Appendix B
Hydrologic Engineering Management Plan for Flood Damage Reduction Feasibility-Phase Studies

B-1. Introduction

This generic HEMP is appropriate for hydrologic analysis associated with a typical USACE flood damage reduction feasibility study. The intent of the hydrologic engineering analysis would be to determine existing and future stage-frequency relationships at all key points in the study area, along with flooded area maps by frequency. This analysis would be performed for without-project and for various flood reduction components which are considered feasible for relief of the flood problem.

B-2. Preliminary Investigations

This initial phase includes reviewing literature 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) Previous USACE work.

(b) U.S. Geological Survey (USGS) (or other Federal agency) reports.

(c) Local studies.

(d) Hydrologic engineering analyses from reconnaissance report.

(e) Initial Project Management Plan.

(f) Other.

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

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

(b) State.

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

(d) Railroads.

(e) Industries.

(f) Other.

(5) Scope major hydrologic engineering analysis activities.

(6) Prepare detailed Hydrologic Engineering Management Plan.

b. Obtain study area maps.

(1) County highway maps.

(2) USGS quadrangle maps.

(3) Aerial photographs.

(4) Others.

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

d. Field reconnaissance.

(1) Interview local agencies and residents along the stream and 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-sectional 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-sectional locations. Consider

dictating notes to a hand-held tape recorder to get a complete and detailed record.

e. Write survey request for mapping requirements and/or cross sections and high water marks.

B-3. Development of Basin Model

This phase of the analysis involves the selection of historic events to be evaluated, the development of runoff parameters from gauged data (and/or regional data from previous studies) to ungauged basins, and the calibration of the basin model to historic flood events. This step assumes at least some recording stream gauge data is 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, highwater marks, etc.).

(2) From USGS rating curves and time versus stage relationships for each event, develop discharge hydrographs at each continuously recording stream gauge. Estimate peak discharge from floodcrest gauges.

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

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

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

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

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

(d) Consider types of alternatives and future assessments.

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

(a) Average subarea totals--isoheytal maps.

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

(6) Determine best estimates of unit hydrograph and loss rate parameters for each event at each stream gauge.

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

(a) Starting values of parameters.

(b) Rainfall totals and patterns (different weightings of recording rain gauges).

(8) Fix most stable parameters and rerun.

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

(10) Resimulate 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 gauge 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.

(b) Temporal distribution--weighting in accordance with information from nearby recording raingages.

(2) Average subarea loss rates.

(a) From adopted values of optimization analyses.

(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 gauges and physical basin characteristics.

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

(c) From similar gauged or known basins.

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

d. Channel routing characteristics.

(1) Modified puls from water surface profile computations (HEC-2).

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

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

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 area-capacity data (elevation area-storage relationships).

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

f. Generate hydrographs. Including the routing information of paragraph B-4, generate historic runoff hydrographs at locations of interest by combining and routing through the system for each flood.

B-4. Hydraulic Studies

These studies are used to determine water surface profiles, economic damage reaches, and modified puls channel routing criteria.

a. Prepare water surface profile data.

(1) Prepare cross sections (tabulate data from each section).

(a) Make cross sections perpendicular to flow.

(b) Ensure sections are typical of reaches upstream and downstream of cross section.

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

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

(3) Bridge computations--estimate where floods evaluated 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. Check elevations. Manually check all differences in water surface elevations across the bridge that are greater than 3 ft.

d. Obtain rating curves. 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.

B-5. Calibration of Models to Historic Events

This study step concentrates on "debugging" the hydrologic and hydraulic models by recreating actual historic events, thereby gaining confidence that the models are reproducing the observed hydrologic responses.

a. Check hydrologic model.

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

(2) If no stream gauges exist, check discharges at rating curves developed from water surface profiles at high water marks. Consider accuracy of gauged discharge measurements, + or - 5 percent or worse.

b. Adjust models to correlate with high water marks by ±1 ft (rule of thumb--may not be applicable for all situations).

c. Adopt hydrologic and hydraulic model parameters for hypothetical frequency analysis.

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

The next phase of the analysis addresses how often specific flood levels might occur at all required points in the study watershed. This operation is usually done through use of actual gauge data (when available) to perform statistical frequency analyses and through hypothetical storm data to develop the stage-frequency relationships at all required points.

a. Determine and plot analytical and graphical frequency curves at each stream gauge. Adopt stage/discharge frequency relations at each gauge. Limit frequency estimate to no more than twice the data length (i.e., 10 years of data should be used to estimate flood frequencies no rarer than a 20-year recurrence interval event).

b. Determine hypothetical storms.

(1) Obtain hypothetical frequency storm data from NOAA HYDRO 35, NWS TP40 and 49, or from appropriate other source. Where appropriate, develop the standard project and/or the probable maximum storm.

(2) Develop rainfall pattern for each storm, allowing for changing drainage area within the watershed model.

c. Develop corresponding frequency hydrograph throughout the basin using the calibrated hydrologic model.

d. Calibrate model of each frequency event to known frequency curves. Adjust loss rates, base flow, etc. The frequency flows at ungauged areas are assumed to correlate to calibrated frequency flows at gauged locations.

e. If no streamflow records or insufficient records exist to develop analytical frequency curves, use the following procedure:

(1) Obtain frequency curves from similar nearby gauged basins.

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

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

(4) Plot all the frequency curves (including other methods if available) and based on engineering judgement adopt a frequency curve. This curve may actually be none of these but simply the best estimate based on the available data.

(5) 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.

f. Determine corresponding frequency water surface elevations and profiles from the rating curves developed by the water surface profile evaluations.

B-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 H&H 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 reflecting decreased time-to-peak and decreased storage.

(2) Loss-rate coefficients reflecting increased imperviousness and soil characteristics changes.

(3) Routing coefficients reflecting decreased travel times through the watersheds hydraulic system.

d. Operate the hydrology model and determine revised discharge-frequency relationships throughout the watershed for future without project conditions.

B-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 include both structural (reservoirs, levees, channelization, diversions, pumping, etc.) or nonstructural (flood forecasting and warning, structure raising or relocation, flood proofing, etc.). Considerably less hydrologic engineering effort is necessary for modeling non-structural alternatives compared to structural.

a. Consider duplicating existing and future without-project hydrologic engineering models for individual analysis of each alternative or component.

b. Model components. 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. The charts given in Chapter 3 of EM 1110-2-1416 contain more information on the analysis steps for each of the following alternatives:

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

(2) Levees--adjust cross-sectional geometry based on proposed levee height(s). Evaluate effect of storage loss behind levee on storage-outflow relationships and determine revised discharge-frequency relationships down stream and upstream, if considered significant.

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

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

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

c. Evaluate the effects of potential components on sediment regime.

(1) Qualitatively--for initial screening.

(2) Quantitatively--for final selection.

d. Consider 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.

e. Perform alternate evaluation and selection. 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 B-8 could be relatively straightforward for one or two components or quite complex, requiring numerous reiterations as more cost and design information is known as project refinements are made. Paragraph B-8 is usually the area of the HEMP requiring the most time and cost contingencies.

B-9. Hydraulic Design

This paragraph and paragraph B-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 reporting process.

a. Reservoirs--dam height, spillway geometry, spillway cross section, outlet works (floor elevation, length, appurtenances, etc.), scour protection, pool guide taking line, etc.

b. Levees--levee design profile, freeboard requirements, interior drainage requirements, etc.

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

d. Diversions--similar to channel design, also diversion control (weir, gates, etc.)

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.

B-9. Prepare H&H Report in Appropriate Level of Detail

The last step will be to thoroughly document the results of the technical analyses in report form. Hydrologic and hydraulic information presented will range from extensive for feasibility reports to very little for most FDM's.

a. Text.

b. Tables.

c. Figures.