequencies for Natural Ungaged Watersheds—A Proposed Nationwide Test*, was issued by the Hydrology Subcommittee in 1981 (*2*). The second document provided a classification of the procedures and results of a pilot test of several methods. It concluded that a massive nationwide test is needed to provide an authoritative basis for procedure selection and to recommend a national guide for ungauged watersheds.

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The use of *Bulletin 17B* (*1*) has been extensive since its publication for gauged watersheds. However, its methods apply to special conditions that are not often found in urban watersheds. Homogeneous peak discharge data are generally not available for watersheds experiencing urban development. Urban flood information studies usually require complete hydrographs for stream and storage routings analyses. Therefore, the guidance in *Bulletin 17B* will generally not suffice in the small urban watershed situation. Although the ungauged watershed report provided information on some available hydrologic methods, it did not include information regarding the extent of use for various methods in present-day engineering practice. Many hydrologic studies are being performed on small urban watersheds for planning, design, land-use regulations, flood insurance, and other purposes. A potpourri of methods are available, but limited guidance is offered on which methods are appropriate for various sets of conditions. Thus, it is difficult for administrators and managers to know when reasonable results are available. With the prevailing problems in mind, the Hydrology Subcommittee formed a working group to evaluate the prospects for providing guidance on small urban watersheds.

The purpose of this paper is to identify hydrologic methods commonly applied to analyses of flood flows in small urban watersheds. This paper is not intended to provide guidance or recommendations on the application or selection of hydrologic methods for various water resource purposes, including flood frequency analysis. Information is presented on the applications of hydrologic methods for small urban watersheds as developed from responses to a questionnaire distributed by the Hydrology Subcommittee. The questionnaire was to provide the first step in developing guidance on the appropriate use of the methods. It is unlikely that consensus guidance on the application of hydrologic methods for small urban watersheds will evolve in the near future; however, groups of experts continue to be formed to further this objective. Sound guidance is an elusive objective cloaked in controversy and thus requires time, effort, funding, and compromise.

SUMMARY OF QUESTIONNAIRE

From an evaluation of questionnaire responses, the author made some general observations concerning the estimation of hydrologic flood flows for small urban watersheds. Among the most revealing observations are that

- Practitioners may not be fully aware of some of the effective methods available for analyzing small urban watershed flood flows;
- Practitioners tend to use methods with which they have the greatest familiarity;

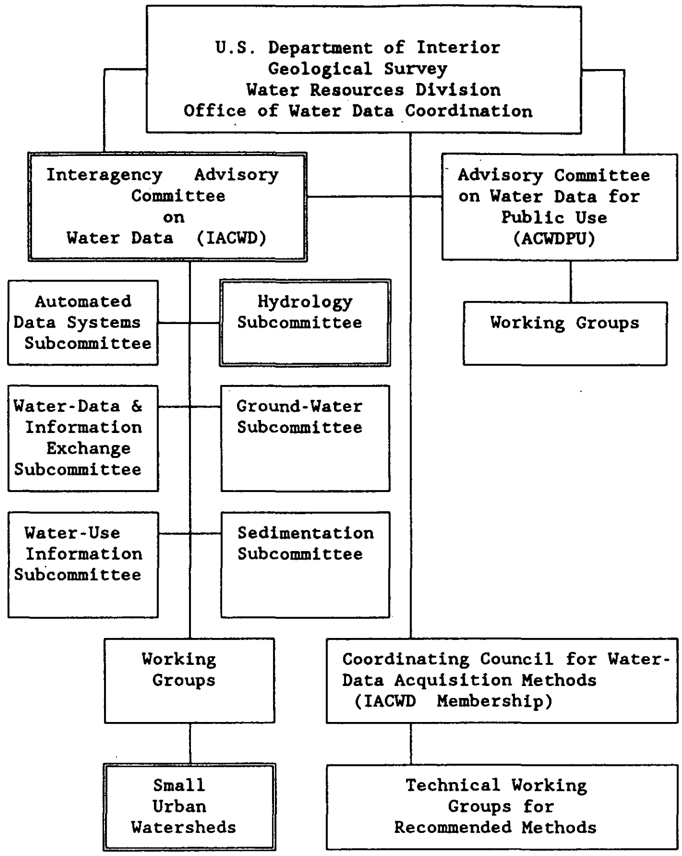

FIGURE 1 Organizational chart.

- Procedures for rural watersheds may be in use without adjusting for the impacts of urbanization;
- Some practitioners are apparently not using the most recent version of the hydrologic models; and
- There appears to be a tendency to use less involved methods.

Although these observations are deducted from responses provided on the questionnaire and would require further communication with the respondents to verify and explain the observations, they do point to the need for the development of generally accepted guidelines for hydrologic method applications. For example, the application of procedures developed for rural areas to an urbanized watershed can result in significant underestimation of flood flows. Use of something other than the most recent version of a hydrologic model may not seriously affect the results, but it may be an inefficient means of study. Practitioners must also use care in the selection of methods. Less involved procedures may be satisfactory for most situations; however, the consequences of cursory estimates are important considerations in the level of effort devoted to the computation of synthetic floods.

A possible implication of the results of the questionnaire is that the conclusions of the report on ungauged watersheds (*2*) may be influencing decisions about the selection of hydrologic methods. Since funding of the nationwide test was not provided and does not appear likely, the hydrologic community must deal with the conception that a nationwide test is the only mechanism for an authoritative national guide on hydrologic methods for ungauged watersheds. Study managers apparently have a difficult task in convincing decision makers that an in-depth hydrologic method should be used in the face of the previous conclusion that results cannot be scientifically proven to be better than those obtained by a less demanding method. Although scientific proof of the superiority of some methods over others, given a specific set of conditions, may not be readily obtainable, technical expertise and experience can be used to provide guidance on which methods are more likely to give consistently good results. Therefore, guidance on the selection and application of hydrologic methods for flood estimates of small urban watersheds appears to be needed as soon as practicable.

PROFESSIONAL SOCIETIES

Expertise in the application of hydrologic methods is available within the public, private, and academic sectors. Professional society membership normally reflects a cross section of these sectors. Journal articles, committee reports, and proceedings of professional meetings offer extensive literature related to hydrologic methods. Many of these documents, as well as publications of the federal government, are available through the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

On the basis of questionnaire responses, which indicate a need for more information on microcomputer hydrologic models, and needs for storm water management practices, the work of two professional societies is described briefly in the following sections.

American Society of Civil Engineers

The membership of ASCE contains many engineers who are engaged in hydrologic studies. They include practicing private firms, educators, and researchers as well as local, state, and federal agencies. Being concerned about professional integrity and sound engineering practices, ASCE has directed significant effort in the field of urban water resources. Toward this effort ASCE has established several committees that deal with the hydrology of small urban watersheds.

The ASCE Task Committee on Microcomputer Software has sent questionnaires to vendors regarding available models for urban hydrology analyses and details about their application. Results of the survey were presented at the National Conference on Hydraulic Engineering in New Orleans, Louisiana, August 14–18, 1989.

American Geophysical Union

The American Geophysical Union (AGU) may be described more as a scientific organization than a professional society, because its members and activities are generally oriented toward research. However, its Hydrology Committee is one of the strong elements of the organization and is deeply involved in urban hydrology. This committee published a monograph (*3*) on state-of-the-art practices in the field of urban hydrology and storm water management. Another example of AGU Hydrology Committee efforts in urban watersheds is sponsorship of personal computer workshops on methods for flood frequency analysis and flood forecasting. This activity was provided during the International Association of Hydrological Sciences, Third Scientific Assembly, May 10–19, 1989, Baltimore, Maryland.

USER'S NEEDS

Present Use of Urban Flood Frequencies

Urbanization of watersheds increases the percentage of impervious land area, with the direct result of increased volumes of runoff from rainfall events. The increased volume of runoff may be accompanied by higher flood peaks and increased, possibly erosive, flow velocities. The consequences of this cause-and-effect relationship between urbanization and increased runoff have required organizations involved in the planning, management, and maintenance of urban areas to become knowledgeable of hydrologic analysis.

Transportation planners and design engineers have a keen interest in flood volume and frequency with regard to water conveyance through bridge openings and culverts. Protecting costly bridge structures and embankments from damage due to overtopping is a critical design item. Planning for watershed changes over the proposed life of structures is difficult, but it is an important task. For example, a culvert in a rural area designed to pass a 100-year flood flow may be adequate to pass only a 50-year flood after urban development of the watershed.

In response to increasing losses from flooding throughout the nation, the U.S. Congress established the National Flood Insurance Program (NFIP) through the National Flood Insurance Act of 1968. Under the mandate of NFIP, administered by the Federal Emergency Management Agency's (FEMA's) Federal Insurance Administration, studies of 100-year flood hazards have been conducted for all flood-prone communities. The results of those studies provide the basis for management of flood risk areas and the provision of flood insurance to homeowners and non-residential building owners within communities that participate in NFIP. The issuing of building permits, community zoning issues, and land development are among the activities affected by flood frequency analyses conducted as part of a flood insurance study for NFIP.

Economic justification, design, and operations of flood control projects require flood information. Storm drainage facilities are usually designed with floods of a specific frequency in mind. These activities and others require information on floods in order to proceed in an orderly fashion. Incorrect analysis of floods can involve excessive expenditures or could result in serious damage to facilities based on underestimated flood magnitudes and frequencies.

Planning Future Hydrologic Studies

The nature and direction of future urban hydrologic studies should be shaped through insights gained from an examination of the amount of use given to various flood analyses for urban watersheds. Serious questions may evolve from this examination, such as the following:

- Are users taking advantage of the state-of-the-art practice? If not, what are the reasons for limited use of apparently more effective methods?
- Is the state of the art adequate for user needs? If not, what direction should research and development take?
- Does user response to the questionnaire reflect real-world applications of various hydrologic models? If not, what would cause the results to be skewed?
- Do the questionnaire results indicate the need for coordinated guidance on the use of hydrologic models? If so, who should provide this guidance and what should be the extent of the guidance?

Although this paper is not of the scope needed to answer these and other pertinent questions, activities of other organizations may help to resolve some of the questions. For example, the Water Science and Technology Board of the National Research Council sponsored a committee report entitled *Opportunities in the Hydrologic Sciences* (*4*). That committee report addressed items such as scientific development to the present, outstanding historical achievements, intellectual frontiers and scientific challenges, new data requirements, qualifications of the people needed, and an indication of applications.

ORGANIZATION OF WORK GROUP

Early Concepts

The Hydrology Subcommittee recognized the need for a working group on methods for analyzing flood flows from small urban watersheds. Agency interest was solicited by the subcommittee chairman, and an initial work group was established in 1982. This group included FEMA, the U.S. Army Corps of Engineers (USACE), Soil Conservation Service (SCS), USGS, Agricultural Research Service, Tennessee Valley Authority, and FHWA. The early activities of this group were devoted to the development of a statement of work. The objective of this activity was to develop guidance on the selection of methods for analyzing flood flows from small urban watersheds. This objective was to be accomplished by a contractor who would review methods, consult with agencies and other users, and prepare a user's manual. The investigation was designed to include

- Watersheds (up to 30 mi^2),
- Development (natural to 100 percent urban), and
- Flow (peaks, volumes, hydrographs).

The final product was expected to identify methods of analyses and provide guidance on the selection and application of methods. Since the contractual arrangement was anticipated to involve considerable funding, the separate agencies investigated sources of funds that could be used to support this activity. Federal budgets are planned well in advance of receipt of an actual appropriation from Congress. Thus, a time-consuming process is involved, and competition for research-type funding is intense.

Questionnaire Status

In 1985 the work group concluded that insufficient funds would be committed by the federal agencies to pursue a contracted study. Lacking full funding for planned activities, the work group agreed to pursue its statement of work on a limited basis with member support. Examining efforts that could be implemented by the task committee, information on the current use of methods became a high-priority item. Thus, the task committee began to prepare an appropriate questionnaire that could be circulated among the practitioners of urban hydrology. It was agreed that the questionnaire should glean enough information from users to help prepare future guidance on flood methods for urban watersheds. In February 1987 the parent Hydrology Subcommittee approved the task committee's recommendation to distribute the questionnaire to organizations experienced in hydrologic modeling. A distribution list was prepared; it included the following:

- Federal agencies on the Hydrology Subcommittee,
- State agencies involved in water resources, and
- Private contractors performing hydrologic analyses.

The distribution list did not include educational and research institutions because the information gathering was directed toward practitioner use rather than research and development. However, future efforts in guidance on the selection and application of hydrologic models would need to involve this segment of hydrologic experts. The questionnaire was mailed in February 1987. Although most responses were received in a timely manner, there were a few delays in the receipt of completed questionnaires.

RESULTS OF QUESTIONNAIRES

Respondent Information

Respondents to the questionnaire were grouped by their employers and are listed as federal, state, or private practitioners in hydrologic analyses. Figure 2 depicts the percentage distribution by the source of responses. It does not indicate the numbers of respondents, because many respondents provided information on more than one hydrologic method.

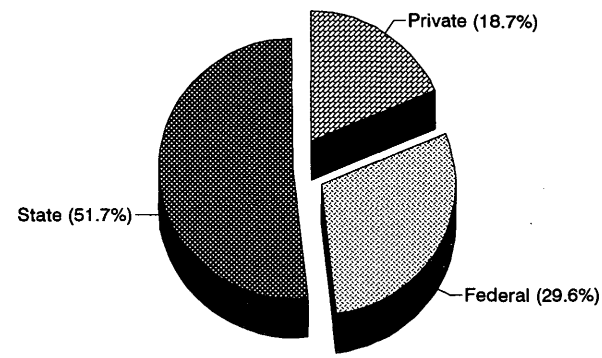

FIGURE 2 Source of responses.

Classification of Methods

Many hydrologic methods were identified in the responses to the questionnaire; however, the list does not include all available methods. To consolidate the responses for data management purposes, all responses were sorted to a classification system containing 12 categories. The individual hydrologic method was used as a classification title when significant usage of that method was indicated by answers to the questionnaire. Information on the classification of methods is provided in Table 1 and Figure 3.

Details on the numbers of studies performed in the year preceding completion of the questionnaire (1986) are given in Table 1. This is a 1-year sample and reflects neither variations in method use from one year to another nor a longer-term summary of method use.

Reasons for Selection of Method

Table 2 provides an interesting comparison among methods regarding the most prevalent reasons given for using a particular hydrologic method. Review of such information is important in planning a strategy for obtaining guidance on the selection of hydrologic methods. Obviously, an individual user will not benefit from selection guidance if an agency or customer dictates the method that is to be used for a specific study. The user and client may, however, benefit from application guidance. Although the results of this activity provide good general information, technical information such as reliability and reproducibility of results is probably best obtained via an expert systems approach.

Response Regarding Physical Features

The United States has a wide variety of physical features that influence the amount and rate of runoff from a watershed. Several of these features were included in the questionnaire, and responses reflect the peculiarities of different parts of the country. Physical features included in the questionnaire were watershed size, slope of terrain, type of soil cover, density of vegetation, and annual precipitation. Responses on this aspect are not included in this paper; however, a careful review of this information by experts in hydrologic analysis could provide insight on the proper use of a hydrologic method for the environment in which it was used. Such information is important to the criticality of completing guidance on the selection and application of hydrologic methods. When physical features

TABLE 1 Classification of Methods

ORDER	METHOD	NO. OF STUDIES	PERCENT
1	TR-55	10,763	51.3
2	Rational	4,054	19.5
3	TR-20	1,954	9.3
4	USGS Rural Regression Equations	1,265	6.0
5	USGS Urban Regression Equations	529	2.5
6	FHWA Small Rural Watersheds	500	2.4
7	HEC-1	485	2.3
8	Log-Pearson Type III	360	1.7
9	SCS Hand Methods	219	1.0
10	Synthetic Flood Frequency	155	0.7
11	Other Runoff Hydrograph Models	138	0.7
12	Miscellaneous	553	2.6
	TOTAL	20,975	100.0

and the use of hydrologic models are considered, other aspects not addressed by the questionnaire should also be considered. Some of these important aspects are watershed shape (long and narrow basins have longer response times than short and wide basins); many methods do not have the capability to combine and channel route subbasin runoff; others do not provide the ability to route runoff through storage.

CONCLUSIONS FROM RESPONSES

After examining the responses to the questionnaire, the author drew some general conclusions regarding the use of hydrologic methods as applied to small urban watersheds. Other analysts experienced in hydrologic models may arrive at different conclusions. Some of the more obvious conclusions are as follows:

- The number of studies performed in a 1-year period (20,000 plus) indicates that there is a great deal of activity in hydrologic analyses of small urban watershed.
- Calibrated rainfall runoff models such as TR-20 and HEC-1 constitute a small percentage (12 percent) of all models used.

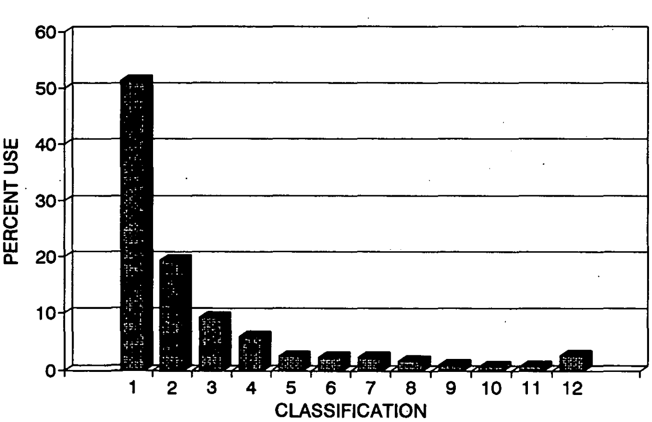

FIGURE 3 Use of hydrologic methods.

TABLE 2 Reasons for Selection of Method

CLASSIFIED METHOD	RESPONSE RANKING 1	2	3	4	5	6
TR-55	F	E	A	D	B	C
Rational	F	E	A	B	D	C
TR-20	E	F	D	A	B	C
USGS Rural Regression Equation	F	E	A	D	B	C
USGS Urban Regression Equation	F	E	A	D	B	C
FHWA Small Rural Watersheds	F					
HEC-1	E	F	A	D	B	C
Log-Pearson Type III	F	E	A	B	D	C
SCS Hand Methods	F	E	A	D		
Synthetic Flood Frequency	F	E	A	D		
Other Runoff Hydrograph Models	E	F	D	A	B	C
Miscellaneous	F	E	A	D	B	C

Legend:

A - Economic Feasibility
B - Required by Regulations
C - Specified in Contract
D - Unique Environment
E - Organizational Familiarity
F - Ease of Use

- Practitioners of hydrologic analysis are interested in the procedures being used by their peers, because 94 percent of the respondents requested copies of the result(s) of the survey.
- Ease of use was the most prominent response regarding the reason for selection of methods.
- Respondents generally do not view small urban watersheds as unique environments because this reason for method use ranked midway in responses.
- Results of the survey confirm the need for guidance on the selection and application of hydrologic methods for flood frequency analysis being applied to small urban watersheds.

OTHER ASSESSMENTS OF HYDROLOGIC METHODS

Since the Federal Interagency Hydrology Subcommittee survey of hydrologic methods was summarized in 1989 and has not been published for general information, it appeared prudent to supplement the results of that survey with additional and more recent information. Data from two individual assessments are provided for comparison.

State Highway Departments

Probably thousands of hydrologic computations for sizing highway water passages (culverts and bridges) are made each year. Sizes are generally based on specific quantiles (peak flows and their associated exceedence frequencies). This survey conducted by the Maryland State Highway Administration in 1990 included 45 states and the hydrologic methods used by their highway departments. Table 3 gives the hydrologic methods cited and the number and percentage of states that use them.

Some interesting observations from this survey are that

- Eighteen states indicated the use of only one hydrologic method in their engineering analyses of waterway openings;
- Three states use five different hydrologic methods; and
- Thirty-three states use hydrologic methods that produce only peak flows (hydrographs are not available from the methods selected).

This survey did not include information on the reasons that specific hydrologic methods were selected. However, from examination of the methods selected, it appears that simplicity of use, consistency of results, and nonuse of hydrographs are important considerations. Because of the limitations of this survey, it appears that state highway departments do not become involved in detailed hydrologic analyses. This assumption may be correct for most of the states surveyed; however, it is certainly not true for the Illinois Department of Transportation (IDOT). IDOT is an example of a state highway organization that has a leading role and responsibility for sound hydrologic analyses within the state. For those states that do not have a lead agency for coordinating and reviewing hydrologic analyses, IDOT serves as an example of how state highway organizations can provide this important service. Although several federal agencies and other state agencies may be performing hydrologic studies within a state, there may be no state agency with responsibility or adequate funding to coordinate studies and to maintain some level of consistency throughout the state.

National Flood Insurance Program

Most of the communities in the NFIP have base (100-year) floods included in their flood insurance studies (FISs). Thus, FEMA is currently more in a revision mode than in its earlier development mode insofar as hydrologic studies are involved. The majority of revision studies involving hydrologic analyses are performed by engineering firms that represent owners of property within the designated 100-year floodplain. These property owners are seeking relief from NFIP by convincing FEMA that their estimate of the 100-year flood is more correct than the estimate in the FIS. Dewberry & Davis (D&D) serves as a technical evaluation contractor for FEMA Regions 1 through 5. In this role D&D reviews the technical adequacy of hydrologic studies in revision requests as well as those studies performed by FEMA's study contractors who update FISs. A survey of the hydrologic methods being used in review cases was conducted during August 1993 for Regions 1 through 5. Results of that survey are included in Table 4.

TABLE 3 Use of Hydrologic Methods by State Highway Departments

HYDROLOGIC METHODS	NUMBER OF STATES	PERCENT OF STATES
Regional Regression Equations (USGS)	36	80
Rational (Mulvaney's Equation)	19	42
Bulletin 17-B (Interagency Hydrology Subcommittee)	8	18
Other Methods (Used by One State)	7	16
TR-55 (SCS)	6	13
TR-20 (SCS)	4	9
HEC-1 (USACE)	3	7
FHWA Procedures	3	7

An earlier survey of the hydrologic methods used during FEMA's development mode would have resulted in a table more consistent with that showing the results of the state highway department survey. Less use of rainfall runoff models such as HEC-1 and TR-20 would have been reported. Although the FEMA survey shows HEC-1 as the most prominent hydrologic model used, in many instances the HEC-1 model uses the curve number loss function and unit hydrograph procedure from TR-20. HEC-1 does not include the Att-Kin routing procedure from TR-20 as one of its routing options. Therefore, it is difficult to obtain exactly the same results from the two models unless hydrograph routing is not involved.

Another observation not available from the survey is that the kinematic wave option available in HEC-1 is seldom used in hydrologic studies submitted to FEMA in the eastern half of the United States. The reasons for the lack of popularity of this valuable urban hydrology procedure are not readily apparent. However, unfamiliarity with the procedure and more intense input requirements could be deterrents.

RAINFALL DATA AND AVAILABLE MODELS

Those who are part of water resource programs being administered by various federal, state, and local organizations face important decisions regarding the use of hydrologic models and rainfall data. The traditional rainfall probability relationships published by the National Weather Service (NWS) many years ago are being updated

TABLE 4 Hydrologic Methods Used by FEMA, Regions 1 to 5

HYDROLOGIC METHODS	NUMBER OF STUDIES	PERCENT
HEC-1 (USACE)	34	25
Regional Regression Equations (USGS)	28	21
Bulletin 17B (Interagency Hydrology Subcommittee)	25	18
TR-20 (SCS)	23	17
Rational (Mulvaney's Equation)	10	7
TR-55 (SCS)	8	6
Others (used in one study)	8	6
TOTAL	136	100

in parts of the United States. However, funds are not available for a complete revision of these important documents. In fact, several years of study and revision would be needed to complete such an undertaking if all needed funding was available, thus the need for decisions on the use of new data developed by a group other than NWS. The state of Illinois has directed that its *Bulletin 70* be used when performing hydrologic studies within the state. Other entities have performed rainfall probability studies for use in lieu of the NWS documents. Although special rainfall studies may provide more up-to-date information, they can create problems for federal or state programs insofar as consistent results are concerned. This is especially true when in-depth detailed analyses are not involved.

Development of new hydrologic models also causes concern for administrators and technical experts attempting to become proficient in the use of the large array of models available. When the new models are developed within federal agencies that support the models by correcting errors and adding improvements, concerns are less dramatic. However, when model development is by private individuals or through research grants, there is much less opportunity for continuing support and improvement. FEMA has established rules for the use of hydrologic models in NFIP; however, many of those requesting revisions submit proposed changes that are based on the use of models that do not comply with FEMA rules. This can cause property owners considerable expense in redoing the studies or going through the process of obtaining FEMA's approval for the use of the model. Many federal agencies, such as the USGS, USACE, SCS, and FHWA, have their own hydrologic models that were designed for the specific needs of the agencies. However, many of these models are used by the private sector, often with some add-on modules that increase the total number of models available for use. Thus, organizations without their own hydrologic models are confronted with the difficult task of selecting or approving models for use in their programs. Presentations on specific hydrologic models, such as these being made for TRB, are useful for those individuals evaluating models for use or approval. Although these presentations are only a sample of the available hydrologic models, sorting out the pros and cons of the different models is a formidable task. Two of the presentations involve models used extensively as indicated by the surveys that were conducted; however, the other two models are more involved, and their use is probably limited to individuals highly trained in their application. Interest in SCS and USACE models will be related more to their practical applications, whereas interest in the other two models (DR3M and HSPF) will tend toward scientific applications.

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Publication of this paper sponsored by Committee on Hydrology, Hydraulics, and Water Quality.