US Army Corps
of Engineers
Hydrologic Engineering Center

Reservoir Storage Determination by Computer Simulation of Flood Control and Conservation Systems

September 1979

TP-66

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* September 1979	**2. REPORT TYPE** Technical Paper	**3. DATES COVERED** *(From - To)*

4. TITLE AND SUBTITLE Reservoir Storage Determination by Computer Simulation of Flood Control and Conservation Systems	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Bill S. Eichert	**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-66
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 International Symposium on Specific Aspects of Hydrological Computation for Water Projects, Leningrad, USSR, September 1979.

14. ABSTRACT
The paper presents ways that a comprehensive simulation computer program (HEC-5) can be used in planning a water resources system composed primarily of multipurpose reservoir with flood control as a major project purpose. In addition, techniques for determining reservoir storage requirements for flood control, water supply and hydropower are presented.

15. SUBJECT TERMS
simulation, flood control, reservoirs, mathematical models, water supply, hydropower, rule curve, system analysis

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	UU	16	**19b. TELEPHONE NUMBER**

Reservoir Storage Determination by Computer Simulation of Flood Control and Conservation Systems

September 1979

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-66

RESERVOIR STORAGE DETERMINATION BY COMPUTER [1]
SIMULATION OF FLOOD CONTROL AND CONSERVATION SYSTEMS

by Bill S. Eichert[2]

INTRODUCTION

This paper presents ways that a comprehensive simulation computer program can be used in planning a water resources system composed primarily of multipurpose reservoirs with flood control as a major project purpose. The computer program HEC-5, Simulation of Flood Control and Conservation Systems, will be used to illustrate the ways in which a generalized computer program can be applied to a wide variety of reservoir systems. The HEC-5 model can be used in almost any reservoir system regardless of location, project purposes, and physical conditions in the basin by specifying as input data such items as the configuration of the reservoirs in the basin, the project purposes, streamflow data, channel routing criteria, evaporation data, etc.

OVERVIEW OF SIMULATION MODEL

The model HEC-5 as described in the users manual (reference 1), is a simulation model that can simulate the operation of a system of reservoirs for both flood control and conservation purposes. The operation for flood control is based on evacuating the seasonal flood control space in each

---

[1]Presented at International Symposium on Specific Aspects of Hydrological Computation for Water Projects, Leningrad, USSR, September 1979.

[2]Director, The Hydrologic Engineering Center, U.S. Army Corps of Engineers, 609 Second Street, Suite D, Davis, California 95616, USA.

reservoir as soon as possible without causing flooding at specified downstream locations. This type of operation is possible of course only if the flood control outlets are gated. Where a choice exists about which reservoir should release the most water, the decision is made based on balancing the storage within the reservoirs among themselves according to a prespecified set of storage levels input to the model. The release decisions are complex because of the streamflow routing effects which cause the releases for a given time period to be spread out over many future periods.

The conservation operation is based upon releasing water to supply all specified requirements for flow (and energy for hydropower sites) at all locations in the basin without wasting any water. Where a choice exists about which reservoir should be drawn down the most, the decision is based on balancing the storage within the reservoirs among themselves using the same set of storage levels as in the flood control operation.

The program has the capability of using any computational time interval from one hour to one month for a given flood or time sequence. It also has the ability to combine time sequences that have different computational time intervals so that monthly computations can be performed during non-flood periods and short interval routings (daily or multi-hourly) can be used during flood periods.

While the program is primarily a hydrologic simulation tool, it also has economic evaluation capabilities for determining flood control and hydropower benefits (see references 2 and 3). Economic evaluation capabilities for flood control include flood damage, flood damage reduction, benefit-costs ratios, and net benefits. The benefits for operating for hydropower are based on input unit prices for primary and secondary energy plus a penalty for shortages in primary energy. Other conservation benefit evaluation capabilities are planned for future additions.

Selection of the best location and size of each project must be accomplished by using the model to simulate alternative systems separately based on a structured strategy formulation (reference 6), knowledge of the system and objectives, public input, and plain sound judgment which is required to reduce the number of such alternative systems to a reasonable number. The use of operation research techniques has, thus far, not proven to be widely useful because of the complexities of water resources systems and noncommensurate objectives in water resource management.

CRITERIA FOR STORAGE SELECTION

The determination of the amount of reservoir storage for a specified purpose such as flood control is based on hydrologic analyses that are governed by project formulation criteria. While project formulation criteria are beyond the scope of this paper, the guiding formulation principles in most free enterprise countries are generally that the project, with the specified amount of storage, must be economically justified (benefit/cost ratio must exceed one), the project should be formulated to the extent practical to maximize net economic benefits, and the project should not result in significantly increased flood hazards for any flood event, especially one that would exceed the design capacity of the reservoir system (see reference 4). Projects with conservation storage should also provide a reasonable guarantee (probability) of dependable water supply from the reservoirs.

The usual procedure for determining the location and size of the projects in a system is based on selecting and analyzing projects (including economic and environmental analyses) of various sizes and locations which will provide different degrees of protection for flood control and different amounts of firm energy and yields for hydropower and water supply, respectively. Determination of system or project flood control storage is usually done separately from the conservation storage determination.

FLOOD CONTROL STORAGES

Flood control studies are usually initiated by determining reservoir sites for several alternative systems that can provide a reasonable level of protection (in many instances full protection against the largest historical flood is initially assumed) to the communities affected by extensive flood damages. The better systems, and thus the selected reservoir sites, can be determined by using a computer program such as HEC-5 that will simulate the detailed hydrologic operation of each system and provide the estimated flood damages with and without the system in place (see references 5 and 6). The system is usually operated for all major historical floods, and then an estimate of the basin-wide expected annual flood damages (EAD) is computed. Where study funds are limited, a few historical and/or synthetic floods (and ratios of those floods to reflect a broad range of flood event magnitudes) can be used to estimate the EAD. Once the best system is obtained, each project can then be easily deleted in turn from the model to determine if each reservoir is justified on a "last added" basis. One data model for the HEC-5 program can be constructed for all the above studies if all the potential sites are included initially. The specific system to be evaluated can then be specified by a single card which specified which reservoirs are to be deleted from the system.

The initial amount of flood control storage in each selected site is usually tested by selecting and evaluating several acceptable alternative levels of protection and by evaluating the benefits and costs of the system for each. The size is then based on the principle of maximizing net benefits as long as an acceptable degree of protection is provided and that social and environmental concerns are acceptably addressed or compensated.

WATER SUPPLY STORAGE

An additional criterion used in the selection of reservoir water supply storage is that the supply must be reasonably dependable. In the United States, the criterion for dependable is usually that the project must be able to provide the stated dependable yield through a recurrence of the most severe critical drought of record. Very few projects in the United States have been designed using stochastic flows instead of historical flows. The limited use of models to generate synthetic flows even for monthly periods (see reference 7) is due in large part to deficiencies in the models for reproducing droughts in many locations as severe as some recorded droughts. Most water supply studies are for single reservoirs operating to satisfy seasonal requirements for water at the dam and at a nearby downstream location, although many system studies for irrigation and water supply have been conducted.

The HEC-5 model can be used to determine the reservoir storage requirements for various conservation purposes using the same basic data model as constructed for flood control purposes. Additional data will have to be added to the model, such as evaporation rates and flow requirements for conservation purposes. The flow data cards for non-flood events will be substituted for or added to the flood flow data cards.

Most conservation studies initially ignore flood control operations, and use monthly flows for the period of record. Thus the conservation studies are conducted to determine how much reservoir storage is required to supply the estimated demands on the system. If the demands exceed the available yield then the project is sized to produce the maximum yield that will meet the required economic, social, and environmental concerns while still maintaining a reasonable drawdown period (not to exceed 7-10 years).

For determining reservoir sites and amounts of storage in meeting system demands, the program is used in an iterative fashion, similar to the flood control situation. Several alternative reservoir systems are selected along with the conservation storage to be used in each reservoir. Several simulation runs of the program are then made for each alternative system to determine the minimum amount of storage required to supply all conservation requirements including hydropower. The selection of the best system is then based on non-hydrologic criteria, since each of the feasible alternative solutions has been developed to provide the specified yields with an acceptable degree of reliability.

Prior to the start of the system runs, it may be useful to use the program on each reservoir individually in order to determine how much conservation storage would be required to provide certain fixed demands on the project or conversely to determine the yields that can be expected from a certain amount of conservation storage. The HEC-5 program does have routines in it to automatically determine the maximum yields given the storage, or the storage based on fixed yields. The yields can include seasonally varying water supply demands at or below the reservoir and seasonal hydropower energy demands. The optimized storage can also vary seasonally.

HYDROPOWER STORAGE

Storage requirements for hydropower projects are determined in a similar manner to other conservation purposes. Use of the HEC-5 program can be made for single projects as well as for systems of reservoirs.

The determination of the storage requirement for a single reservoir can be automatically made with the model based on supplying a prescribed seasonal energy demand schedule for the reservoir. The firm annual energy from a fixed amount of storage can also be determined automatically by the program.

System energy requirements can be supplied for a reservoir system which includes several power reservoirs. These requirements are met in addition to the normally reduced individual project energy requirements by drafting water from the power projects to keep them in balance with each other as prescribed by user input target storage levels. The system energy requirements are developed, for that part of the regional energy load that is to be provided by hydropower projects, using a series of simulations of the system by the HEC-5 model. The system hydropower energy requirements are normally changed by the user until the power system storage is exhausted during the most critical period of historical streamflow.

Pumped storage projects can be simulated by the model with or without other reservoirs. One recent simulation was for a system of three power reservoirs in series operating as a system with the middle reservoir having reversible turbines. The operation of this system was made on a daily basis for the period of record (about 20 years) and an hourly operation was made for several selected weekly periods (see reference 8).

RULE CURVE OPERATION

The use of seasonal rule curves to allow the use of flood control storage for conservation purposes during certain seasons when the need for flood control is reduced is very beneficial in certain geographical locations. The computer model HEC-5 can be used to develop these rule curves, but each attempt to improve the rule curves requires a new system simulation of the hydrologic and economic consequences of that change.

MULTIPURPOSE OPERATION

Once the reservoir sites are established and the approximate conservation storage determined on a monthly basis, the same data model can be used to simulate the operation for both flood control and conservation purposes. A single time step may be selected for the routing, such as using daily flows for the period of streamflow record or a combination of flow time sequences can be used such as using monthly flows during the non-flood periods and daily or multihourly routing during the flood period. The long multipurpose routing can be useful for firming up project storages and for providing useful information on duration and frequency of various hydrologic variables such as flows, reservoir storages, energy production, etc.

CONCLUSIONS

The use of a computer model such as HEC-5 allows the detailed simulation of the hydrologic and economic consequences of a system of reservoirs and is a major improvement over previous techniques that required detailed sequential routings by hand methods. Nevertheless, the general problem of sizing and siting multipurpose reservoir system is so complex and each application has so many combinations of potential solutions that it is impossible to ever get the optimum system. The determination of a near optimum solution is still greatly dependent upon the ability of the engineer to organize and follow a systematic approach in developing alternative system configurations and performance criteria that can be used to satisfy water management needs. The future role that operation research techniques can play in screening these potential solutions into a manageable number of alternatives is still very much in doubt. With the strong current public sentiment in many countries against designing and constructing reservoir systems, the future for major progress in this area seems bleak.

REFERENCES

1. U.S. Army Corps of Engineers, Hydrologic Engineering Center, "HEC-5, Simulation of Flood Control and Conservation Systems - Users Manual," March 1979.

2. Eichert, B.S., "HEC-5C, A Simulation Model for System Formulation and Evaluation," U.S. Army Corps of Engineers, Hydrologic Engineering Center, Technical Paper 41, March 1974.

3. Eichert, B.S., "Hydrologic and Economic Simulation of Flood Control Aspects of Water Resource Systems," U.S. Army Corps of Engineers, Hydrologic Engineering Center, Technical Paper 43, August 1975.

4. Eichert, B.S., and D.W. Davis, "Sizing Flood Control Reservoir Systems by System Analysis," U.S. Army Corps of Engineers, Hydrologic Engineering Center, Technical Paper 44, March 1976.

5. Eichert, B.S., J.C. Peters, and A.F. Pabst, "Techniques for Real-Time Operation of Flood Control Reservoirs in the Merrimack River Basin," U.S. Army Corps of Engineers, Hydrologic Engineering Center, Technical Paper 45, November 1975.

6. Johnson, W.K., and D.W. Davis, "Analysis of Structural and Nonstructural Flood Control Measures Using Computer Program HEC-5C," U.S. Army Corps of Engineers, Hydrologic Engineering Center, Training Document No. 7, November 1975.

7. U.S. Army Corps of Engineers, Hydrologic Engineering Center, "HEC-4, Monthly Streamflow Simulation, Users Manual," February 1971.

8. McMahon, G.F., V. Bonner, and B.S. Eichert, "Operational Simulation of the Reservoir System with Pumped Storage,"U.S. Army Corps of Engineers, Hydrologic Engineering Center, Technical Paper 60, February 1979.

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