US Army Corps
of Engineers
Hydrologic Engineering Center

Hypothetical Flood Computation for a Stream System

December 1968

TP-12

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
December 1968

2. REPORT TYPE
Technical Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Hypothetical Flood computation for a Stream System

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Leo R. Beard

5d. PROJECT NUMBER

5e. TASK NUMBER

5F. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center (HEC)
609 Second Street
Davis, CA 95616-4687

8. PERFORMING ORGANIZATION REPORT NUMBER
TP-12

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/ MONITOR'S ACRONYM(S)

11. SPONSOR/ MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Presented at the International Association of Scientific Hydrology Symposium, Tucson, Arizona, 8-15 December 1968.

14. ABSTRACT

One of the computer packages being developed in the Hydrologic engineering Center of the Corps of Engineers is the Flood hydrograph Package, which performs all common operations in deriving and using flood hydrographs entirely in core storage of computers as large as the IBM 7094. One of the problems managed by this program is flood computation throughout an entire stream system in one operation. Ordinarily, a design or hypothetical flood might be derived from a storm centered in the tributary area. After floods are computed in this manner for several subareas within a stream system, it is often necessary to compute floods for the combined areas at various locations. The originally computed floods cannot be routed and combined, since the storm cannot center over all subareas at once. It is ordinarily necessary to recomputed each subarea flood for every combining point downstream, and to label each re-computation as the contribution to that particular location. In a complex system, such as a storm drain or major river basin, this procedure would lead to great amounts of computation and considerable confusion. Essential features of the computer package and the simplified stream system analysis are described.

15. SUBJECT TERMS
routing, flood forecasting, computer programs ,runoff forecasting, synthetic hydrology, snowpacks, snowmelt, water loss, hydrograph analysis, regulation, urbanization, rainfall-runoff relationships

16. SECURITY CLASSIFICATION OF:

a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
U	U	U	UU	28

19a. NAME OF RESPONSIBLE PERSON

19b. TELEPHONE NUMBER

Hypothetical Flood Computation for a Stream System

December 1968

US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil

TP-12

Papers in this series have resulted from technical activities of the Hydrologic Engineering Center. Versions of some of these have been published in technical journals or in conference proceedings. The purpose of this series is to make the information available for use in the Center's training program and for distribution with the Corps of Engineers.

25 April 1968

HYPOTHETICAL FLOOD COMPUTATION FOR A STREAM SYSTEM

Leo R. Beard(2)

INTRODUCTION

A design flood, defined as the flood for which a hydraulic structure is designed, can be selected in many ways, one of which consists of a detailed economic analysis of costs and benefits associated with protection against various magnitudes of floods. Regardless of the manner in which it is selected, certain general relationships exist between sizes of tributary area and size of flood, partly because average storm intensities decrease as area covered increases, and for various other reasons. Although there is not ordinarily a unique relationship between rainfall and runoff at a particular location, such that the probability of a flood would correspond with the probability of the causative rainfall, there are nevertheless reasons for computing design floods from rainfall (and snowmelt). These are usually to assess limiting flood magnitudes or to estimate floods where conditions in the tributary area change from historical conditions or where runoff records are not available.

A comprehensive computer program has been developed in The Hydrologic Engineering Center of the Corps of Engineers to manage the various problems associated with computation of runoff from rainfall and snowmelt quantities.

---

(1) Prepared for presentation at the International Association of Scientific Hydrology Symposium, Tucson, Arizona, 8-15 December 1968.

(2) Director, The Hydrologic Engineering Center, Corps of Engineers, Sacramento, California.

The hydrologic features of this computer program, particularly regarding a new technique for decreasing flood magnitudes per unit area with size of drainage basin, are described herein.

SNOWPACK ACCUMULATION AND DEPLETION

Those basins where snow accumulation and snowmelt are significant factors in flood production are divided into elevation zones of 1000-foot range in order to account for marked changes of temperature with elevation. Temperatures specified for each interval correspond to the bottom elevation of the lowest zone and are decreased with elevation in accordance with a specified lapse rate. If desired, they are also modified for changes in latitude.

In each elevation zone, precipitation is considered to occur as snowfall if the temperature is below a specified value. Snowmelt within each elevation zone is computed in accordance with generalized relations used by the U.S. Army Corps of Engineers, with an option between a straight degree-day computation and a comprehensive energy-budget computation, using methods described in the Corps of Engineers manual.(3) The former method usually gives more satisfactory results, because the detailed data required for energy-budget computations are usually not available during each interval of the storm. Snowfall is added to the snowpack in each elevation zone and snowmelt is subtracted during each storm interval. Rainfall is added to snowmelt to obtain the total water input for each interval.

(3) Runoff from Snowmelt, EM 1110-2-1406, Corps of Engineers, 5 Jan 1960.

NON-LINEAR LOSS RELATION

A great many studies relating basin-average rainfall amounts for short intervals in a storm to observed runoff indicate a distinctly non-linear relationship between rainfall intensity and loss rate (infiltration). Considering the non-homogeniety of soils, vegetation and precipitation throughout a basin, this non-linearity between basin-average (lumped) amounts is logical. The following equation has been used in these studies, with a constraint that loss does not exceed water input (rainfall plus snowmelt) for each interval:

$$L = KP^E \tag{1}$$

in which

L = loss in inches per hour during interval
K = coefficient decreasing with increased ground wetness
P = rainfall plus snowmelt in inches per hour during interval
E = constant exponent between zero and 1.0

It will be noted that a value of zero for E would correspond to loss rates independent of rainfall intensity (the traditional assumption) and that an exponent of 1.0 would correspond to loss rates directly proportional to rainfall intensity. Hydrograph reconstitution studies have indicated the exponent to range ordinarily between 0.5 and 0.9, and frequently an average of 0.7 has been adopted for purposes of uniformity.

Loss rates during snowmelt floods are small in comparison with observed losses during rainfloods. Accordingly, separate loss functions are used in the computer program for snow-covered areas and for snow-free areas. In each case, the loss coefficient K in equation 1 decreases with ground wetness during a storm in accordance with the following equation:

$$K = K_o \, C^{-(\Sigma L/10)} \qquad (2)$$

where

K_o = loss coefficient at start of storm (Different for snow-free and snow-covered areas)

C = coefficient controlling rate of decrease of K (Different for snow-free and snow-covered areas)

ΣL = accumulated loss during storm (Different for each elevation zone)

Figure 1 illustrates the use of equations 1 and 2.

During long-duration snowmelt floods, rainfall and snowmelt losses from snow-covered areas decrease in this manner, but rainfall losses in snow-free areas are considered to increase gradually throughout the flood period, inasmuch as temperatures are gradually increasing and the ground surface becomes drier. This rate of increase in K is arbitrarily set at one percent of the initial value per day.

LINEAR RUNOFF TRANSFORM

The excess quantities of rainfall and snowmelt during each interval are added for all elevation zones and expressed as basin-mean excess in inches. These quantities are then transformed to runoff at the concentration point by use of the unit hydrograph technique developed by C. O. Clark.(4) This method is selected because it provides a means of direct computation from only 2 coefficients and a time-area curve. The advantage of using the time-area curve is that changes in basin configuration, such as diversions, reservoir construction, etc., can be immediately reflected in the modified time-area curve. For use in studies where a time-area curve is not obtained from detailed maps, for any of various reasons, a typical time-area curve is provided in the computer program. This is usually satisfactory, since the shape of the time-area curve has little influence compared with time and storage coefficients. Also, a unit hydrograph with specified Snyder coefficients (T_p and C_p)(5) can be obtained by automatic successive approximations of the Clark coefficients (TC and R).

The computation procedure used does not include separation of surface flows from sub-surface or ground-water return flows. All of these phases of flows are included in a single unit hydrograph. However, runoff from antecedent storms that would have occurred in the absence of the current storm (or snowmelt event) is added as a recession flow to runoff computed from the current storm.

---

(4) C. O. Clark, Storage and the Unit Hydrograph, Trans. ASCE, Vol. 110, 1945.

(5) Flood Hydrograph Analyses and Computations, EM 1110-2-1405, Corps of Engineers, 31 August 1959.

Also, after the total runoff recedes below a specified value, runoff computed by use of the unit hydrograph is constrained from receding below a specified maximum exponential rate of recession. This device precludes the necessity of treating sub-surface and return flows separately, which is otherwise necessary because of strong non-linearities in the relation of recession flow to rainfall and snowmelt amounts.

The linear unit-hydrograph transform or convolution process is ordinarily adequate, if the tendency for change in unit hydrograph characteristics with flood magnitude at a given location is recognized. Non-linearities of this convolution process within a flood, which are known to exist, are extremely difficult to determine accurately and have minor effect relative to uncertainties of precipitation and loss functions.

DERIVATION OF RUNOFF FUNCTIONS

A routine is included in this computer program to derive the unit-hydrograph and loss-rate coefficients that best reconstitute an observed flood hydrograph by a least-squares procedure. The gradient optimization procedure used is described in a previous publication(6) by the writer. Provisions are included to fix any of the variables desired in order to simplify a regional correlation analysis of the resulting coefficients.

---

(6) Leo R. Beard, Optimization Techniques for Hydrologic Engineering, Water Resources Research, Vol. 3, No. 3, 1967.

For example, the exponent of precipitation in the loss rates function would ordinarily be fixed so that coefficients derived for different locations can be compared directly. There is also a provision for permitting the engineer to influence the exact nature of the hydrograph reconstitution to some extent by temporarily distorting the observed hydrograph and thus forcing a reconstitution that would be more acceptable than the one automatically derived in the least-squares operation.

DERIVATION OF ROUTING COEFFICIENTS

A provision is also included in the program to derive routing coefficients that best reconstitute downstream hydrographs from observed upstream hydrographs and estimates of intermediate runoff. In all cases, this is a process of successive approximations. In the case of continuous functions, such as Muskingum coefficients, the optimization routine used is that employed for reconstituting hydrographs from rainfall and snowmelt, discussed above. In the case of discrete functions, such as straddle or stagger, successive values of the parameters are examined until the standard error of reconstitution begins to increase. An optimum combination of a discrete parameter and any other parameter is determined by sub-optimizing the other parameter for each successive value of the discrete parameter until the sub-optimum standard error of reconstitution decreases.

HYDROGRAPH ROUTING AND COMBINING

Hydrographs of runoff computed for various sub-basins can be routed and combined to form hydrographs at downstream locations. In order to account for changes in shape and time of the hydrographs as they travel downstream, a variety of commonly-used routing procedures are included in the computer program. These include the Muskingum (coefficient) method, the storage-lag method, the multiple-storage method, and the Straddle-stagger method.(7) Also, a reservoir routing (modified Puls) routine is included. In order to compute hydrographs for a large number of points within a stream system, storage space within the computer core is released as soon as a hydrograph has been routed or combined with another hydrograph. It is, of course, printed out before removal from storage. In order to require the smallest number of hydrographs in storage at any one time, it is necessary to start the computation at the most remote upstream location. Proper combining of hydrographs requires that, once a hydrograph is computed upstream of a location, all operations upstream of that location must be performed before performing the operation for a location that is not above that combining point. This is because the latest computed, routed or combined hydrographs are those used in each new combining operation. Channel losses must be expressed as a linear function of flow in each routing reach (a constant loss plus a ratio of the remaining flow).

---

(7) Routing of Floods Through River Channels, EM 1110-2-1408, Corps of Engineers, 1 March 1960.

MULTIPLE-FLOOD COMPUTATION

In order to evaluate the effects of changes at any location within a river basin on flows at a downstream point, it is necessary to distribute precipitation throughout the tributary area in a balanced manner, if computation and management feasibility is to be obtained. Otherwise, a great many storm centerings must be used for each successive downstream evaluation, in order to reflect a reasonable range of potential events at that location. In computing a balanced flood, it is recognized that averaging techniques might obscure rare combinations that should possibly be considered in special analyses.

Since the average depth of precipitation over a tributary area generally decreases with the size of area, it would ordinarily be necessary to recompute a decreasing balanced-flood quantity contributed by each subarea to successive downstream points. In order to avoid this proliferation of hydrographs, it is proposed that different floods corresponding to various depths of precipitation be computed for the entire river basin complex. The depths of precipitation selected should correspond to design quantities for specified drainage basin sizes covering the range of interest. Thus, by providing a table of drainage area vs. design precipitation depth, and a time distribution pattern, various floods can be computed. To minimize confusion, these can be called flood 1, flood 2, etc.

Each of these floods would correspond to a specified drainage basin size, and would be the design flood magnitude for any point in the basin whose tributary area corresponds to that size. Above such points, there would be a balanced contribution from all parts of the subbasin. In order to obtain design floods for locations whose tributary area does not exactly correspond to the selected precipitation amounts for a numbered flood, the design flood hydrograph is obtained by interpolating between the two numbered floods whose precipitation corresponds to area sizes nearest the tributary area size. An illustrative example is shown in Figure 2. The interpolation routine used is linear with respect to the logarithm of area size.

The average rates of precipitation for very large areas are small, and adopted loss functions might indicate very low runoff volumes for such precipitation intensities. However, it is recognized that some locations within the basin are experiencing much higher rates of precipitation, while other locations may be obtaining little or no precipitation. In order to account for this, stream system computations are made first for the large precipitation amounts (corresponding to small areas) and continued successively for floods 2, 3, etc., each representing successively larger design area sizes (lower precipitation depths). The excess amounts obtained for each flood are retained in the computer, and used as a proportional contribution for the next flood system computation. The proportion used is the ratio of drainage area sizes that precipitation amounts represent on the design depth-area curve. In effect, the incremental design-criterion precipitation volume for the second flood computation is considered to occur over the incremental design-criterion area size that such precipitation represents. This combination is applied to all sub-basins, thus maintaining a balance of runoff within the entire basin. As an example, if design precipitation is 10 inches for 100 square miles (flood 1) and 9 inches for 500 square miles (flood 2), precipitation of flood 2 for a 10-square mile sub-area would consist of 10 inches over 2 square miles and (90-20)/8 or 8.75 inches over 8 square miles.

Where orographic effects appreciably influence precipitation amounts, the "depth-area" curve of design precipitation can represent ratios to some base precipitation pattern, such as normal annual precipitation, and these would be multiplied by normal precipitation amounts specified for each elevation zone of each sub-area.

It is possible that a storm centered over one tributary can produce a larger flood than would result from the storm spread over both tributary basins above a confluence, despite the additional area of precipitation. This occurs in the system computation occasionally. Although each base flood below a confluence is computed by direct addition of tributary hydrographs, the interpolation procedure used can produce a smaller design flood below the confluence than on the larger contributor of two tributaries. When this occurs, the program provides for an examination of the peaks and volumes of tributary floods, and assures that the flood below the confluence is interpolated such that quantities below the confluence are at least as large as for each tributary flood.

ASSESSMENT OF REGULATORY EFFECTS

One of the most difficult problems in the functional evaluation of a system of flood control reservoirs is determining the over-all effect that a reservoir located on a remote tributary has on floods at a downstream point. A storm might center mainly on this remote tributary, in which case the effect is large; or it might produce little precipitation in that tributary area, in which case the effect could be trivial.

Considering that all magnitudes of storms can occur and that a variety of centerings can also occur more-or-less independently, the expected (average) effect of a reservoir is ordinarily approximated closely by evaluating its effect on a balanced type of flood for each general range of magnitude at the downstream point. Thus, the expected (average usable for economic evaluations) relation between regulated flows and unregulated flows of the same exceedence probability, for any configuration of reservoirs, can be derived from the effects demonstrated in the set of balanced floods computed generally as discussed herein. This would require only two complete multiple-flood system computations: one for unregulated conditions and one for regulated conditions for a given plan of development.

EFFECTS OF URBANIZATION AND CHANNEL IMPROVEMENT

Some dramatic changes have occurred in certain stream systems where urbanization and channel improvement have greatly modified the surface and stream channel characteristics. These changes generally result in reduced losses (increased volumes of runoff) and more rapid concentration of streamflows. Both natural percolation and ponding can be greatly reduced by urbanization and channel improvement. To account for reduction in infiltration loss, a coefficient of imperviousness is used, which simply assumes 100% runoff for the impervious proportion of the drainage basin and usual losses for the remainder. In order to account for reduced storage effects and for more rapid concentration of flows, the unit hydrograph coefficients are reduced in proportion to the estimated increase in average velocity of travel through the stream system. An example is shown in Figure 3.

COMPUTER OPERATION

The flood hydrograph computer package is written in FORTRAN IV and requires about 32,000 words of memory. On an ultra-high-speed computer such as the CDC 6600, time requirement is nominal, since all operations are performed within core. The greatest time requirement is associated with reconstitution of snowmelt floods where 100 to 200 complete computations of snowmelt, losses, etc., in 10 elevation zones and 120 daily ordinates requires about one minute of central processor time. For rainflood reconstitution, only a few seconds is required. A complete multiple-flood system computation of hydrographs involving snowmelt in a few dozen sub-areas requires about one minute.

A great variety of operations is performed by the program. Each of the general operations indicated above, such as derivation of unit hydrograph or loss rate or routing coefficients, computation of runoff, routing, etc., can be manipulated in many ways. For example, precipitation can be specified as basin-mean values or ratios or station values or can be computed according to some standard criteria. Unit hydrographs can be furnished or computed. Precipitation can be accompanied by snowmelt or not, and in the latter case it is automatically treated as rainfall. This great variety of operations can be tailored to each specific need by use of control numbers in the input data. While many of the operation sequences are intricate and require considerable thought, the controls are designed to simplify use of the program as much as possible.

An automatic plot routine for showing hydrographs and related data in graphic form on the printed output is included. Plotting for each operation is completely pre-programmed, including selection of items to be plotted, titling and selecting scales to be used, and arrangement on the paper. An example is shown in Figure 4.

A summary of pertinent system flows is provided for ease of review and appraisal. An example is shown in Table 1.

CONCLUSION

The comprehensive flood hydrograph computer package described performs virtually all types of flood hydrograph studies needed for the functional evaluation of flood control improvements. A large-memory, high-speed computer is required. Computations are rapid and easily controlled by simplified input data.

The program provides a unique procedure for computing design floods for a complex stream system, whether it be a major river basin such as the Ohio River basin or an urban storm drain system. Provisions are included for easily evaluating the effects of structural improvements and urbanization on flood runoff.

ACKNOWLEDGMENT

Development of the work described herein was accomplished in The Hydrologic Engineering Center of the Corps of Engineers, United States Army.

TABLE 1

EXAMPLE OF SUMMARY

RUNOFF SUMMARY, AVERAGE CFS

		PEAK	6-HOUR	24-HOUR	72-HOUR
HYDROGRAPH AT	12	59149	57215	42822	21117
HYDROGRAPH AT	11	79768	77522	60807	30858
2 COMBINED	11	112991	109755	85194	43360
ROUTED TO	10	104598	102586	83225	43276
HYDROGRAPH AT	10	127176	122450	85687	43782
2 COMBINED	10	143890	142718	128733	71639
ROUTED TO	9	138170	137369	124822	71468
HYDROGRAPH AT	9	195071	188544	136533	71479
2 COMBINED	9	196179	193194	170740	118018
ROUTED TO	7	185625	183919	169052	117602
HYDROGRAPH AT	8	72696	68376	43351	19400
ROUTED TO	7	54039	52808	40567	19373
HYDROGRAPH AT	7	86120	83385	63050	31023
3 COMBINED	7	202396	201870	195779	134849
ROUTED TO	2	199261	198873	191766	133756
HYDROGRAPH AT	6	80062	77468	55231	27000
HYDROGRAPH AT	4	193071	187515	146292	73788
ROUTED TO	3	173310	169998	141264	73580
HYDROGRAPH AT	3	227981	224112	190664	108347
2 COMBINED	3	288290	286461	261218	153019
ROUTED TO	2	280807	279240	255912	152654
HYDROGRAPH AT	5	177219	174568	151181	86251
HYDROGRAPH AT	2	167530	162671	119635	62599
4 COMBINED	2	378638	375645	341845	234443
ROUTED TO	1	354100	352570	333319	231980
HYDROGRAPH AT	1	195160	190571	150126	82832
2 COMBINED	1	354100	352820	336090	252032

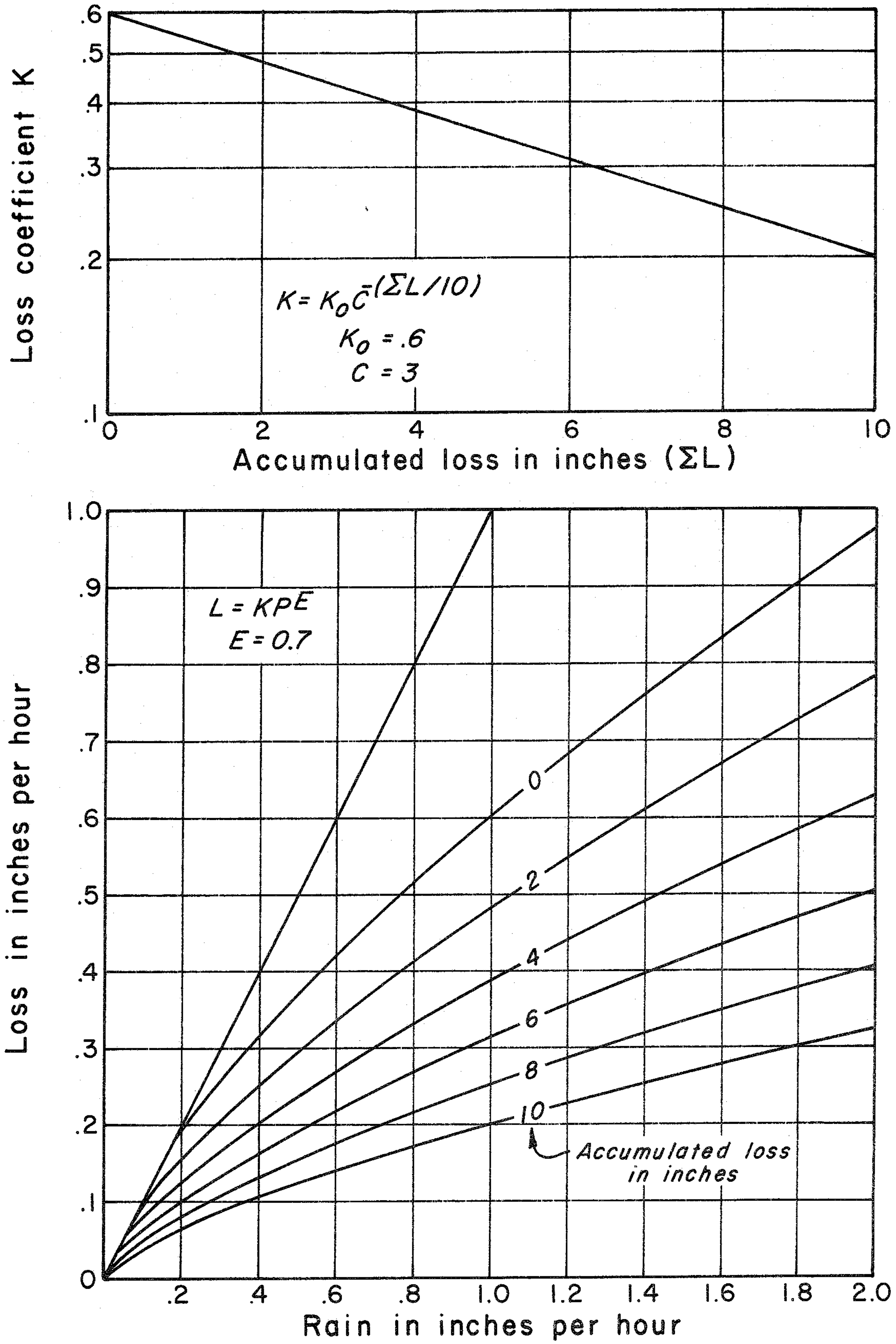


Figure 1
EXAMPLE OF LOSS FUNCTION

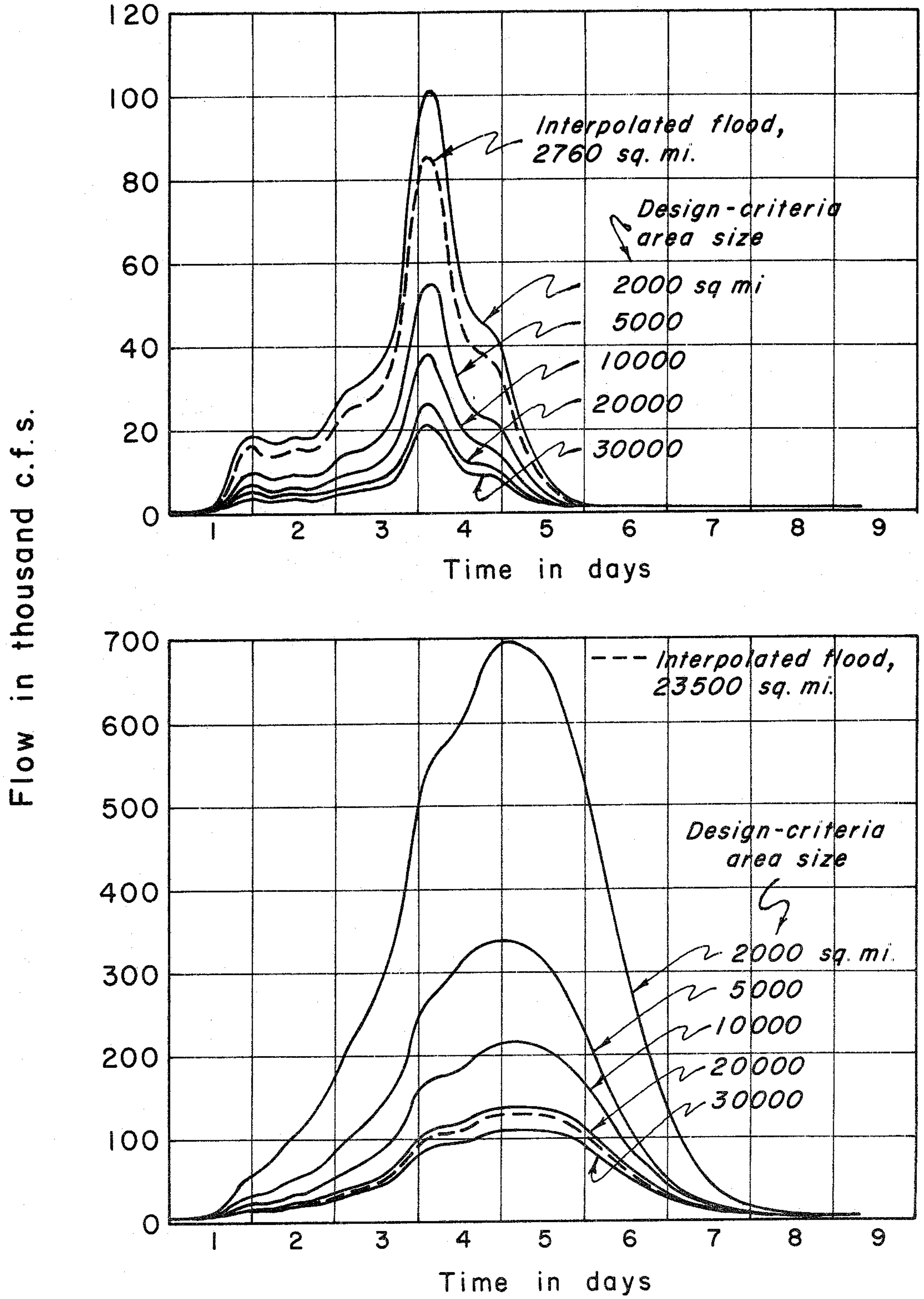


Figure 2

EXAMPLE OF MULTIPLE FLOOD INTERPOLATION

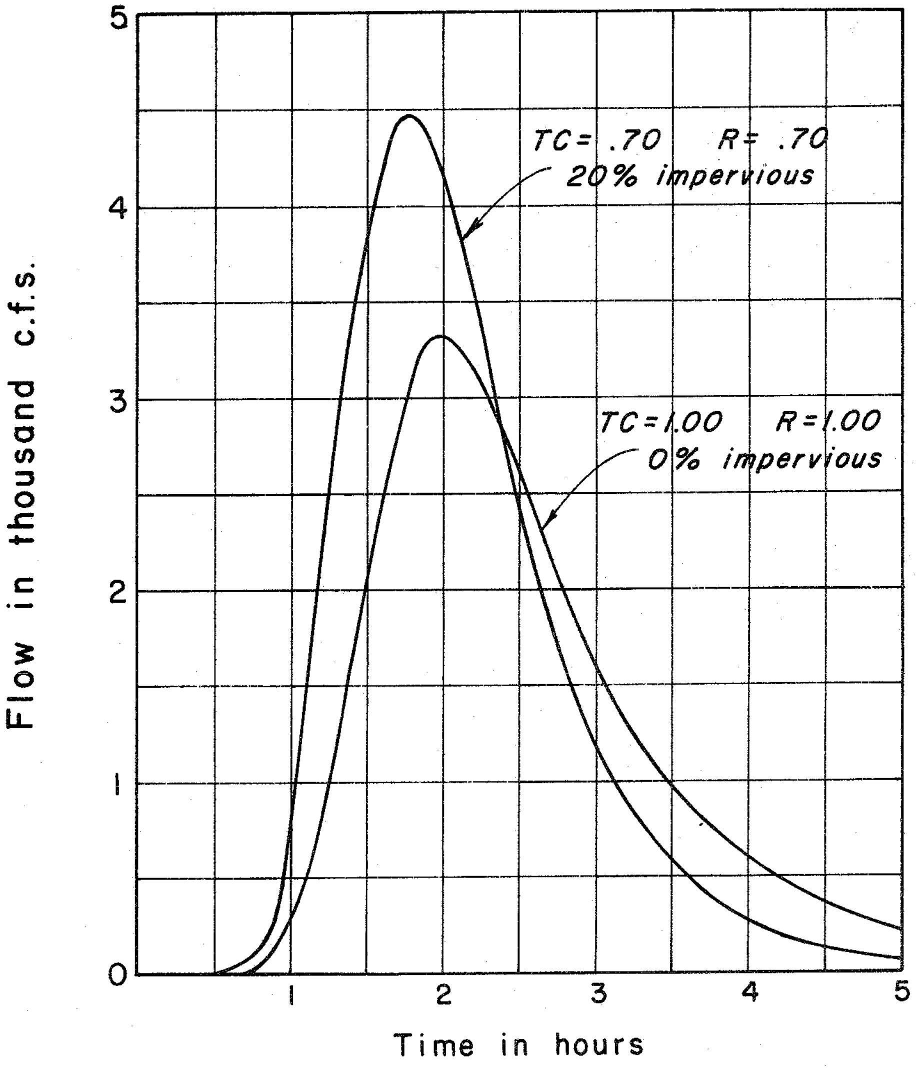
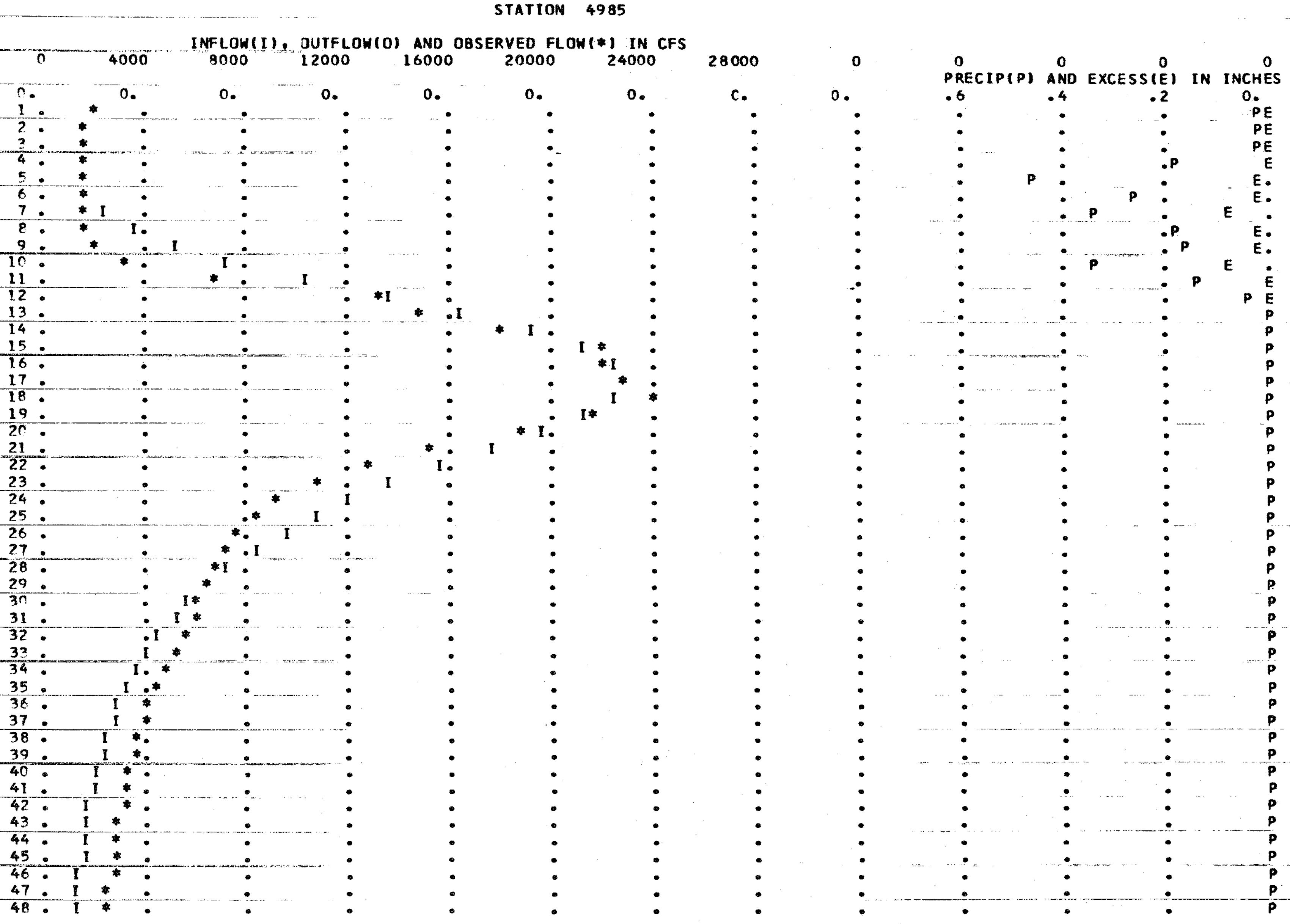


Figure 3

EXAMPLE OF
URBANIZATION EFFECT

Figure 4

EXAMPLE OF PLOTTING



Technical Paper Series

TP-1	Use of Interrelated Records to Simulate Streamflow
TP-2	Optimization Techniques for Hydrologic Engineering
TP-3	Methods of Determination of Safe Yield and Compensation Water from Storage Reservoirs
TP-4	Functional Evaluation of a Water Resources System
TP-5	Streamflow Synthesis for Ungaged Rivers
TP-6	Simulation of Daily Streamflow
TP-7	Pilot Study for Storage Requirements for Low Flow Augmentation
TP-8	Worth of Streamflow Data for Project Design - A Pilot Study
TP-9	Economic Evaluation of Reservoir System Accomplishments
TP-10	Hydrologic Simulation in Water-Yield Analysis
TP-11	Survey of Programs for Water Surface Profiles
TP-12	Hypothetical Flood Computation for a Stream System
TP-13	Maximum Utilization of Scarce Data in Hydrologic Design
TP-14	Techniques for Evaluating Long-Tem Reservoir Yields
TP-15	Hydrostatistics - Principles of Application
TP-16	A Hydrologic Water Resource System Modeling Techniques
TP-17	Hydrologic Engineering Techniques for Regional Water Resources Planning
TP-18	Estimating Monthly Streamflows Within a Region
TP-19	Suspended Sediment Discharge in Streams
TP-20	Computer Determination of Flow Through Bridges
TP-21	An Approach to Reservoir Temperature Analysis
TP-22	A Finite Difference Methods of Analyzing Liquid Flow in Variably Saturated Porous Media
TP-23	Uses of Simulation in River Basin Planning
TP-24	Hydroelectric Power Analysis in Reservoir Systems
TP-25	Status of Water Resource System Analysis
TP-26	System Relationships for Panama Canal Water Supply
TP-27	System Analysis of the Panama Canal Water Supply
TP-28	Digital Simulation of an Existing Water Resources System
TP-29	Computer Application in Continuing Education
TP-30	Drought Severity and Water Supply Dependability
TP-31	Development of System Operation Rules for an Existing System by Simulation
TP-32	Alternative Approaches to Water Resources System Simulation
TP-33	System Simulation of Integrated Use of Hydroelectric and Thermal Power Generation
TP-34	Optimizing flood Control Allocation for a Multipurpose Reservoir
TP-35	Computer Models for Rainfall-Runoff and River Hydraulic Analysis
TP-36	Evaluation of Drought Effects at Lake Atitlan
TP-37	Downstream Effects of the Levee Overtopping at Wilkes-Barre, PA, During Tropical Storm Agnes
TP-38	Water Quality Evaluation of Aquatic Systems
TP-39	A Method for Analyzing Effects of Dam Failures in Design Studies
TP-40	Storm Drainage and Urban Region Flood Control Planning
TP-41	HEC-5C, A Simulation Model for System Formulation and Evaluation
TP-42	Optimal Sizing of Urban Flood Control Systems
TP-43	Hydrologic and Economic Simulation of Flood Control Aspects of Water Resources Systems
TP-44	Sizing Flood Control Reservoir Systems by System Analysis
TP-45	Techniques for Real-Time Operation of Flood Control Reservoirs in the Merrimack River Basin
TP-46	Spatial Data Analysis of Nonstructural Measures
TP-47	Comprehensive Flood Plain Studies Using Spatial Data Management Techniques
TP-48	Direct Runoff Hydrograph Parameters Versus Urbanization
TP-49	Experience of HEC in Disseminating Information on Hydrological Models
TP-50	Effects of Dam Removal: An Approach to Sedimentation
TP-51	Design of Flood Control Improvements by Systems Analysis: A Case Study
TP-52	Potential Use of Digital Computer Ground Water Models
TP-53	Development of Generalized Free Surface Flow Models Using Finite Element Techniques
TP-54	Adjustment of Peak Discharge Rates for Urbanization
TP-55	The Development and Servicing of Spatial Data Management Techniques in the Corps of Engineers
TP-56	Experiences of the Hydrologic Engineering Center in Maintaining Widely Used Hydrologic and Water Resource Computer Models
TP-57	Flood Damage Assessments Using Spatial Data Management Techniques
TP-58	A Model for Evaluating Runoff-Quality in Metropolitan Master Planning
TP-59	Testing of Several Runoff Models on an Urban Watershed
TP-60	Operational Simulation of a Reservoir System with Pumped Storage
TP-61	Technical Factors in Small Hydropower Planning
TP-62	Flood Hydrograph and Peak Flow Frequency Analysis
TP-63	HEC Contribution to Reservoir System Operation
TP-64	Determining Peak-Discharge Frequencies in an Urbanizing Watershed: A Case Study
TP-65	Feasibility Analysis in Small Hydropower Planning
TP-66	Reservoir Storage Determination by Computer Simulation of Flood Control and Conservation Systems
TP-67	Hydrologic Land Use Classification Using LANDSAT
TP-68	Interactive Nonstructural Flood-Control Planning
TP-69	Critical Water Surface by Minimum Specific Energy Using the Parabolic Method

TP-70	Corps of Engineers Experience with Automatic Calibration of a Precipitation-Runoff Model
TP-71	Determination of Land Use from Satellite Imagery for Input to Hydrologic Models
TP-72	Application of the Finite Element Method to Vertically Stratified Hydrodynamic Flow and Water Quality
TP-73	Flood Mitigation Planning Using HEC-SAM
TP-74	Hydrographs by Single Linear Reservoir Model
TP-75	HEC Activities in Reservoir Analysis
TP-76	Institutional Support of Water Resource Models
TP-77	Investigation of Soil Conservation Service Urban Hydrology Techniques
TP-78	Potential for Increasing the Output of Existing Hydroelectric Plants
TP-79	Potential Energy and Capacity Gains from Flood Control Storage Reallocation at Existing U.S. Hydropower Reservoirs
TP-80	Use of Non-Sequential Techniques in the Analysis of Power Potential at Storage Projects
TP-81	Data Management Systems of Water Resources Planning
TP-82	The New HEC-1 Flood Hydrograph Package
TP-83	River and Reservoir Systems Water Quality Modeling Capability
TP-84	Generalized Real-Time Flood Control System Model
TP-85	Operation Policy Analysis: Sam Rayburn Reservoir
TP-86	Training the Practitioner: The Hydrologic Engineering Center Program
TP-87	Documentation Needs for Water Resources Models
TP-88	Reservoir System Regulation for Water Quality Control
TP-89	A Software System to Aid in Making Real-Time Water Control Decisions
TP-90	Calibration, Verification and Application of a Two-Dimensional Flow Model
TP-91	HEC Software Development and Support
TP-92	Hydrologic Engineering Center Planning Models
TP-93	Flood Routing Through a Flat, Complex Flood Plain Using a One-Dimensional Unsteady Flow Computer Program
TP-94	Dredged-Material Disposal Management Model
TP-95	Infiltration and Soil Moisture Redistribution in HEC-1
TP-96	The Hydrologic Engineering Center Experience in Nonstructural Planning
TP-97	Prediction of the Effects of a Flood Control Project on a Meandering Stream
TP-98	Evolution in Computer Programs Causes Evolution in Training Needs: The Hydrologic Engineering Center Experience
TP-99	Reservoir System Analysis for Water Quality
TP-100	Probable Maximum Flood Estimation - Eastern United States
TP-101	Use of Computer Program HEC-5 for Water Supply Analysis
TP-102	Role of Calibration in the Application of HEC-6
TP-103	Engineering and Economic Considerations in Formulating
TP-104	Modeling Water Resources Systems for Water Quality
TP-105	Use of a Two-Dimensional Flow Model to Quantify Aquatic Habitat
TP-106	Flood-Runoff Forecasting with HEC-1F
TP-107	Dredged-Material Disposal System Capacity Expansion
TP-108	Role of Small Computers in Two-Dimensional Flow Modeling
TP-109	One-Dimensional Model for Mud Flows
TP-110	Subdivision Froude Number
TP-111	HEC-5Q: System Water Quality Modeling
TP-112	New Developments in HEC Programs for Flood Control
TP-113	Modeling and Managing Water Resource Systems for Water Quality
TP-114	Accuracy of Computer Water Surface Profiles - Executive Summary
TP-115	Application of Spatial-Data Management Techniques in Corps Planning
TP-116	The HEC's Activities in Watershed Modeling
TP-117	HEC-1 and HEC-2 Applications on the Microcomputer
TP-118	Real-Time Snow Simulation Model for the Monongahela River Basin
TP-119	Multi-Purpose, Multi-Reservoir Simulation on a PC
TP-120	Technology Transfer of Corps' Hydrologic Models
TP-121	Development, Calibration and Application of Runoff Forecasting Models for the Allegheny River Basin
TP-122	The Estimation of Rainfall for Flood Forecasting Using Radar and Rain Gage Data
TP-123	Developing and Managing a Comprehensive Reservoir Analysis Model
TP-124	Review of U.S. Army corps of Engineering Involvement With Alluvial Fan Flooding Problems
TP-125	An Integrated Software Package for Flood Damage Analysis
TP-126	The Value and Depreciation of Existing Facilities: The Case of Reservoirs
TP-127	Floodplain-Management Plan Enumeration
TP-128	Two-Dimensional Floodplain Modeling
TP-129	Status and New Capabilities of Computer Program HEC-6: "Scour and Deposition in Rivers and Reservoirs"
TP-130	Estimating Sediment Delivery and Yield on Alluvial Fans
TP-131	Hydrologic Aspects of Flood Warning - Preparedness Programs
TP-132	Twenty-five Years of Developing, Distributing, and Supporting Hydrologic Engineering Computer Programs
TP-133	Predicting Deposition Patterns in Small Basins
TP-134	Annual Extreme Lake Elevations by Total Probability Theorem
TP-135	A Muskingum-Cunge Channel Flow Routing Method for Drainage Networks
TP-136	Prescriptive Reservoir System Analysis Model - Missouri River System Application
TP-137	A Generalized Simulation Model for Reservoir System Analysis
TP-138	The HEC NexGen Software Development Project
TP-139	Issues for Applications Developers
TP-140	HEC-2 Water Surface Profiles Program
TP-141	HEC Models for Urban Hydrologic Analysis

TP-142	Systems Analysis Applications at the Hydrologic Engineering Center
TP-143	Runoff Prediction Uncertainty for Ungauged Agricultural Watersheds
TP-144	Review of GIS Applications in Hydrologic Modeling
TP-145	Application of Rainfall-Runoff Simulation for Flood Forecasting
TP-146	Application of the HEC Prescriptive Reservoir Model in the Columbia River Systems
TP-147	HEC River Analysis System (HEC-RAS)
TP-148	HEC-6: Reservoir Sediment Control Applications
TP-149	The Hydrologic Modeling System (HEC-HMS): Design and Development Issues
TP-150	The HEC Hydrologic Modeling System
TP-151	Bridge Hydraulic Analysis with HEC-RAS
TP-152	Use of Land Surface Erosion Techniques with Stream Channel Sediment Models
TP-153	Risk-Based Analysis for Corps Flood Project Studies - A Status Report
TP-154	Modeling Water-Resource Systems for Water Quality Management
TP-155	Runoff simulation Using Radar Rainfall Data
TP-156	Status of HEC Next Generation Software Development
TP-157	Unsteady Flow Model for Forecasting Missouri and Mississippi Rivers
TP-158	Corps Water Management System (CWMS)
TP-159	Some History and Hydrology of the Panama Canal
TP-160	Application of Risk-Based Analysis to Planning Reservoir and Levee Flood Damage Reduction Systems
TP-161	Corps Water Management System - Capabilities and Implementation Status