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Foreword

Hydrologic engineering is a critical element in planning and evaluating flood damage reduction measures and actions. Successful study completion of the hydrologic analysis requires management of time, money and human resources. The hydrologic engineering study products must satisfy study team and project sponsor needs. It is important to plan the technical work at the beginning of the study for effective and efficient implementation. Development of a hydrologic engineering management plan for the study is a crucial first step towards accomplishing these objectives. This document describes activities required to design and prepare a hydrologic engineering management plan for a Corps water resources investigation. It is intended that such plans be used as a basis for determining firm estimates of hydrologic engineering study resources and as a technical guide throughout the conduct of the study.

FOR THE COMMANDER:

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U.S. Army Corps of Engineers
Washington, DC 20314-1000

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Engineering and Design
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Table of Contents

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Engineering and Design
HYDROLOGIC ENGINEERING STUDIES DESIGN

Chapter 1
Introduction

1-1. Purpose

a. Current planning and management guidance for civil works studies requires careful technical activity management. Hydrologic engineering is a critical item, especially for feasibility investigations.

b. Successful study completion requires management of time, money, and human resources to accomplish the necessary technical studies in an effective manner. Hydrologic engineering study products must satisfy study team and project sponsor needs. The technical studies must also be completed within available financial resources. It is important to plan the technical work at the beginning of the study to accomplish these requirements. Development of a hydrologic engineering management plan (HEMP) for the study is a crucial first step towards accomplishing these objectives. This document describes activities necessary to design and prepare a HEMP for a Corps water resource investigation.

1-2. Applicability

a. This pamphlet is applicable to HQUSACE elements, major subordinate commands, districts, laboratories, and separate field operating activities having civil works responsibilities in the hydrology and hydraulics fields.

b. The term hydrologic engineering is used throughout this engineer pamphlet (EP) to encompass activities in hydrology, hydraulics, water control management, sediment analyses, water quality, or other water-related elements addressed in a Corps water resource investigation. Similarly, the hydrologic engineering management plan includes all activities in these disciplines. The HEMP is intended to include the terms "hydraulic study work plan" and "sediment study work plan" used in other engineering manuals and publications.

1-3. References

Appendix A lists references that should be reviewed for various types of water resource investigations and reporting levels. A list of frequently used acronyms is provided in Appendix B.

Chapter 2
The Hydrologic Engineering Management Plan

2-1. General

The HEMP is a technical outline of the hydrologic engineering studies necessary to formulate a solution to a water resource problem. A HEMP could be an initial or detailed work outline. An initial HEMP is developed to define key issues and activities sufficient to address study time and cost. A detailed HEMP outlines significant technical activities in sufficient detail for the responsible engineer to perform the analysis.

2-2. Use

The use of a hydrologic engineering management plan is threefold. It is the following:

a. Basis for firm time and cost estimates. Accurate estimates cannot be obtained without taking sufficient time to develop firm and justifiable estimates for the feasibility or the preconstruction engineering and design (PED) phase. The HEMP should reflect the hydrologic information needs of the study team and define the method of proceeding through the entire study process. Agreement between hydrologic engineering, planning, and project management on the study scope must be reached for an accurate cost estimate. The HEMP should be viewed as a contract to perform the stated work for the agreed-upon amounts of funds and time. Written records and daily or weekly logs of accomplishments are important to properly manage and track the study time and fund expenditures throughout the study.

b. Technical guide for the hydrologic engineer. Many feasibility-phase or PED investigations require two or more years of hydrologic engineering effort. Even an experienced hydrologic engineer cannot foresee all facets of a multi-year study without significant planning and input from others. A detailed technical outline allows work to be performed effectively and efficiently, without close supervision. The preparation and use of a HEMP provides inexperienced hydrologic engineers with a clearer understanding of the analysis procedures and reporting process. A HEMP provides the basis for meaningful discussion and negotiation and helps in making decisions on refinements and changes as the study progresses.

c. Review contract. The HEMP provides the contract that will be used to guide the review of the hydrologic engineering final project.

2-3. Personnel Involved

The HEMP is a hydrologic engineering document usually prepared by the principal engineer for the study. It is not required or approved by other disciplines, but must incorporate information needs of all disciplines. The hydrologic engineer plays the most important role in its development, but others have input as well. They include:

a. Senior personnel--the HEMP may be prepared by an experienced engineer or a section chief to ensure that the time and cost estimates are adequate and that they address all study issues. Supervisors should review and critique the HEMP.

b. Project manager (PM)--discussions on the effect of the HEMP to the overall project schedule, cost, budget, and all other project processes should be held with the PM that is responsible for the progress of the project.

c. Planning technical manager--discussions with the planning technical manager on the alternatives to be addressed, level of detail, combinations of different alternatives, study milestone dates, and other pertinent information should be held, agreed upon, and incorporated into the HEMP.

d. Economist--the economist is important in establishing the type of analysis required. Significant agricultural damages require knowledge of the time of year and duration of the flood and typically use a continuous simulation analysis. A study area with primarily urban damages could use an event analysis. Information on damage reaches is necessary to estimate the location of hydrologic computation points to give stage-frequency information at designated damage centers. This type of information is required to perform risk-based analysis for project alternatives in close coordination with economists and all other team members.

e. Local sponsor--the sponsor almost always has useful hydrologic information on the study area. The sponsor may also have definite views on the type and size of flood damage alternatives most suitable for the investigation.

f. Cost engineer--the cost engineer must have hydrologic engineering design information in sufficient detail to prepare project costs.

g. Realty specialist--the real estate specialist needs stage-frequency, area inundated, project location, and other information to complete the analysis.

h. Other team members--structural, geotechnical, mechanical engineers, regulatory personnel, the recreational planner, and environmental specialist usually need specific information from the hydrologic engineer.

i. Review authority--controversial, complex, or costly hydrologic analyses should be discussed with Division and possibly HQUSACE hydrologic engineering personnel to confirm the approach and procedures proposed. This should be accomplished both informally and through the mandatory technical review conferences. These disciplines should be contacted, as necessary, during the reconnaissance-phase study to ascertain their needs and views on hydrologic information required for the feasibility-phase investigation.

2-4. HEMP

The HEMP should outline feasibility study hydrologic engineering activities to be included in the initial project management plan (IPMP), or the detailed project design needed in the project management plan (PMP). The HEMP should be prepared at the end of the reconnaissance study so that time and funds needed may be firmly estimated during the feasibility-phase study. It becomes part of the IPMP forming the basis for the Feasibility Cost-Shared Agreement (FCSA). Similarly, a HEMP is prepared at the end of the feasibility-phase study to establish hydrologic engineering time and costs necessary for PED. HEMPs are prepared during the feasibility phase, to detail all hydrologic engineering work necessary during feasibility, and during the PED phase for the balance of the hydrologic engineering effort. It is assumed throughout this document that both HEMPs will be prepared, but this does not mean that both are always required. In fact, if a detailed hydrologic engineering management plan can be developed at the end of the reconnaissance phase, it should be done. A sequence for developing hydrologic engineering management plans is shown in Figure 1.

Receive reconnaissance-phase study funding

Complete reconnaissance-phase study, with an economically justified solution found

Prepare HEMP for inclusion in IPMP

Submit reconnaissance-phase report

Receive feasibility-phase funding

Complete feasibility-phase study, with NED plan selected

Prepare HEMP for inclusion in PMP of PED-phase study; submit feasibility-phase study

Receive PED-phase study funding

Complete PED (design memorandum (DM), plans, and specs)

Construction

Figure 1. Sequence of hydrologic planning activities for Civil Works studies

Chapter 3
Scoping the Investigation

3-1. General

A preliminary assessment should be made to gain an understanding of the key issues and concerns to be addressed in the analysis. This assessment leads to an initial hydrologic engineering management plan, based on the main considerations of the study.

3-2. Study Objective

The major study objectives should be defined; flood damage reduction, navigation, water supply, environmental restoration, water control, hydropower, etc. Geographic scope of the study should be determined and key locations requiring hydrologic information specified. Preliminary hydrologic engineering requirements and strategies to accomplish these objectives may be postulated.

3-3. Type of Study

The type of study requires different levels of hydrologic planning, ranging from very little to extensive. The various studies for which a HEMP may be developed are described in the following paragraphs, with reconnaissance, feasibility, and preconstruction engineering and design comprising the usual path for most Corps studies.

a. Reconnaissance-phase study.

(1) Initial HEMP. An initial HEMP should be prepared to provide a cost estimate for the reconnaissance phase, which is 100 percent Federally funded. However, reconnaissance funds are usually obtained in advance of hydrologic engineering planning, as this phase emphasizes the use of existing studies and data to perform the hydrologic analysis. For this situation, a HEMP may be prepared and used as an internal document. If time and funding permit, establishing the without-project hydrology and hydraulics for the existing condition of the watershed is desirable.

(2) IPMP. An IPMP is the end result of a successful reconnaissance-phase study, which must include adequate technical hydrologic engineering information to successfully complete a feasibility cost-sharing agreement (FCSA) with the sponsor. The hydrologic engineering management plan must identify the major technical activities and establish time and cost estimates. The estimates are used in the initial project management plan to develop funding and scheduling required for the feasibility-phase investigation. An initial HEMP would normally be prepared at the end of the reconnaissance phase. Any complex or unusual technical hydrologic issues should be discussed at the technical review conference (TRC) required at the end of reconnaissance and included in the plan. An example of an initial hydrologic engineering management plan for a local protection project is shown in Appendix C.

b. Feasibility-phase study.

(1) Detailed HEMP. As soon as feasibility funding is received, the initial HEMP of the reconnaissance phase may be expanded to detail the hydrologic engineering activities for week-to-week use by the hydrologic engineer throughout the study. Technical studies are detailed so that work activity durations may be established, milestone dates set, etc. Examples of detailed HEMP's are shown in Appendices D, E, and F. This phase results in a feasibility report with a series of engineering appendices. The appendices are in sufficient detail to allow the work effort to generally proceed directly to the design memorandum phase.

(2) Project management plan. A project management plan is prepared at the end of the feasibility-phase study, assuming an economically justified project is recommended and a cost-sharing partner exists. It requires sufficient hydrologic engineering detail to scope, cost, and schedule the activities for the balance of preconstruction engineering and design. The PMP forms the basis for the project cooperation agreement (PCA) with the sponsor, to complete the detailed design and construct the project. The major hydrologic engineering activities for PED must be identified and cost estimates made for the project management plan. Figure 1 illustrates this phase.

c. Preconstruction engineering and design. The PED phase concentrates on the detailed design of the project. It would normally be expected to consist of one or more design documents and plans and specifications to construct the project.

(1) Design memoranda. The project should move directly from the feasibility phase to PED, with a design memorandum (DM) to establish the detailed technical design necessary to construct the project. Consequently, a detailed HEMP would be prepared at the start of PED to outline the balance of the technical hydrologic engineering effort. This detailed HEMP would build on the initial hydrologic engineering management plan prepared for the PMP. PED hydrologic activities often include physical

model testing, detailed hydraulic design, quantitative sediment transport analysis, two-dimensional flow analyse, etc., which provide the technical detail for final design of the project.

(2) Plans and specifications. The detailed HEMP prepared at the start of PED should include the hydrologic activities necessary for this phase of the project. Hydrologic engineering effort in the plans and specifications phase typically incorporates results of physical model tests into the hydraulic design, preparation of stage hydrographs to show potential high-water periods affecting construction, minor modifications in the hydraulic design based on the additional detailed topographic and soils data obtained, and any changes found in the site conditions.

d. Continuing authority. These studies are typically performed as a two-phase process: a reconnaissance report performed at Federal expense, followed by a cost-shared detailed project report.

(1) Reconnaissance. The reconnaissance phase of a continuing authority study is similar to a feasibility investigation. It is performed at 100-percent Federal expense under the continuing authorities program. A HEMP is prepared for the reconnaissance phase after receipt of funding. The HEMP would be similar to that of paragraph 3-3*a* to establish funding requirements for the reconnaissance-phase study.

(2) Detailed project report. The detailed project report (DPR) is equivalent to a feature design memorandum; therefore, a hydrologic engineering management plan similar to that needed for the PMP would be prepared at the end of the reconnaissance report, with a detailed HEMP formulated after receipt of detailed project report funding. The hydrologic engineering management sequence for continuing authority studies is illustrated in Figure 2.

e. Regulatory. An assessment of the impact of a proposal is necessary to obtain a permit for project construction in the floodplain. The hydrologic information needed to submit the permit for Corps projects should be readily available from previous work. A hydrologic engineering management plan for regulatory purposes should seldom be necessary.

f. Water control. Establishing a water control plan for a new project or updating an existing plan for new or changed purposes represents a major hydrologic engineering effort. The plan is described in a water control manual. Funding is usually from the operation and maintenance (O&M) program for an existing project. General investigations funding (reconnaissance and feasibility) is appropriate for analyzing the addition of new project purposes to an existing project. A HEMP is necessary to establish time and cost estimates for O&M funding. A detailed hydrologic engineering management plan is prepared for technical activities after receipt of funding. Hydrologic engineering funding for water control activities for a new project should be included with the HEMP for the PED-phase work effort.

g. Water supply. These investigations normally concentrate on potential reservoir storage reallocation for

Initial funding

Prepare HEMP for reconnaissance study

Receive funding for reconnaissance-phase study

Complete reconnaissance report, with an economically justified project resulting

Prepare HEMP for detailed project report study

Receive detailed project report funding

Complete detailed project report

Prepare plans and specs, construct project

Figure 2. Sequence of hydrologic planning activities for continuing authority studies

water supply or for drought operation planning. A two-phase planning process (reconnaissance and feasibility) would be followed for reservoir reallocation studies, with the HEMP requirements similar to those described in paragraphs 2-3*a* and *b*. Drought operation planning is usually done for an existing project with O&M funding. A HEMP would be necessary for accurate estimates.

3-4. Key Items to Evaluate

a. Major issues. The HEMP must outline the information and methods necessary to address the major issues of the hydrologic engineering study. Methods and procedures needed to address complex or precedent-setting problems, sensitive environmental concerns, use of outside consultants (including Corps labs), local sponsor requirements, the need for new physical or analytical model development, adverse effects caused by a potential project, etc., would be scoped for budgeting purposes.

b. Level of detail. Although the study phase will usually establish the overall level of detail, the interdisciplinary planning team must be queried to obtain their ideas on the hydrologic information they need. However, the hydrologic engineering effort often plays the largest role in determining the level of detail. Depending on the appropriate study costs, several iterations between the hydrologic engineer and the study team may be necessary to establish a level of detail commensurate with the level of study funding. The development of a detailed plan, prepared at the start of the study, should result in a more efficient and effective progression of the study. Adequate planning at the start of the study may result in lower overall hydrologic engineering costs.

c. Hydrologic information availability and requirements. Databases would be examined to determine the rainfall, streamflow, topographic, and other records available for the particular study. The need for establishing a limited data collection program to address the objectives of the study would be determined. Existing Federal and non-Federal projects (reservoirs, levees, water withdrawals, etc.) affecting the analysis would be determined.

d. Unusual features.

(1) Items requiring additional engineering effort. Items peculiar to the study area that require additional hydrologic engineering effort must be addressed, especially if the work is necessary in the feasibility investigation.

(a) Flat slopes and wide floodplains could require a one- or two-dimensional unsteady flow analysis, resulting in significant higher study costs compared to using simpler models.

(b) Major quantitative sedimentation investigations may be necessary to firmly establish project feasibility. Reservoirs and extensive channel modifications may require significant quantitative sediment investigations during the feasibility phase.

(c) Physical model testing may be required during feasibility to ensure the workability of a project, such as locating a replacement lock away from the main navigation channel or designing a super-critical flow channel for a highly populated area.

(d) Lake stage-frequency analysis in closed basins, that do not drain to a downstream watershed.

(e) Major groundwater, snow hydrology, water quality, or other investigations.

(f) Complex reservoir system problems in which political or environmental issues mandate extensive and unusual systems modeling.

(g) Unstable rating relationships, complex interior flood control studies, multi-reservoir analyses, and other difficult water resource analyses must be recognized and evaluated during the early planning process leading to a HEMP.

(2) Peer review. Studies having unusual features and complex analyses may benefit from peer review. HQUSACE has established a peer review procedure through the HQUSACE-sponsored Hydrology Committee, with membership consisting of selected senior hydraulic engineers from Districts and Divisions. The Hydrology Committee will meet with District personnel to review the study/project and offer suggestions on the District's plan of analysis. The District incurs no cost for committee participation. Separate committees on Channel Stabilization, Tidal Hydraulics, and Water Quality are also available for assistance on unusual features in these areas. ER 15-2-14 further describes these four committees.

e. Study boundaries. The HEMP must distinguish between study boundaries and project boundaries in the development of estimates. Project effects often extend far upstream and downstream on the main stem of the study stream, as well as up tributaries. Proposed projects may change the flood hydrology and sediment regime throughout the watershed, not just near the proposed project. Changes in water control management practices at Corps reservoirs can also affect interests remote from the reservoir site. The hydrologic analysis must include the evaluation of all positive and negative effects of a potential project or water control management change throughout the stream system or study area.

f. Likely alternatives. The screening process used in the reconnaissance phase should result in a reduced number of alternatives to evaluate in detail for determination of the national economic development (NED) plan during the feasibility phase. The HEMP will include the most practical alternative(s) or combinations of alternatives to estimate the cost of the hydrologic engineering work effort. The major with-project scenarios must be developed by the study team for both preliminary and final scoping of the technical activities. The no-action case must also be determined for comparison to the with-project alternatives. Similarly, agreement should be reached among study team members, during the HEMP preparation, concerning the number of iterations (or sizes) to be evaluated for each alternative. Three or four sizes for each of two or three alternatives should be adequate for most studies.

3-5. Major Hydrologic Engineering Activities Required

The Corps typically assesses with- and without-alternative conditions for the main study objective(s).

a. Flood damage reduction. The HEMP should describe or reference the major study components: watershed hydrology, river hydraulics, frequency analysis, sedimentation analysis, storage operation, hydraulic design, etc., for both the with and without alternative condition. Analysis will often involve discrete events, either actual or, more typically, hypothetical, and will include development of uncertainty relationships for risk-based analysis. ER 1105-2-100 contains additional information in this area.

b. Water control management. The HEMP should describe or reference the major study components: flood control capabilities, storage allocated for various project purposes, drought augmentation, operational analyses, data systems, forecasting, etc., for the existing and proposed method of regulation. Analyses usually involve discrete events and continuous record techniques. ER 1110-2-240 and EM 1110-2-3600 contain additional information in this area.

c. Water supply investigations. The HEMP should describe or reference the major study components: existing project purposes and storage allocations of each, upstream and downstream demands, supply analysis, hydraulic data (uniform database), drought frequency analysis (volumes and durations), distribution system (pumping, conveyance, and storage), etc., for the existing and proposed reallocation of reservoir storage. Analysis may be for one or more severe droughts, although the full period of record can be used, similar to water control management methods. ER 1110-2-241 and ER 1110-2-1941 contain additional information.

3-6. Primary Hydrologic Engineering Investigation Products

The hydrologic engineering results needed by the study team may include the following information, as discussed by general study type:

a. Flood damage reduction. The main product will be the damage reduction effects of the selected alternative on the floods in the watershed. Supplemental investigation products could include: discharge-frequency relationships, flood elevations, and areas inundated with and without a specified structural alternative (reservoir, channel, levee, diversion, pumping plant), stage-duration relationships, sizes of various alternatives for costing purposes, sedimentation analyses, residual flooding, flood forecasting and warning system, etc. Nonstructural alternatives may require only the without-project condition, since these alternatives affect the stage-damage relationship only and result in little, if any, change in hydrologic or hydraulic relationships.

b. Water control management. The main product will be a new or revised set of procedures for project operation and hydrologic forecasting, contained in a water control manual. A range of flows should be addressed, from the inflow design flood to the record drought. Effects on the watershed sediment regime could be a required product. Supplemental investigation products could include: operation procedures, stage-duration and frequency, discharge-frequency, emergency operation procedures, gage data network, computer equipment needed, conservation and/or hydropower procedures, flood warning and preparedness procedures, and other required information.

c. Water supply investigations. The main product will be a reservoir storage reallocation to satisfy changed demands, such as decreased hydropower storage for increased water supply storage, or to satisfy as many critical demands as possible during time of drought. Water supply studies are usually performed for storage reallocations of existing reservoirs or for drought contingency planning for existing Federal reservoirs. Drought contingency planning analysis is a separate study, but is usually included as an appendix to a reservoir water control manual. Supplemental investigation products could include both seasonal and annual: current and modified condition discharge-frequency, reservoir storage-frequency, pool elevation-duration, flow- or storage-duration relationships, and power generation values.

Chapter 4
Development of an Initial HEMP

4-1. General

A typical strategy would first include a preliminary assessment identifying the problems and issues described in both this chapter and in Chapter 3. This assessment would result in the preparation of an initial hydrologic engineering management plan, sufficient to scope time and funding requirements. The initial HEMP would include appropriate contingencies to establish total hydrologic engineering cost for inclusion in the initial project management plan or in the PMP. If time and funds are available at the end of the reconnaissance phase, a detailed HEMP could be prepared in lieu of the initial plan. A senior hydrologic engineer could develop the initial hydrologic engineering management plan, while the responsible engineer could expand this document into a detailed HEMP. The activities in Chapters 3, 4, and 5 are summarized in Figure 3.

4-2. Field Inspection

An early field inspection is necessary to become familiar with site-specific problems that must be incorporated in the HEMP. A continuous field presence should be maintained throughout the study to keep pace with changes to the study area. Field inspection would focus on any features causing analysis problems, ongoing changes in the study area, interviews with locals concerning past flood experiences or changes to the area since large past floods, contacting local agencies to obtain information on the area and on any plans for modifications that could affect the Corps analysis, and other items of interest.

4-3. Coordination

Various coordination and information needs must be addressed in the HEMP.

a. Study team needs. The various hydrologic information needs of the interdisciplinary planning team have been briefly described in Chapter 2, paragraph 2-3. Anticipated hydrologic information needs should be obtained from the study team during the reconnaissance process for inclusion in time and cost estimates and schedule for the feasibility phase.

b. Sponsor needs.

(1) The sponsor usually has valuable information about the study area. The sponsor may have some capability for obtaining necessary information pertinent to the project or for performing some of the hydrologic engineering necessary for the study, which could be a credit to the sponsor. The cost-sharing partner normally has specific views on the type of alternatives believed most suitable for the study area. All of these possibilities would be reflected in the HEMP.

(2) An initial HEMP is useful in dealing with the local sponsor on necessary hydrologic engineering activities and in justifying the hydrologic engineering cost estimate, which the sponsor must cost-share. Discussing the necessary hydrologic activities, summarized in a HEMP, with the sponsor is more likely to result in agreement on the effort involved than to simply present the sponsor with a total cost.

c. Feasibility cost-sharing agreement. The FCSA cannot be negotiated adequately without having the hydrologic engineering work defined in sufficient detail. The hydrologic engineer must be involved in any negotiations concerning hydrologic engineering, or in hydrologic engineering work that the sponsor might perform for the project. The hydrologic engineer must approve the technical value of the sponsor's work before it can be accepted as a sponsor credit.

4-4. Collecting Information

The hydrologic engineer must evaluate the available data, as well as estimate what additional data are necessary for conducting the study. Actual climatologic, hydrologic, hydraulic, sediment, water quality and infrastructure data available would be determined, sources and quality of such data evaluated, and any special needs for a limited data collection program determined. Topographic information necessary to develop accurate water surface profile information will be estimated.

4-5. Basic Analysis Approaches

The analysis approach must be based on the hydrologic information needs of the study team, unusual features of the study, the type of alternatives requiring investigation, the significance of the alternatives on the sediment

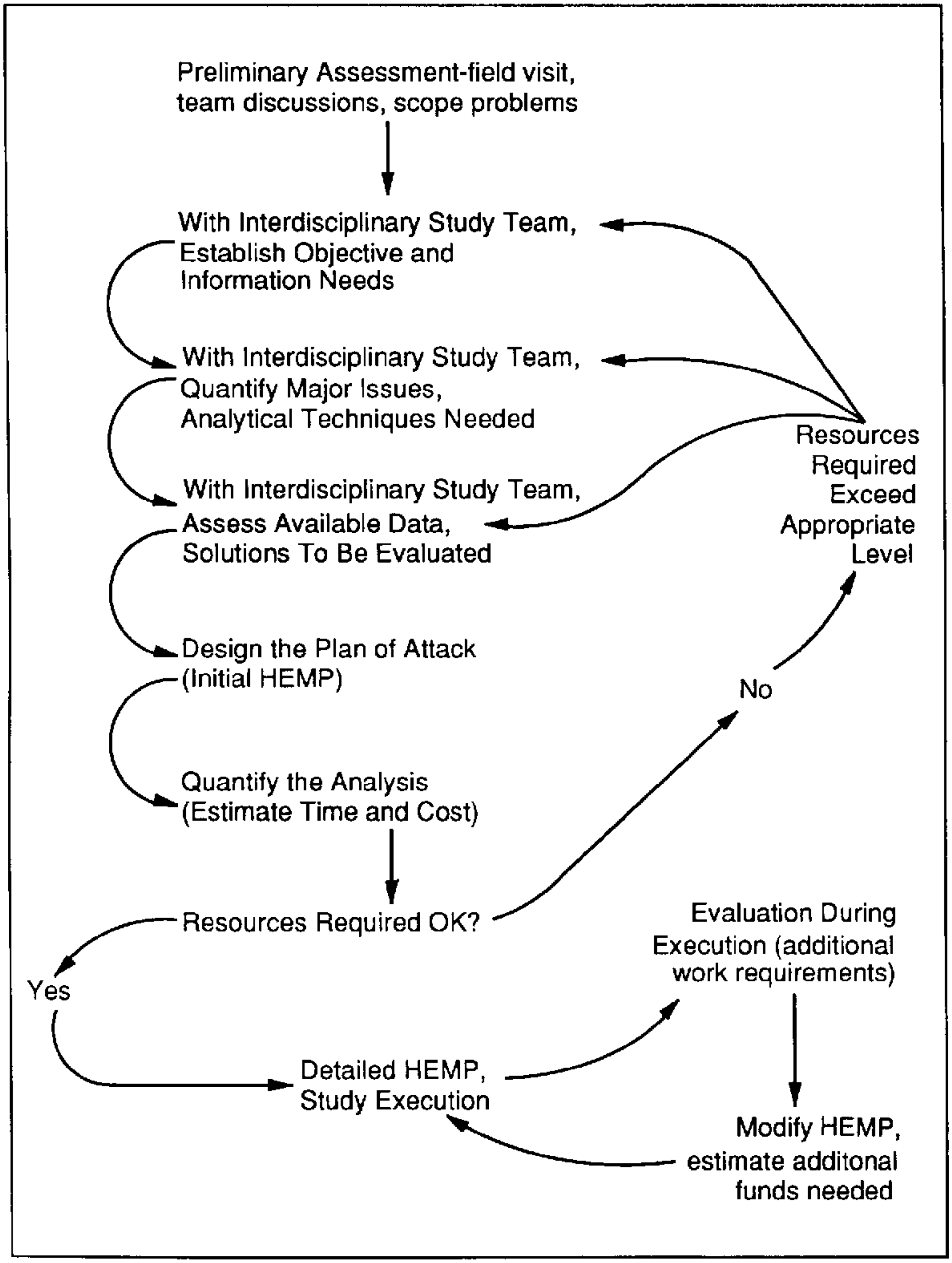

Figure 3. Hydrologic study design

regime, and other considerations. Selection of the appropriate hydrologic model, a single event or a continuous model, steady or unsteady flow procedures, and qualitative or quantitative sediment analysis must depend on the judgment and skills of the responsible hydrologic engineer. Models and procedures should be selected based on the reduction of uncertainty in the end product. If a sophisticated model or procedure does not give a significantly improved result and reduced uncertainty, a less sophisticated method is probably appropriate. Selection of new models or procedures could include an allowance for assistance by the (HEC), the U.S. Army Engineer Waterways Experiment Station (WES), or other consultants. New models and innovative, unusual procedures should be approved by higher authority at the technical review conference held at the end of the reconnaissance phase, or earlier. Peer review by the appropriate HQUSACE-sponsored committee should also be considered for unusual or complex analyses.

4-6. Initial HEMP Preparation

Using information from the preliminary assessment, identify the major activities, including alternatives to be analyzed and the range of sizes to study. The initial HEMP would be used to estimate human resource requirements for each activity to establish a total hydrologic engineering study cost. An example of an initial HEMP for a flood control study is presented in Appendix C.

4-7. Time and Schedule Estimates

With the initial HEMP, determine the human resources required for each major technical hydrologic engineering study component (rainfall analyses, water surface profile, channel modifications, etc.) and for the complete hydrologic engineering effort. Estimate the human resources necessary for each discipline (hydrologic engineer, technician, supervisor, etc.). Estimate when necessary information must be furnished to (or received from) other study team members. Clearly indicate the number of alternatives to be evaluated and the number of sizes to analyze for each alternative. Determine if special training is necessary for the responsible engineer to effectively perform the study. Include any other factors having a significant impact on required time for the hydrologic engineering analysis, along with any assumptions on which the estimate is based. Include a reasonable contingency allowance.

4-8. Funding Estimates

Determine the chargeable rate for each technical discipline used in the hydrologic work. Include all direct and indirect overhead charges for the division to which hydrologic engineering is assigned and for the District. At the time of publication of this EP, the chargeable rate for District personnel averaged about 2.8-3.0 times the base salary. For example, if an engineer earned $25/hour base wages, the project is charged $70-75/hour for each hour charged by the staff member. Total the funds for each major activity and for the total hydrologic engineering effort. Forward the estimate to the planning technical manager for approval of hydrologic time and costs.

4-9. Resource Evaluation/Negotiation

a. Through an iterative process, come to agreement with all concerned on study objectives, analysis approaches, alternatives to be analyzed, sizes to study, and level of detail obtainable with funding constraints. Prepare written documentation on this agreement and include any problems, difficulties, or lack of engineering detail that may result from this reduced effort. Finalize these activities in the HEMP for inclusion in the initial project management plan, or PMP. Reference these changes and agreements in the hydrologic engineering management plan, or in separate documentation.

b. The IPMP is reviewed and approved by the chief of each technical division. The signature of the Chief of the Engineering Division (the division to which hydrologic engineering is normally assigned) on the IPMP indicates that the hydrologic engineer agrees to perform these activities for the funding specified. The responsibility then falls on the hydrologic engineer to ensure that the actual time and costs are commensurate with the agreed amount. Additional hydrologic work required by the interdisciplinary planning study team or sponsor during the feasibility or design phase must result in additional resources being made available by the project or study manager.

Chapter 5
Development of a Detailed HEMP

5.1. General

After receipt of funding for the feasibility or design phase, the hydrologic engineer would build on the initial hydrologic engineering management plan to develop the fully detailed HEMP.

5-2. Document Contents

Using the results of Chapters 3 and 4, develop the detailed HEMP commensurate with the level of reporting. The detailed HEMP for the feasibility phase would document the step-by-step analysis of data development, storm studies, routing operations, unit hydrograph development, model calibration, etc., while the detailed HEMP for the PED phase would document the hydraulic design, physical model testing requirements, hydrologic studies needed for water control manuals, detailed sediment investigations, multi-dimensional modeling efforts, etc. Appendices D through F give generic examples of different hydrologic engineering management plans. The document should be reviewed and approved by the immediate supervisor. Complex analyses may benefit from a higher level review. A courtesy copy should be provided to the study or project manager.

5-3. Activity Sequence

For scheduling purposes, assign durations to each work item for all significant activities in the entire HEMP. Establish milestone dates for each major component. Use milestone dates for furnishing necessary information to various members of the interdisciplinary planning team, receiving information required from others to meet the study completion date, and meeting any other scheduled events.

5-4. Hydrologic Study Management

The detailed hydrologic engineering management plan could be used on a day-to-day or week-to-week basis, especially for relatively new hydraulic engineers. Periodic updates and further detailing of tasks should be performed as work progresses or as additional effort becomes necessary to meet new interdisciplinary planning team or local sponsor requests. Additional work effort required by others, that is not included in the HEMP, becomes the basis for increases in hydrologic engineering time and cost allocations. This situation again emphasizes the need for a HEMP and for the responsible hydrologic engineer to use it throughout the study.

5-5. Study Documentation and Reporting

Update the HEMP for final documentation of the completed technical study so that future, similar work will have a better planning basis. Recording the actual human resources expended for each major activity is particularly useful for estimating future studies. Use the completed hydrologic engineering management plan for the outline of a technical hydrologic engineering appendix to the study documentation.

Appendix A
References

A-1. Required Publications

ER 15-2-14
Committees on Tidal Hydraulics, Channel Stabilization, Water Quality and Hydrology

ER 1105-2-100
Guidance for Conducting Civil Works Planning Studies

ER 1110-2-240
Water Control Management

ER 1110-2-241
Use of Storage Allocated for Flood Control and Navigation at Non-Corps Projects

ER 1110-2-1941
Drought Contingency Plans

EM 1110-2-1701
Hydropower

EM 1110-2-3600
Management of Water Control Systems

EM 1110-2-4000
Sedimentation Investigations of Rivers and Reservoirs

U.S. Army Corps of Engineers. 1992.
"Proceedings of a Seminar on Initial Project Management Plans for Hydrologic Engineering and Economic Analysis," SP-25, Hydrologic Engineering Center.

A-2. Related Publications

ER 5-7-1 (FR)
Project Management

ER 1110-2-1150
Engineering and Design for Civil Works Projects

ER 1110-2-1460
Hydrologic Engineering Management

EP 1165-2-1
Digest of Water Resources Policies

EM 1110-2-1413
Hydrologic Analysis of Interior Areas

Cochran 1965
Cochran, Albert L., Memorandum "A," Hydrologic Engineering Associated with Survey Studies, January 1965.

Water Resources Council. 1982.
"Guidance for Determining Flood Flow Frequency," Bulletin No. 17B, Geological Survey, U.S. Department of the Interior.

Appendix B
List of Acronyms

CECW
Corp of Engineers, Civil Works (Washington, DC)

CECW-EH
Above plus Engineering Division, Hydrology and Hydraulics Branch

COOP
Continuity of Operations

DM
Design Memorandum

DPR
Detailed Project Report

EC
Engineer Circular

EM
Engineer Manual

EP
Engineer Pamphlet

ER
Engineer Regulation

ETL
Engineer Technical Letter

FCSA
Feasibility Cost Sharing Agreement

GDM
General Design Memorandum

HEC
Hydrologic Engineering Center

HEC-DSS
Hydrologic Engineering Center Data Storage System (family of computer programs)

HEMP
Hydrologic Engineering Management Plan

HQUSACE
Headquarters, United States Army Corps of Engineers

IPMP
Initial Project Management Plan

LRR
Limited Reevaluation Report

M&I
Municipal and Industrial (water supply)

NED
National Economic Development (plan)

NWS
National Weather Service

O&M
Operation and Maintenance

OMRRR
Operation, Maintenance, Repairs, Replacement, Rehabilitation

PCA
Project Cooperation Agreement

PED
Preconstruction Engineering and Design

PMP
Project Management Plan

PRM
Prescriptive Reservoir Model

SCS
Soil Conservation Service

SSARR
Streamflow Synthesis and Reservoir Regulation (model)

TRC
Technical Review Conference

USBR
United States Bureau of Reclamation

USGS
United States Geological Survey

WCDS
Water Control Data System

WES
U.S. Army Engineer Waterways Experiment Station

WRDA
Water Resource Development Act

Appendix C
Initial Hydrologic Engineering Management Plan (HEMP) for a Flood Damage Reduction Feasibility Study

C-1. Scenario

a. The study objective is the development of a flood protection plan for a community experiencing periodic flooding from a stream draining a few hundred square miles. The reconnaissance-phase study was based primarily on flood insurance study data and an abbreviated hydrologic engineering analysis. The study has determined that a levee project is economically feasible. The community is willing to be the cost-sharing local sponsor and would like a minimum certifiable level of protection of a 1 percent chance event. A gage with 15 years of discharge data is available at the site, with additional, short-record gages located elsewhere in the watershed.

b. The feasibility phase will establish existing and future without-project conditions. After discussions with the interdisciplinary study team and local sponsor, it was decided that three heights of levee will be studied, along with six combinations of levee height and channel improvements to develop the economic optimum plan. A total of nine alternatives will be evaluated. As all the levee alternatives are along a similar alignment, a detailed interior flood analysis will be evaluated for only the National Economic Development Plan (NED) levee or levee and channel plan. The hydrologic engineer must prepare an initial Hydrologic Engineering Management Plan (HEMP) for the hydrologic engineering cost estimate for the feasibility phase.

c. This sample initial HEMP represents what one might develop at the end of the reconnaissance-phase study for a time and cost estimate for use in the initial project management plan.

C-2. Preliminary Investigations/Initial Preparation

Finalize study objectives; confer with the study team members on hydrologic engineering information requirements, study constraints, development information needs, and field reconnaissance; prepare survey data request; prepare detailed HEMP.

C-3. Development of Basin Model Hydrologic Engineering Center (HEC-1)

a. Calibration of runoff parameters. Using basin gage data, develop unit hydrograph and loss rate parameters for use in the study.

b. Delineation of subareas. Subdivide study watershed based on the need for discharge-frequency information at specific locations: major tributaries, damage index points, routing reaches, project sites, etc.

c. Subarea rainfall-runoff analysis of historic events. Develop historic storm events, and subarea loss rate and unit hydrograph data for ungaged areas.

d. Channel routing characteristics. Determine based on information in Appendix D (Paragraph D-3*d*).

e. Assemble, debug HEC-1 model.

C-4. Hydraulic Studies

a. Prepare Water Surface Profile Data--Code HEC-2 model of study reach, after receipt of surveys. Estimate "n" values, section locations, bridge routines applicable, effective flow areas. Debug model.

b. Calibrate HEC-2 model to gage data and high-water marks from recent floods.

c. Develop storage-outflow relationships and flood wave travel time, by routing reach, for information required in Paragraph C-3*d* above.

C-5. Calibration of Models to Historic Events

Calibrate the HEC-1 and -2 models to recorded events and high-water marks. Make preliminary selection of hydrologic and hydraulic model parameters for hypothetical flood event analysis.

C-6. Frequency Analysis for Existing Land Use Conditions

a. Perform statistical analysis of gaged data for peak discharge-frequency relationship. Also estimate discharge-frequency relationships through available/applicable regression equations at key locations, to use in later comparisons.

b. Hypothetical Storms (HEC-1)--Develop hypothetical frequency storm data from the National Oceanic and Atmospheric Administration HYDRO 35, and National Weather Service Technical Publications 40 and 49. Develop the Standard Project Storm. Develop rainfall pattern for each storm, including precipitation depth-area adjustments. Develop corresponding hydrograph for each hypothetical event throughout the basin using the calibrated hydrologic model of Paragraph C-5.

c. If judged appropriate, further calibrate model to reproduce the peak discharge calculated from the statistical analysis at the gage site. Emphasize the 2-year through 10-year event, since the data record is short. Make adjustments to loss rates and unit hydrograph coefficients for rarer events, as judged reasonable. Compare results to statistical and regression-derived peak discharge frequency relationships; further adjust coefficients as considered reasonable.

d. Using the results of steps *a*., *b*., and *c*., above, adopt a discharge-frequency relationship at each needed location. Develop probability distribution of discharge uncertainty for use in risk-based analyses.

e. Determine corresponding water surface profiles and inundated areas for selected frequencies at required locations. Furnish data to planning and economics.

f. Adopt stage-discharge relationship at each required location for damage computations. At the gage site with 15 years of data, determine deviations about the adopted stage-discharge relationship. Further evaluate through sensitivity studies. Develop probability distribution of stage uncertainty for risk-based analysis.

C-7. Future Without-Project Analysis

Determine future stage-discharge relationships, based on future watershed changes affecting the hydraulics. If necessary, adjust discharge-frequency and stage-discharge risk/uncertainty relationships. Furnish data to economics.

C-8. Levee Alternative Evaluations

For the preliminary levee alignment, develop revised discharge-frequency and stage-frequency relationships for each of the three different levee heights. If judged necessary, determine revised stage-discharge risk/uncertainty relationship. Roughly size a “minimum facility” interior flood control system for each. With the economist, perform risk and uncertainty studies to establish the claimable level of protection (risk-based) and average annual benefits resulting for each.

C-9. Levee and Channel Alternative Evaluation

a. For two sizes of channel, reestablish stage-frequency relationships for each of three levee sizes (six alternatives). Evaluate the discharge and stage uncertainties for with-project conditions. Roughly size a “minimum facility” interior system for each alternative, if necessary. With the economist, perform a risk-based analysis to determine project benefits and claimable level of protection for each alternative. Perform qualitative sediment analyses for channel modifications to roughly determine dredging frequency for channel maintenance. After economic analysis to tentatively establish the NED plan (levee height) from among the nine alternatives, design top of levee grade for controlled overtopping.

b. If a channel modification is included in the NED plan, perform sensitivity tests to determine the importance of channel maintenance assumptions and costs on the NED plan. If a more conservative sedimentation analysis results in significant cost increases, possibly invalidating the NED plan, additional sediment analyses will be required in feasibility. Hydrologic engineering work for a quantitative sediment analysis is not included in this estimate. Adjust final levee grade for any sediment effects.

c. As necessary, furnish hydrologic information, as it becomes available, to other study team members: stage-duration and frequency to environmental, data for Environmental Assessment Report, etc.

d. Nonstructural analysis of emergency procedures in the event of levee overtopping--evacuation and flood warning.

C-10. Residual Flooding and Interior Flood Control

a. Establish residual flooding for remaining flood damages with the NED project. Evaluate higher levels of interior flooding protection compared to the “minimum facility.” Interior flood control measures are distinguished from minimum facilities in that these additional measures require net benefits and minimum facilities do not require incremental economic justification, only cost-effective design.

(1) Using the Interior Flood Hydrology Program, evalu ate two gravity outlets larger than the “minimum facility” at each of the three gravity drain locations.

(2) Evaluate interior excavated storage at the only site where it is currently thought feasible.

(3) Evaluate three capacities of pumping plants at each of two sites.

(4) Evaluate interior ditch improvements for the two main ditches.

b. Forward data to an economist and cost engineer for each increment. Supply hydrologic data for wetland determination and mitigation, as necessary.

C-11. Hydraulic Studies

Some of the design work will have already been incorporated in the above activities.

a. Levees--levee design profile, controlled overtopping design, gravity drain design for “minimum facility,” etc.

b. Channels--channel geometry, bridge modifications, scour protection, channel cleanout requirements, channel and bridge transition design, etc.

c. Drains--size, slope, material, inlet/outlet, operation procedures, etc.

d. Pumping--capacities, start-stop pump elevations, sump design, outlet design, scour protection, operating floor elevations, etc.

C-12. Hydrologic Engineering Reporting Requirements

a. Project Management Plan--Estimate major hydrologic engineering activities in the preconstruction engineering and design (PED) phase, prepare initial HEMP for PED work, prepare time and cost for hydrologic engineering, activity schedule.

b. Hydrologic Engineering Appendix to the Feasibility Report--Using the detailed HEMP as appropriate, outline and write the text, prepare tables and figures.

c. Environmental Assessment Report--Provide data to environmental section. Supply text, figures, plates, as needed.

Appendix D
Generic Detailed Hydrologic Engineering Management Plan (HEMP) for a Flood Damage Reduction Study

D-1. General

This sample detailed HEMP would be appropriate for the hydrologic and hydraulic analysis associated with a typical Corps feasibility report for an urban watershed. It would be prepared at the end of reconnaissance-phase study or start of the feasibility phase. The intent of the hydrologic engineering analysis would be to determine existing and future discharge-frequency and stage-discharge relationships at key points in the study area, along with flooded area maps by frequency. This analysis would be performed without project and for various flood reduction components that are considered feasible for relief of the flood problem.

D-2. Preliminary Investigations

This initial phase includes a literature review of previous reports, obtaining the available data, and requesting additional information needed to perform the investigation.

a. Initial preparation.

(1) Confer with the other disciplines involved in the study to determine the objectives, the hydrologic engineering information requirements of the study for other disciplines, study constraints, etc.

(2) Scope study objectives and purpose.

(3) Review available documents.

(a) U.S. Geological Survey reports.

(b) Previous Corps work.

(c) Local studies.

(d) Hydrologic engineering analysis for reconnaissance report.

(e) Initial Project Management Plan.

(f) Other.

(4) Obtain hydrologic (historic and design discharges, discharge-frequency relationships, etc.) and hydraulic (high-water marks, bridge designs, cross sections, etc.) data.

(a) Local agencies (city/county highway departments, land use planning, etc.).

(b) State (state highway departments, planning agencies, water resource agencies, etc.).

(c) Federal U.S. Geological Survey (USGS), U.S. Soil Conservation Service (SCS), U.S. Bureau of Reclamation (USBR), etc.

(d) Railroads.

(e) Industries.

(f) Other.

(5) Scope major hydrologic and hydraulic activities.

(6) Prepare detailed HEMP.

(7) Obtain study area maps.

(a) County highway maps.

(b) USGS topographic quadrangle maps.

(c) Aerial photographs.

(d) Others.

(8) Estimate location of cross sections on maps (floodplain contractions, expansions, bridges, etc). Determine mapping requirements (orthophoto) in conjunction with other disciplines.

b. Field reconnaissance.

(1) Interview local agencies, and residents along the stream, review newspaper files, etc., for historic flood data (high-water marks, frequency of road overtopping, direction of flow, land use changes, stream changes, etc.). Document names, locations, and other data for future reference.

(2) Finalize cross-section locations/mapping requirements.

(3) Determine initial estimate of "n" values for later use in water surface profile computations.

(4) Take photographs or slides of bridges, construction, hydraulic structures, and floodplain channels and overbank areas at cross-section locations. Consider dictating notes to a hand-held tape recorder to get a complete and detailed record.

c. Survey request. Write survey request for mapping requirements and/or cross sections and high-water marks.

D-3. Development of Basin Model (HEC-1)

This phase of the analysis involves the selection of historic events to be evaluated, the development of runoff parameters from gaged data (and/or regional data from previous studies) and correlating these data to ungaged basins and the calibration of the basin model to historic flood events. This step assumes that at least some recording stream gage data are in or near the study watershed.

a. Calibration of runoff parameters.

(1) Select historic events to be evaluated based on available streamflow records, rainfall records, high-water marks, etc.).

(2) From USGS rating curves and time-versus-stage relationships for each event, develop discharge hydrographs at each continuously recording stream gage. Estimate peak discharge from flood crest gages.

(3) Develop physical basin characteristics (drainage areas, slope, length, etc.) for basin above each stream gage.

(4) Select computation time interval (Δt) for this and subsequent analyses. The computation interval must:

(a) Adequately define the peak discharge of hydrographs at gages.

(b) Consider type of routing and reach travel times.

(c) Have three to four points on the rising limb of the unit hydrograph for the smallest subarea of interest.

(d) Consider types of alternatives and future assessments.

(5) Using all appropriate rain gages (continuous and daily), develop historic storm patterns that correspond to the selected recorded runoff events for the basins above the stream gages.

(a) Average subarea totals from isoheytal maps or total gage precipitation weightings.

(b) Temporal distribution from weightings of nearby recording rain gages.

(6) Determine best estimate unit hydrograph and loss rate parameters for each event at each stream gage by calibrating to recorded flood hydrographs.

(7) Make adjustments for better and more consistent results between events at each stream gage. Adjustments are made to:

(a) Starting values of parameters and/or

(b) Rainfall totals or patterns (different weightings of rain gages).

(8) Hold constant the most stable parameters, or relationships between parameters, and resimulate rainfall/runoff process to estimate other parameters.

(9) Adopt final unit hydrograph and base flow parameters for each gaged basin.

(10) Re-simulate with adopted parameters held constant to estimate loss rates.

(11) Use adopted parameters of unit hydrographs, loss rates, and base flow to reconstitute other recorded events not used in the above calibration to test the correctness of the adopted parameters and to "verify" the calibration results.

b. Delineation of subareas. Subareas are delineated at locations where hydrologic data are required and where physical characteristics change significantly.

(1) Index locations where economic damage computations are to be performed.

(2) Stream gage locations.

(3) General topology of stream system.

(a) Major tributaries.

(b) Significant changes in land use.

(c) Significant changes in soil type.

(d) Other.

(4) Routing reaches.

(5) Location of existing physical works (reservoirs, diversions, etc.) and potential location of alternate flood reduction measures to be studied.

c. Subarea rainfall-runoff analysis of historic events.

(1) Subarea rainfall.

(a) Average subarea rainfall from isohyetal maps or weighting of total gage precipitation.

(b) Temporal distribution from weighing in accordance with information from nearby recording rain gages.

(2) Average subarea loss rates.

(a) From adopted values of parameter calibration.

(b) From previous studies of similar basins in the region.

(c) Others.

(3) Unit Hydrograph Parameters.

(a) From relationships based on calibration results at stream gages (Section II) and physical basin characteristics.

(b) From previous regional study relationships of unit hydrograph parameters and physical basin characteristics.

(c) From similar gaged or known basins.

(d) From judgment, if no data are available.

d. Channel routing characteristics.

(1) Modified Puls from water surface profile computations (Hydrologic Engineering Center (HEC-2)).

(2) Optimized from stream gage data (HEC-1).

(3) Adopted parameters from previous studies, experience, etc.

(4) Derived from reach hydraulics (Muskingum - Cunge).

e. Reservoir routing (if reservoirs are present). This type of routing must be performed where storage has a significant effect on reach outflow values, with reservoirs being the most notable example. However, one must also apply these techniques where physical features warrant, such as roads crossing a floodplain on a high fill, especially where culverts are used to pass the flow downstream.

(1) Develop surface area-capacity data (elevation-surface area-storage relationships).

(2) Develop storage-outflow functions based on outlet works characteristics.

f. Runoff hydrographs. Using the subdivided rainfall-runoff model, including existing projects and the routing information of Section D-3 above, generate runoff hydrographs for previously selected runoff events at desired locations. Final calibration of the hydrologic model is described in Section D-5.

D-4. Hydraulic Studies

These studies are used to determine water surface profiles, economic damage reaches, and modified Puls channel routing criteria (if used). This example assumes that an evaluation was previously made that a steady flow-rigid boundary water surface profile analysis is appropriate.

a. Prepare water surface profile data.

(1) Cross sections (tabulate data for each section).

(a) Make cross sections perpendicular to flow.

(b) Each cross section should be typical of the reach from half the distance to the next section both upstream and downstream of the current locations.

(c) Develop effective flow areas. If modified Puls routing criteria are to be determined from water surface profile analyses, the entire section must be used (for storage) with high “n” values in the non-effective flow areas.

(2) Refine “n” values from field reconnaissance and from analytical calculation and/or comparison with “n” values determined analytically from similar streams.

(3) Bridge computations--estimate how high the selected floods will reach on each bridge and select either:

(a) Normal bridge routine.

(b) Special bridge routine.

(4) Develop cross sections above and below bridges to model effective bridge flow (use artificial levees or ineffective flow area options, as appropriate).

b. Proportion discharges. Proportion discharges based on hydrologic analyses of historic storms and plot peak discharge versus river mile. Compute a series of water surface profiles for a range of discharges. Analysis should start below study area so that profiles will converge to proper elevations at study limits. May want to try several starting elevations for the series of initial discharges.

c. Manual check. Manually check all large differences in water surface elevations across the bridge, say, greater than 3 ft.

d. Results. The results are a series of rating curves at desired locations (and profiles) that may be used in subsequent analyses. Additional results are a set of storage versus outflow data by reach which, along with an estimate of hydrograph travel time, allow the development of modified Puls data for the hydrologic model.

D-5. Calibration of Models to Historic Events

a. General. This study step concentrates on “de-bugging” the hydrologic and hydraulic models by recreating actual historic events, thereby gaining confidence that the models are reproducing the observed hydrologic responses. This effort would continue from the activities described in Paragraph D-3.

b. Calibration procedure.

(1) Check historic hydrographs against recorded data, make adjustments to model parameters, and rerun the model.

(2) If no stream gages exist, check discharges at rating curves developed from water surface profiles at high-water marks.

(3) Adjust models to correlate with high-water marks.

(4) Adopt hydrologic and hydraulic model parameters for hypothetical flood event analysis.

(5) Quantify uncertainty of the stage-discharge relationship at each site where damage analysis is to be performed. As appropriate, use recorded gage data, comparison of profile to high-water marks, minimum deviation, and engineering judgement.

D-6. Frequency Analysis for Existing Land-Use Conditions

The next phase of the analysis addresses how often specific flood levels will occur at all required points in the study watershed. The procedures include developing discharge-and stage-frequency relationships at stream gages (when available) through statistical analysis using recorded peak discharges and at other required locations using available hypothetical storm data.

a. Statistical analysis. Using the procedures described in Bulletin 17B (Water Resources Council 1982), determine and plot analytical and graphical frequency curves at each stream gage. Adopt stage/discharge frequency relations at each gage. Regional relationships, regression analyses, and the results of hypothetical storm studies will be used to extend the records for rarer floods.

b. Hypothetical storms (HEC-1).

(1) Obtain hypothetical frequency storm data from the National Oceanic and Atmospheric Administration (NOAA) HYDRO 35, National Weather Service (NWS) Technical Publications (TP) 40 and 49, or from appropriate other sources. Where appropriate, develop the Standard Project and/or the Probable Maximum Storm.

(2) Develop a rainfall pattern for each storm. Include precipitation depth-area adjustments, where necessary.

(3) Develop a corresponding hydrograph for each hypothetical event throughout the basin using the calibrated hydrologic model.

(4) If deemed necessary, calibrate model of each frequency event to known frequency curves. Adjust loss rates, base flow, etc. as required, while remaining within reasonable limits for each parameter. The peak flow frequency at each ungaged area is assumed to be consistent with calibrated peak flow frequencies at gaged locations.

(5) If streamflow data are insufficient to develop analytical frequency curves, use the following procedure:

(a) Obtain frequency curves from similar nearby gaged basins.

(b) Develop frequency curves at locations of interest from previous regional studies (USGS, Corps of Engineers, State, etc.).

(c) Determine frequency hydrographs for each event from hydrologic model and develop a corresponding frequency curve at the locations of interest throughout the basin.

(d) Plot all the frequency curves (including those using other methods if available) and, based on engineering judgement, adopt a frequency curve. The adopted curve may not be any of the developed curves, but simply the best estimate based on the available data.

(e) Calibrate the hydrologic model of each frequency event to the adopted frequency curve. The frequency curve at other locations may be determined from the calibrated model results, assuming consistent peak flow frequencies.

(6) Quantify the uncertainty in the discharge-frequency relationship at all locations where damage computations will be performed. As appropriate, use gage data, regression equations, calibrated models to determine equivalent length of record.

(7) Determine corresponding water surface elevations and profiles for selected frequencies from the rating curves developed by the water surface profile evaluations.

D-7. Future Without-Project Analysis

Where hydrologic and/or hydraulic conditions are expected to significantly change over the project life, these changes must be incorporated into the hydrologic engineering analysis. Urbanization effects on watershed runoff are the usual future conditions analyzed.

a. From future land use planning information obtained during the preliminary investigation phase, identify areas of future urbanization or intensification of existing urbanization.

(1) Types of land use (residential, commercial, industrial, etc.).

(2) Storm drainage requirements of the community (storm sewer design frequency, on-site detention, etc.).

(3) Other considerations and information.

b. Select future years in which to determine project hydrology.

(1) At start of project operation (existing conditions may be appropriate).

(2) At some year during the project life (often the same year as whatever land use planning information is available).

c. Adjust model hydrology parameters for all subareas affected by future land use changes.

(1) Unit hydrograph coefficients, usually reflecting decreased time-to-peak and decreased storage.

(2) Loss rate coefficients, usually reflecting increased imperviousness and decreasing infiltration characteristics.

(3) Routing coefficients, usually reflecting decreased travel times and storage capabilities.

d. Operate the hydrology model and determine additional discharge-frequency relationships throughout the watershed that represent future, without-project conditions.

e. Evaluate the need to adjust uncertainty parameters of stage-discharge and discharge-frequency relationships, compared to existing conditions.

D-8. Alternative Evaluations

For the alternatives jointly developed with the members of the interdisciplinary planning team, modify the hydrologic and/or hydraulic models to develop the effects of each alternative (individually and in combination) on flood levels. Alternatives can be either structural (reservoirs, levees, channelization, diversions, pumping, etc.) or non-structural (flood forecasting and warning, structure raising or relocation, floodproofing, etc.). Considerable less hydrologic engineering effort is necessary for modeling non-structural alternatives compared to structural.

a. Procedure.

(1) Consider duplicating existing and future without-hydrologic engineering models for individual analysis of

each alternative or component. The results provide existing and future, with-project information for each alternative to be evaluated.

(2) Most structural components are usually modeled by modifying storage-outflow relationships at the component location and/or modifying hydraulic geometry through the reach under consideration.

(a) Reservoirs--adjust storage-outflow relationships based on spillway geometry and height of dam.

(b) Levees--adjust cross-section geometry based on proposed levee height(s). Evaluate effect of storage loss behind levee on storage-outflow relationships and determine revised discharge- and stage-frequency relationships downstream, if considered significant. Develop uncertainty relationship for the revised stage-discharge function.

(c) Channels--adjust cross-section geometry based on proposed channel dimensions. Evaluate effect of channel cross section and length of channelization on floodplain storage, modify storage-outflow in reach, and determine revised downstream discharge-frequency relationships, if considered significant.

(d) Diversions--adjust hydrology model for reduced flow downstream of the diversion and to identify where diverted flow rejoins the stream (if it does).

(e) Pumping--adjust hydrology model for various pumping capacities to be analyzed.

(3) Evaluate the effects of potential components on the sediment regime. Refer to guidance given in EM 1110-2-4000.

(a) Qualitatively--for initial screening.

(b) Quantitatively (where necessary)--for final selection.

b. Nonstructural components.

(1) Floodproofing/structure raises--elevations of design events primarily.

(2) Flood forecasting--development of real-time hydrology model, determination of warning times, etc.

c. Alternative evaluation and selection.

(1) Alternative evaluation and selection is an iterative process, requiring continuous exchange of information between a variety of disciplines. An exact work flow or schematic is not possible for most projects, thus Paragraph D-7 could be relatively straightforward for one or two components or quite complex, requiring numerous reiterations as more cost and design information is known and project refinements are made. Paragraph D-7 is usually the area of the HEMP requiring the most time and cost contingencies.

(2) For the selected alternative, provide hydrologic information to environmental engineers for use in studies concerning the effects of the recommended project.

D-9. Hydraulic Design

This paragraph and Paragraph D-8 are partly intertwined, as hydraulic design must be included with the sizing of the various components, both to operate hydrologic engineering models and to provide sufficient information for design and costing purposes. Perform hydraulic design studies commensurate with the level of detail of the study process.

a. Reservoirs. Dam height, spillway geometry, spillway cross section, outlet works (floor elevation, length, appurtenances, etc.), scour protection, pool guidetaking line, etc.

b. Levees. Levee design profile, interior flood control requirements, etc.

c. Channels. Channel geometry, bridge modifications, scour protection, channel cleanout requirements, channel and bridge transition design, etc.

d. Diversions. May be similar to channel design activities, also would include diversion control (weir, gates, etc.). Where the diversions are tunnels, open channel flow and pressure conduit hydraulic analyses may be necessary, depending on tunnel capacity and range of possible discharges.

e. Pumping. Capacities, start-stop pump elevations, sump design, outlet design, scour protection, etc.

f. Nonstructural. Floodproofing or structure raise elevations, flood forecasting models, evacuation plan, etc.

D-10. Hydrologic Engineering Reporting Requirements

The last step must thoroughly document the results of the technical analyses in report form. Hydrologic and hydraulic information presented will range from extensive for feasibility reports to minimal for a typical Feature Design Memorandum (FDM(s)).

a. Project Management Plan.

(1) Major hydrologic engineering activities in the preconstruction engineering and design (PED) phase.

(2) Time and cost for hydrologic engineering.

(3) Activity schedule.

b. Hydrologic Engineering Appendix.

(1) Text.

(2) Tables.

(3) Figures.

c. Environmental Impact Statement/Environmental Assessment Report.

(1) Hydrologic information/data as necessary.

(2) Portions of text, selected figures and tables.

Appendix E
Generic Detailed Hydrologic Engineering Management Plan (HEMP) for a Water Control Management Study

E-1. Sample HEMP

This sample HEMP can be used as a guide for hydrologic engineering components of a water control management study. This appendix assumes that a general plan for reservoir regulation has been established, which is the result of a water conservation study (Appendix F), a flood control study, or new project construction, and that a water control plan and water control manual are to be developed. The HEMP covers the development of data collection procedures, forecasting procedures, drought detection procedures, development of reservoir regulation rule curves, and other information. Reference is made to ER 1110-2-240 and EM 1110-2-3600. Not included in this appendix are the hydrologic engineering studies needed for a dam safety plan.

E-2. Preliminary Investigations

This is a preparatory phase that includes scoping the project, deciding upon and gathering data, coordinating, etc. (Experience has shown that more than 50 percent of the study's budget can be consumed by data gathering and preparation.)

a. Do initial preparation/coordination.

(1) Identify agencies/parties with which coordination is needed--for data, operational requirements.

(2) Review existing documents.

(a) Design documents.

(b) Interagency agreements.

(c) Studies by Corps.

(d) Studies by other agencies.

(3) Visit existing project(s).

b. Obtain hydrologic data--see Appendices D and F.

c. Scope major hydrologic activities; choose models to be used.

d. Prepare detailed HEMP.

E-3. Develop Study Models

Because the water control management study is the final phase in project development, hydrologic/hydraulic models will most likely have been developed in previous phases of the project. If additional modeling studies are required, then data will have to be obtained and model calibration undertaken. See Appendices D and F. Note that the development of an operational forecast model is treated separately, below.

E-4. Develop Seasonal Flood Control Rule Curve

A seasonal guide curve--specifying the upper limit elevation for flood control throughout the year--may have been developed in earlier study phases; however, this may need review and refinement for actual regulation. Also, the object of the water management study might be to modify the existing rule curve to improve regulation or accommodate a revised policy. This analysis is one of evaluating flood potential throughout the year. If streamflow records are short, the analysis could be augmented by looking at precipitation records to ensure that an adequate sampling of runoff potential for a given calendar date is achieved.

a. Obtain historic flood data for the project site, including secondary floods that occur off-season.

(1) Obtain recorder traces from the U.S. Geological Survey.

(2) Convert traces to streamflow hydrographs.

(3) Compute volumes appropriate to flood control storage.

b. Review long-period rainfall and streamflow records in the region to augment project records. Estimate project inflow data through regional correlation techniques or, perhaps, a rainfall-runoff model.

(1) Decide on a processing technique (DSSMATH, STATS, etc.).

(2) Enter data into database.

(3) Perform calculations.

(4) Display results; verify for reasonableness.

(5) Use rainfall-runoff model if required.

(a) Obtain precipitation records.

(b) Calibrate model.

(c) Apply precipitation, compute hydrograph.

(d) Display, verify reasonableness.

c. Compute volume of water stored for each flood, given the planned flood regulation plan.

(1) Determine computational technique, e.g., spreadsheet, existing model such as the Hydrologic Engineering Center (HEC-5), etc.

(2) Prepare spreadsheet/model, check with test data.

(3) Establish regulation rules, assumptions of forecast knowledge.

(4) Perform routings using newly derived inflow data.

(5) Display results, review for reasonableness.

d. Construct seasonal flood control rule curve.

(1) Plot storage requirement as a function of date.

(2) Plot tentative envelope line representing rule curve. Incorporate limitations for rate of draft, etc.

(3) Identify outlier points, estimate probability of event. Decide whether to envelop or not.

(4) Identify impacts on other project functions and compare with rule curves used in project authorization.

(5) Decide upon final rule curve.

E-5. Develop Forecasting Model

Assess whether the project under consideration warrants a forecast model as a part of the reservoir regulation activities, and whether staffing is available to maintain and operate the model. If that assessment is affirmative, then a model is needed for future operational application. It is likely that an existing study model can be used as a basis for development of the forecasting model. Assess whether forecasting is also to be done for conservation operation purposes, as well as flood control. If so, a continuous model capable of forecasting low-flow conditions might be the appropriate choice.

a. Select computer program (HEC-1F, SSARR, etc.) to be used. Factors to be considered are: size and complexity of basin (reservoir projects, diversions, etc.); type of runoff regime (rain, snow, flash flood potential); and applications required (flood operations, low-flow forecasting).

(1) Review information and models; consult as necessary with users and experts.

(2) Obtain models, run tests.

(3) Evaluate resources needed for real-time application (computers, people, funds).

(4) Select model.

b. Review historic and real-time data availability and obtain hydrometeorological data pertinent to forecasting and project operation. Process data for input to forecast model.

(1) Set up forecast database (likely (HEC-Data Storage System)).

(2) Consider data types needed (precipitation, temperature, streamflow, etc.).

(3) Examine period of record and select flood events that should be used in calibrations.

(4) Obtain data and download to database.

(5) Perform data screening/data display to verify data.

c. Choose likely hydromet station candidates for real-time application.

(1) Review performance of existing real-time telemetry.

(2) Examine feasibility of providing future automation.

(3) Determine relative merit of stations as indices to forecasting runoff.

(a) Compute correlations of precipitation versus runoff.

(b) Examine locations so that a range of elevation and spacial coverage is obtained.

(4) Select likely best candidates.

d. Configure model for operational forecast application. This might be an expansion or a simplification of the study model, if available.

(1) Develop model characteristics.

(a) Project characteristics (storage tables, outflow limits, etc.).

(b) Routing reaches (initial estimates of routing factors).

(c) Basin configuration (combining points, diversions, balances, etc.).

(2) Estimate initial hydromet station weightings.

e. Perform calibration simulations with model with proposed operational data and operational model. Repeat process of calibration and hydromet station selection until best model is configured.

(1) Flood runoff calibrations (rain/runoff model).

(a) Decide on calibration procedure (trial/error, optimization).

(b) Select events for calibration (or continuous simulation).

(c) Make calibration simulation.

(d) Make changes and repeat.

(2) Routing calibration (same process as above).

f. Set up procedures for preparing forecast in real time.

(1) Initialization of forecast run.

(2) Estimating missing data.

(3) Estimating ungaged local inflow.

(4) Incorporation of quantitative precipitation forecasts.

(5) Estimating snowmelt.

g. Test applications of forecast model with forecast/ regulation personnel.

h. Document forecast procedures.

E-6. Develop a Plan for the Water Control Data System (WCDS) and the WCDS Master Plan

The development of forecasting procedures will reveal remote gaging needs, whether it be the installation of new stations or the automation of manually reported stations. The WCDS also includes the computer facilities needed for processing data and executing computer models. These developments are documented in the WCDS Master Plan, which is submitted to higher authority for approval.

a. Establish field requirements for operational data.

(1) Determine frequency of reporting, backup requirements.

(2) Automate existing facilities, if needed.

(3) Establish new stations as necessary.

b. Develop plan for field data collection system--land-line, GOES, line-of-sight radio, etc.

(1) Obtain manufacturer's specifications and costs.

(2) Coordinate with other water resource agencies collecting data in the region. Consult with the Corps of Engineers, Civil Works, Engineering Division, Hydrology and Hydraulics Branch (CECW-EH).

(3) Estimate costs for maintenance--field equipment and receiving site.

(4) Prepare life-cycle cost analysis comparison; select best alternative.

c. Develop plan for WCDS computer processing.

(1) Consult with CECW-EH, HEC, Information Management, and other Corps offices.

(2) Obtain manufacturer's specifications and costs.

(3) Determine software requirements.

(4) Determine continuity of operations requirements.

(5) Perform life-cycle cost analysis; select best alternative.

d. Write WCDS Master Plan; submit for approval.

e. Establish capital and annual expenditure requirements; budget accordingly (Plant Replacement and Improvement Program (PRIP) and annual funds).

E-7. Develop Flood Control Operation Guidance

The water control plan for flood control operations should include several items to assist regulators and project operators in making regulating decisions. These may require new hydrologic and hydraulic studies, or they may simply require development of existing material for presentation in the water control manual.

a. Regulating outlet and spillway gate opening sequences, limitations.

(1) Consult with hydraulic design engineers; project personnel.

(2) Perform or request special hydraulic analysis as required.

(3) Document procedures with text and diagrams as necessary.

b. Spillway gate regulation procedures.

(1) Review guidance and design documents regarding gate regulation schedules.

(2) Prepare a gate regulation diagram.

(a) Select a design flood for recession volume analysis.

(b) Perform routings.

(c) Plot required outflows versus inflow and storage.

(3) Test diagram by routing with different floods (inflow design flood, historic floods). Adjust as necessary.

(4) Finalize guidance plots; prepare documentation.

c. Miscellaneous guidance curves for flood control operations. There may be need for guidance curves and rules that can be used in the flood control operating plan in lieu of or, in conjunction with, a flood forecasting operation. One application would be as a backup to a forecasting system in cases where communications and power are lost. Examples might be: indices to runoff, given precipitation magnitudes; procedures for changing outflows, given reservoir rate of fill; and rules for operating several dams controlling a single control downstream control point.

(1) Determine need for guidance, considering factors such as:

(a) Remoteness of project; communications and transportation viability.

(b) Accuracy and viability of operational forecasting procedures, models.

(c) Basin runoff response.

(2) Perform hydrologic study using models or manual analysis.

(3) Test guidance on historic floods, design floods.

(4) Prepare plots, narrative text.

d. Examples of flood regulation. Examples of flood control regulation provide a useful form of guidance for water control manuals. These can be plots and/or tabulations, accompanied by explanatory text.

(1) Select floods for possible examples, considering factors such as: magnitude of flood; unusual runoff timing or shape of hydrograph; seasonal considerations; and ability to demonstrate use of guidance procedures.

(2) Perform reservoir routings with historic data, using guidance materials that have been prepared.

(3) Plot hydrographs; prepare narrative material.

e. Emergency instructions to dam tenders when communication is lost. This is a mandatory requirement for dams subject to rapid flood runoff requiring gate operations. It is particularly important for dams in remote areas. Coordination is needed with Dam Safety Plan emergency procedures.

(1) Review operating guidance determined in above paragraphs.

(2) Review staffing, travel conditions, and timing for dam tenders with project personnel. Visit project if necessary.

(3) Prepare procedures for non-guided operation:

(a) Staffing requirements.

(b) Data gathering; project monitoring.

(c) Determination of outflows.

(d) Alert procedures.

E-8. Develop Guidance for Conservation Operation

Although not as critical as flood operation guidance because timing and possible emergency conditions are not as problematic, there may be special procedures which are required for low-flow operations. Examples might be (1) procedures for determining instream flow releases as a function of reservoir status, and (2) municipal and industrial release schedules, etc. This activity might be a part of the Drought Contingency Plan studies, Paragraph E-10.

a. Determine need for guidance.

(1) Review studies used for project formulation and design.

(2) Review historic records; select drought periods for examination.

(3) Consult with affected agencies/parties.

(4) Decide on need for further analysis and need for special guidance.

b. Perform hydrologic study as required, using models or manual procedures. (Refer to Paragraphs F-4 and F-5 in Appendix F for details.)

c. Test guidance on varying hydrologic conditions, considering real-time conditions such as forecasting accuracy or slippage in implementing actions.

d. Prepare plots, narrative description for water control manual. (Refer to Paragraph E-11, below.)

E-9. Development of Guidance for Hydroelectric Operations

The design of the hydro plant for the project and the nature of the hydroelectric system involved will determine how the project is to be operated for power production, so additional hydrologic engineering studies for the water control plan may not be extensive. Possible items: (1) rate-of-change restriction studies, including possible river fluctuation studies; (2) block-loading schedules; (3) plant characteristic charts; and (4) unit operating procedures. Refer to EM 1110-2-1701.

a. Identify need for guidance. (See Paragraph E-8, above.)

b. Perform analysis. (Refer to Paragraphs F-4 and F-5 in Appendix F for details.)

c. Prepare material for Water Control Manual. (Refer to Paragraph E-11, below.)

E-10. Develop Drought Contingency Plan

If the project has a water conservation operating objective, then a Drought Contingency Plan is required in the Water Control Manual. Reference is made to ER 1110-2-1941.

E-11. Prepare Water Control Plan and Manual

The final step in the water control management study is the documentation of the plan of operation in the water control manual. If the plan that has been developed represents a significant change in operation from previous operational policy, then public coordination is required if it hasn't already taken place. Refer to ETL 1110-2-251.

a. Ascertain need for public meeting on Water Control Plan. (Refer to WRDA 90, Sec. 3106.) Prepare materials and hold meeting if required.

b. If meeting is required, prepare briefing material and hold meeting.

(1) Decide on presentations to be made.

(2) Review studies, availability of briefing material.

(3) Prepare new visual aids as necessary.

(4) Hold meeting.

(5) Carry out follow-up actions as necessary.

c. Establish manual content, organization, and work program.

(1) Prepare outline of manual.

(2) Assemble material; identify critical items to be worked on.

(3) Assess human resources requirements, time schedule, funds.

(4) Consider contractor assistance.

(5) Obtain agreement and approval of content and approach. Review with division office.

d. Prepare manual.

(1) Decide on plotting methodology.

(2) Prepare required plots and graphics.

(3) Prepare narrative material.

(4) Conduct first draft review by in-house personnel, division office.

(5) Prepare final manual for approval.

Appendix F
Generic Detailed Hydrologic Engineering Management Plan (HEMP) for a Water Supply Investigation

F-1. Sample Detailed HEMP

This sample detailed HEMP can be used as a guide for the hydrologic and hydraulic analysis needed for conducting a water conservation or a storage reallocation study. Examples might include: a water supply allocation plan for a new reservoir project; a drought operating plan for an existing reservoir project or system of projects; and a system-wide reevaluation of a master water control plan considering the potential of benefit reallocation. The analysis would typically employ a reservoir simulation model such as the Hydrologic Engineering Center (HEC)-5 or HEC- Prescriptive Reservoir Model (PRM). Flood control criteria might affect conservation purposes; therefore, flood routing studies may be required, and perhaps a rainfall-runoff model would be employed. The goal would be to evaluate nominated alternatives of storage quantities, firm water supply yields, seasonal rule curves, and instream flow goals by model simulation. The alternatives would be judged by comparing regulated flood frequency curves, low-flow frequency curves, reservoir elevation-duration curves, etc.

F-2. Preliminary Investigations

This is a preparatory phase that includes scoping the project, deciding upon and gathering data, coordinating with agencies affected by the study, etc. (Experience has shown that more than 50 percent of the study's budget can be consumed by data gathering and preparation.)

a. Initial preparation.

(1) Identify agencies/parties with which coordination is needed - for data, operational requirements.

(2) Identify problem, scope study objectives.

(3) Review existing documents.

(a) Design documents.

(b) Interagency agreements.

(c) Previous studies by Corps.

(d) Studies by other agencies.

b. Choice and application of models.

(1) Research, obtain consultation (HEC and others) on which models to employ and how they can be applied.

c. Obtain historic hydrologic/meteorological data.

(1) Project operating records; e.g., reservoir elevations, outflows.

(2) U.S. Geological Survey (USGS) streamflow records.

(3) National Weather Service (NWS) precipitation and temperature data.

(4) Evaporation records.

(5) Snow data.

(6) Irrigation withdrawals.

(7) Consumptive use (municipal and industrial) records.

d. Obtain project requirements and alternatives to be investigated.

(1) Municipal and industrial requirements.

(2) Instream flow requirements.

(3) Mandatory reservoir requirements.

(4) Alternative storage capacities.

(5) Future irrigation demands.

e. Scope major hydrologic activities; choose models.

f. Prepare detailed HEMP.

F-3. Develop Hydrologic Data for Analysis

a. Load raw data into study database (usually HEC-Data Storage System (HECDSS)).

(1) Develop naming conventions/database structure. Ascertain computer requirements. Consult with experts where necessary.

(2) Download data from various sources.

(3) Rough check data viability by display or screening processor.

b. Process hydrologic data for model input (streamflow data). This is a very important and potentially time-consuming step in which a uniform database of streamflow is derived, to be used as inflows in reservoir regulation models. Although monthly data are typically used, a shorter time period (daily or more frequent) may have to be developed if flood regulation analysis is involved. Take full advantage of HEC-DSS-linked programs (STATS, DSSMATH, etc.) to evaluate and process data.

(1) Perform cross-station checks such as double-mass plots to reveal record inconsistencies. Evaluate and correct as necessary.

(2) Decide on period of record to be used, considering data availability and incorporation of significant events.

(3) Estimate missing data.

(4) Compute storage changes at upstream reservoirs. Adjust historic records to remove effects of historic upstream reservoir regulation.

(a) Convert elevations to storage, if necessary, for each project.

(b) Calculate adjusted streamflow at downstream stream gages.

(c) Accumulate storage adjustments where more than one reservoir is involved.

(d) Produce tabulations, statistical summaries for checks.

(5) Process/estimate irrigation depletion data. Correct historic records for changes in irrigation diversions.

(a) Review irrigation records; determine magnitude of impact on study.

(b) Decide on scope of effort.

(c) Compute year-by-year historic diversions and return flows.

(d) Estimate future irrigation depletions.

(e) Compute changes in irrigation: future-historic.

(f) Prepare final computation of corrected flows.

(g) Produce display statistics of final irrigation quantities to be used.

(6) Prepare final computations; display and check data and formatting for model input.

(a) Perform checking computations to check data validity (e.g., compute locals).

(b) Prepare final production of statistical summaries, displays.

(c) Prepare final formatting for model input.

c. Derive synthetic (stochastic) monthly flow record (optional). In addition to the historic period of monthly flows, it may be desirable to employ a synthetic flow sequence, derived by stochastic techniques. This would be particularly important when multiple-year critical periods are being encountered.

(1) Consult with HEC and others on best available programs and techniques to derive a stochastic flow record, given the basin configuration and analysis requirements.

(2) Review technical publications; find examples of applications.

(3) Obtain computer programs, run on test data.

(4) Determine scope and cost of work and benefits of using stochastic record.

(5) Prepare input to stochastic flow generator as program requires.

(6) Analyze output to ascertain its statistical soundness. Revise input as needed.

d. Derive historic or synthetic flood flows. A water supply investigation or storage allocation study may require analysis of flood control criteria. If so, historic and/or synthetic flood hydrographs are needed. Examples of synthetic floods are design floods such as the Standard Project Flood; or, different spacial and temporal flood patterns that appear plausible but have not been observed historically. Derivation of such events would employ a runoff model. (See Appendix D for generic HEMP guidance.)

F-4. Preliminary Analysis

Prior to extensive analysis with hydrologic models (or in place of, for small-scale studies) it may be desirable to perform manual, short-cut water conservation analyses. These include procedures such as (1) mass-curve analysis for identifying critical periods and estimating firm yields; (2) limited scope sequential accounting using a spreadsheet or DSSMATH; and (3) low-flow frequency or flow-duration analysis.

a. Obtain references and consultation on use of methodology as necessary.

(1) Search literature as necessary.

(2) Consult with HEC and others.

(3) Decide on methodology to use.

b. Obtain or construct spreadsheet, computer programs, or other computational procedures.

(1) Obtain or develop computer code.

(2) Test program/spreadsheet.

(3) Develop display routines.

c. Prepare data input for analysis procedure. (See Paragraph F-3.)

d. Obtain project demands, requirements.

(1) Analyze requirements for validity.

(2) Prepare input for program being used.

e. Perform analysis with nominated alternatives to be considered.

(1) Verify technique on current data, if possible.

(2) Execute technique with each alternative.

f. Display results, document as necessary.

F-5. Develop Models for Detailed Study

This phase of the analysis involves the setting up, calibrating, and testing of computer models that are to be used in the analysis. An important part of this effort also is the processing of basic data that are needed for the model simulations. The following outline assumes that a reservoir simulation model with a monthly time-step (e.g., HEC-5) is to be employed, for analysis of seasonal or multi-year reservoir operations. An additional potential evaluation preliminary to HEC-5 is the use of HEC-PRM, a "prescriptive" network-flow model which is used to investigate relative values of alternative operating objectives and strategies in a reservoir system. Also, for flood control evaluations a precipitation-runoff model coupled with a short-term reservoir system and basin routing model might be needed. This might be HEC-1 and HEC-5, the North Pacific Division (NPD) SSARR Program (Streamflow Synthesis and Reservoir Regulation), or the Southwest Division (SWD) Reservoir Simulation and Routing Program.

a. Derivation of prescriptive model: HEC-PRM (optional). A prescriptive model can be used in multiple-purpose reservoir systems to help define the most desired operation, given relative economic values (or penalties) assigned to operating constraints and objectives.

(1) Consult with HEC and/or other users of this model.

(2) Obtain program; develop understanding of its application, requirements, end products.

(3) Decide on use of program and scope of effort.

(4) Formulate basic model structure to represent reservoir system. Decide upon location of reservoirs, nodes.

(5) Define penalty functions at nodes and reservoirs.

(a) Coordinate with economics personnel for penalty function derivation.

(b) Obtain indicators of economic impact versus flow or stage: flood damage, power values, recreation, instream flow (fishery, water quality), navigation, irrigation, and municipal and industrial.

(c) Plot penalty functions and input into model.

(6) Execute model with first estimate of current conditions and constraints.

(7) Check results (seasonal reservoir elevations) against real-world conditions. Modify penalty functions to obtain intuitively "calibrated" model. Repeat model adjusting as necessary.

(8) Perform production runs.

(a) Sensitivity analysis of economic functions.

(b) Potential future changes in operating constraints.

b. Develop descriptive model for monthly routing, e.g., HEC-5. A descriptive model performs a period-by-period simulation of reservoir operation following rule curves and other operating variables. The rule curves represent alternative possibilities of operation, reflecting both existing and nominated alternative conditions. Either may have emerged from the results of the prescriptive model simulation performed above.

(1) Consult as necessary on use and application of model. Obtain program and test.

(2) Formulate basic model structure to represent reservoir system. Decide upon location of reservoirs, control points.

(3) Prepare reservoir model characteristics.

(a) Reservoir elevation/area/storage capacity tables.

(b) Powerhouse characteristics.

(c) Tailwater ratings.

(d) Outlet constraints (maximum, minimum, rate-of-change, etc.).

(4) Prepare river system characteristics.

(a) Irrigation diversion relationships.

(b) Routing characteristics (for flood hydrograph routing).

(c) Natural lake characteristics - elevation/storage/outflow.

(d) Evaporation.

(5) Prepare reservoir rule curves (existing conditions if for an existing system).

(a) Seasonal flood control curves.

(b) Seasonal proportional draft curves.

(c) Other rule curves.

(6) Develop procedures for output display and summary.

(7) Execute model for initial test runs. Check results for reasonableness against known conditions.

(a) Historic regulated flows at control points.

(b) Historic reservoir elevations.

(c) Historic power generation.

(d) Low flow (7-, 10-day volumes, etc.) and flood frequency curves.

(8) Adjust model parameters to obtain a calibrated and tested model. Repeat above steps as necessary.

c. Develop daily (or shorter period) flow routing model.

(1) Determine basin configuration for model.

(a) Control/damage points.

(b) Routing reaches.

(c) Diversions.

(d) Lake characteristics.

(e) Backwater effects.

(2) Derive routing characteristics for individual reaches.

(a) Choose routing method and model.

(b) Obtain data to derive routing coefficients.

(c) Determine local inflows.

(d) Perform routings.

(e) Adjust model characteristics as necessary until calibration is achieved.

(3) Verify total basin model by simulating historic records and comparing with observed data.

F-6. Alternative Evaluations

This task is the "heart" of the water control management study, requiring repeated simulations with nominated alternatives of reservoir operating policies and procedures. It would be performed in close coordination with the interdisciplinary planning team. Alternatives may have been suggested by the prescriptive model, if used, or by the team's agreed-upon formulations.

a. Define nominated alternative; prepare operating rule curve or other criteria accordingly.

b. Execute model; display and examine results.

(1) Seasonal reservoir elevations - number of refill failures, frequency curves, etc.

(2) Instream flow frequency, duration.

(3) Flood frequency curves.

(4) Power generation.

(a) Firm energy.

(b) Average energy.

(c) Capacity.

c. Repeat with alternatives; perform sensitivity tests as necessary.

d. Prepare model results for briefings, public meetings, etc., as necessary.

e. Document results.