Appendix C
Hydrologic Engineering Management Plans for Analysis of Interior Flood Damage Reduction Measures, Napa, California

C-1. Background

a. The Hydrologic Engineering Center (HEC) is performing an interior flood hydrology study of the City of Napa, CA, for the U.S. Army Engineer District, Sacramento. The district is considering a series of levees to reduce the flood damage potential to the city caused by flooding of the Napa River, which flows through the center of the town. Interior flooding that would result because of the levees must be addressed as part of the plan. The study is a preconstruction engineering and design reaffirmation study.

b. The initial task was for HEC to develop a Hydrologic Engineering Management Plan (HEMP) to be used in performing an interior flood hydrologic engineering analysis for the study area. The plan, or HEC's proposal, was to be the basis for deciding if HEC would proceed with the technical study. The district funded HEC $5,000 to develop the HEMP. The final HEMP that was agreed upon is attached as Exhibit C-1.

C-2. Hydrologic Engineering Management Plan Development

a. The development of the HEMP for the Napa study was based on several discussions and reviews. These included discussions with the district's technical and project management staff, review of available information including that from previous studies, review of engineer manuals and other guidance (USACE 1988a, 1990, and 1992), and a field reconnaissance of the study area.

b. The study and project managers, engineers, and economists made presentations and met with the HEC staff to review the Napa study. Two subsequent meetings between HEC and the district's hydraulics staff were held to scope the interior study and to determine the information the district would provide. Maps and previous reports were provided to HEC. A detailed field reconnaissance was conducted by HEC and a meeting was held to review the study with a representative of the Napa City Engineering staff.

c. Key issues identified were the potential effect of San Pablo Bay tidal fluctuations on the exterior stages of the lower study area reaches, tieback levees and associated closure of openings in the highly urban area of Napa Creek, definition of the flow patterns for the interior areas, and analysis of the minimum facilities for the interior areas. The limited rainfall and stream gauge records for the study area also present problems. The district is to provide significant guidance, and where possible, data to address these issues. HEC has retained (under contract) the recently retired city engineer of the City of Napa to assist with specific aspects of the existing flow patterns and storm sewer system.

d. Hydrologic engineering analysis of the interior areas is to be performed using the HEC-Interior Flood Hydrology (HEC-IFH) program (USACE 1992). HEC will establish the with- and without-project conditions for the interior areas. Several size gravity outlets and pumping station capacities will be investigated.

e. HEMP strategy and procedures were defined using an annotated outline format. Study cost estimates are based on the tasks and the assumption that a junior engineer will perform the analyses under the direction of a senior engineer. Cost estimates include actual engineers' salaries times a factor of 2.8 to account for overhead. Overhead charges include secretarial and reproduction expenses. The total HEC cost to perform the study is $65,000. This is based on the district providing HEC a substantial amount of precipitation, runoff, exterior stage, and storm sewer alignment data. The cost is estimated to be more than $150,000 if performed entirely by HEC. A Gant style schedule was subsequently developed based on study milestones defined by the district and the major study tasks to be performed.

Exhibit C-1

C-1-1. Introduction

a. This Hydrologic Engineering Management Plan (HEMP) is developed for the Sacramento District to be used in hydrologic engineering analysis of interior flood damage reduction measures for the City of Napa, CA. Objectives of the hydrologic engineering analysis are to determine (a) the minimum outlet facility associated with the line-of-protection, (b) existing and future stage-frequency relationships for without-project conditions, (c) stage-frequency relationships for a range of gravity outlet and pumping station sizes and configurations for the interior areas, and (d) a formulated set of viable flood damage reduction plans for each interior area (with the assistance of the district staff).

b. The HEMP includes a proposed schedule, person-day, and cost estimate for the hydrologic engineering tasks that HEC would be responsible for completing. These tasks include those described in Sections C-1-5, C-1-6, and C-1-7, "Minimum Facilities Analysis," "Formulation and Comparison of Interior Flood Damage Reduction Measures," and "Technology Transfer." HEC will also be responsible for the portions of Section C-1-4 which deal with the assessment of local flooding when the Napa River is below flood stage. A major HEC goal is to provide the district with the capability of applying HEC's Interior Flood Hydrology (HEC-IFH) program. The degree to which HEC is involved in the formulation process is negotiable. The district will provide stage-damage relationships and other data required to perform the expected annual damage computations for each plan. Cost estimates of the flood damage reduction measures and plans are also to be provided by the district. The district will be responsible for those tasks described in Sections C-1-2, C-1-3, and C-1-4, including preliminary investigations, data development and assembly, and evaluation of without-project conditions for the Napa River. Some of the tasks described in this plan are required for the general hydrologic engineering investigations for the levee, floodwall, and channel improvement features of the Napa River Project. Accordingly, several of the tasks may have already been accomplished. Design requirements for conveyance systems, inlet and outlet works, and cost estimates for project components are not included in the Hydrologic Engineering Management Plan.

C-1-2. Preliminary Investigations

This initial phase includes conducting 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 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) Discuss study type, scope, and objectives.

(3) Review available documents.

(a) USGS reports.

(b) Previous Corps work.

(c) Local studies.

(d) Other.

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

(a) Local agencies.

(b) State.

(c) Federal (USGS, SCS, USBR, etc.).

(d) Railroads.

(e) Industries.

(f) Other.

(5) Scope major hydrologic engineering analysis activities.

(6) Prepare Hydrologic Engineering Management Plan.

b. Obtain study area maps.

(1) County highway maps.

(2) USGS quads.

(3) Aerial photographs.

c. Existing storm sewer design and configuration. The existing and any proposed storm sewer layout, discharge design capacities, and elevation of the inverts of the conveyance network are important for defining drainage areas, minimum facilities, and invert elevations of major conveyance to outlets, gravity outlet inverts, pumping station on-off elevations, and design criteria for inlet and outlet works.

(1) Determine layout and design of existing systems (usually obtained from local public works department or City Engineer).

(2) Determine layout and design of potential future systems. Local drainage system enhancements that have been planned and designed by local interests should be accommodated.

(3) Determine location of flow concentration at the line-of-protection where gravity outlets or pumps may be located and the layout of collector/conveyance systems adjacent to line-of-protection to concentrate flows at these locations where required.

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

(1) Napa River from downstream of the project through the upper end of project.

(2) Major ditches, channels, in the interior areas that will convey flood waters to the interior area outlets.

e. Field reconnaissance. It is important to establish a relationship with Napa area field office counterparts such as Director of Public Works, City Engineer, and other local, state, and federal agency staff people. These people can be key contacts throughout the study. Other field activities are described below.

(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 Manning's "n" values for later use in water surface profile computations.

(4) Take photographs or slides of outlet inverts and ditches that will be cut off by the line-of-protection, bridges, construction, hydraulic structures, and floodplain channels and overbank areas at cross-section locations.

f. Survey request. Write survey request for mapping requirements and/or cross sections and high water marks for Napa River and interior area conveyance systems.

C-1-3. Data/Information Assembly

a. General. Data/information assembly is required for the analysis of the interior area. It includes data for both the interior and exterior (Napa River) areas. The information is applicable for any analytical method, but is specifically targeted for application of the HEC-IFH computer program, and assumes that the analyses will be conducted using both a continuous record and hypothetical event approach. An assessment of HEC-IFH as an appropriate model should be made as early as possible.

The continuous record analysis is the most straightforward approach because of the tidal effects on Napa River stages at interior outlet locations and the need to investigate the coincidence of exterior stages on gravity outlet flows and pumping discharges. Potential problems with the continuous analysis approach are lack of data and poor definition of the interior runoff system. The hypothetical event analysis would enable some refinement of the interior runoff system, but presents problems with the tidal effects and coincident interior and exterior storm analyses.

(1) Define interior areas to be studied. Consideration must be given to alignment of the line-of-protection, minimum facility requirements, runoff topology, topography of local ponding areas, present storm sewer systems and potential for additional storm water collector/conveyance systems.

(2) Delineate interior subbasins for each area considering locations needed for stage-frequency relationships and effects of the storm sewer system.

(3) Select computation time interval (Δt) for this and subsequent analyses. The peak discharge of hydrographs at gauges, normally three to four points on the rising limb of the unit hydrograph, must be defined adequately. Routing reach travel times should also be considered, as should the location and types of flood damage reduction measures to be analyzed. The importance of using a small time interval is dependent on the size of the available ponding area and the associated flow attenuation at the outlets.

b. Rainfall data. This activity includes the assembly of historical storm records and hypothetical frequency event data.

(1) Obtain and verify historic rainfall records of nearby recording and nonrecording rain gauges. Determine weighting of gauges for each interior subbasin.

(2) Develop hypothetical frequency storm depth-frequency-duration relationships for general rain and local storms.

(3) Determine the characteristics of the SPS.

c. Runoff and channel routing data. Interior runoff hydrographs may be computed using HEC-IFH or imported from an external HEC-DSS file generated by a different program. For example, the HEC-1 program may be used to perform the runoff and channel routing of a complex system (more than two subbasins). Externally determined hypothetical or period-of-record runoff hydrographs may be imported into HEC-IFH and used in the computations.

(1) Determine interior subbasin drainage areas, unit hydrograph methods, and variables.

> **NOTE**: HEC-IFH does not use kinematic waves, but HEC-1 can be used to compute hypothetical runoff hydrographs using kinematic waves and imported into HEC-IFH. The use of the kinematic wave approach is not possible for the continuous record analysis unless the runoff sequences are generated by another program (other than HEC-1) and imported to HEC-IFH. An alternative would be to use a HEC-1 model with kinematic wave and 1-in. of runoff to generate unit hydrographs for each interior area. These unit hydrographs could be entered into HEC-IFH and used for hypothetical event and/or continuous simulation analysis.

(2) Determine loss rate methods and values. These include monthly rates for continuous record analysis and event variables for hypothetical event analyses.

(3) Determine base flow. Continuous simulation analysis can incorporate monthly rates, and hypothetical event analysis can incorporate an initial rate and recession variables.

(4) Determine streamflow routing method and parameters.

d. Interior ponding area data.

(1) Develop elevation-area relationships for each ponding area adjacent to line-of-protection. (User should specify 15-20 points to define the relationship.) HEC-IFH will automatically generate the storage values. The minimum value should be at or below the lowest invert elevation to be analyzed for that ponding area. The maximum value should be above the highest stage anticipated in the analysis. (The program will not extrapolate above or below these maximum or minimum elevations.)

(2) If applicable, develop the discharge-elevation relationship for the ditch that connects the ponding area to the gravity outlet and/or pump. (Required only if the ponding area is not adjacent to the outlets at the line-of-protection.)

e. Exterior stage data. These data must include continuous stage hydrographs considering the historic patterns of Napa River discharge values coincident with any tidal effects on the exterior stages at the outlet locations of each interior area to be studied. The hypothetical storm analysis would likely involve analysis assuming storms centered over both the interior area and Napa River drainage basin. There is no apparent straightforward manner to account for tidal effects with the hypothetical approach, although a coincidence weighting method, based on percent time (probability) of the stages of the San Pablo Bay associated with a series of hypothetical flood events occurring for each stage, may be appropriate.

(1) Obtain the period of record for elevations of the San Pablo Bay at the mouth of the Napa River. The time interval must be sufficiently small to capture tidal effects (6-hr stages.)

(2) Obtain the period of record of the discharge values of the Napa River at appropriate gauge locations. Determine if adjustments to the discharge values are required for the outlet locations of each interior area to be analyzed.

(3) Develop a family of rating curves at the outlet locations based on various San Pablo Bay elevations and Napa River discharges. The analysis requires running a series of water surface profiles for various bay elevations.

f. Gravity outlets. Determine typical gravity outlet information and operation criteria.

(1) Determine appropriate gravity outlet locations based on local conveyance systems, storm sewer system layouts and invert elevations, and ponding area locations.

(2) Define typical gravity outlet data: lengths from levee or floodwall dimensions, etc.; inverts/slope from storm sewer and ponding area elevations; box or circular; concrete or MP, etc.; entrance and exit configurations.

(3) Define gravity outlet operation criteria: head differential for closing, any gate closure requirements.

(4) Develop cost estimates for various gravity outlet types and sizes.

g. Pumping stations. Determine typical pumping station data and operation criteria.

(1) Define criteria for number of pumps including base flow pump, back-up units, etc.

(2) Define pump characteristics: requirements for on/off elevation determination (may vary monthly in HEC-IFH); head-capacity-efficiency relationships.

(3) Develop cost estimates for various pumping capacities.

h. Auxiliary flow data. Auxiliary flow includes auxiliary inflow to the interior subbasin, diversions out of the system, seepage inflow from the exterior (Napa River) to the interior area, and overflow out of the interior area.

(1) Determine head-versus-seepage relationships for each interior area.

(2) Determine diversions and diversion rates out of the system, and auxiliary inflow hydrographs, if appropriate.

(3) Determine overflow potential and, if required, the pond elevation-overflow discharge relationship.

i. Water surface profile data. Water surface profile analyses are used to determine water surface elevations and rating relationships for the Napa River (and perhaps major conveyance channels to the interior outlets), flood damage reaches, and modified Puls channel routing criteria.

(1) Cross sections (tabulate data from each section). Make cross sections perpendicular to flow. Sections should be typical of reaches upstream and downstream of cross section. Develop effective flow areas.

(2) 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 noneffective flow areas. Refine "n" values from field reconnaissance and from analytical calculation and/or comparison with "n" values determined analytically from other similar streams.

(3) Bridge and culvert computations. Estimate where floods evaluated will reach on each bridge and select either: (a) normal routine, or (b) special routine.

j. Stage-damage relationships. Representative stage-damage relationships for the interior areas at runoff concentration points (proposed outlet locations) are required for identification of interior plans which maximize net flood damage reduction benefits.

C-1-4. Without-project Conditions Analysis for Minimum Facility Evaluation

a. General. The without-project analysis involves determination of conditions both without the line-of-protection and with the line-of-protection in place. Stage-frequency relationships for these conditions are needed to select a minimum facility. The without-project condition used to formulate and evaluate the interior flood damage reduction measures will assume the minimum facility is in place and is therefore described in Section C-1-5, "Minimum Facility Analysis." The procedures described assume that HEC-IFH will be used to determine interior area local hypothetical storm event runoff hydrographs.

b. Napa River flooding without line-of-protection. This information should be available from the line-of-protection design analysis. It is used to determine Napa River flood elevations over the interior areas and to compare the elevations with those caused by local flooding when the Napa River is below flood stage (see paragraph C-1-4*c*). A series of stage-frequency relationships for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent chance exceedance events should be developed and provided for each interior area.

c. Local runoff flooding without line-of-protection. This analysis is for local flooding without the line-of-protection in place, assuming the present storm sewer system is in place and the Napa River is at or below flood stage. It is the target condition for the minimum outlet facility analysis. Stage-frequency relationships including the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent chance exceedance events are developed for each interior area as described below.

(1) Define precipitation and runoff data sets for computing hypothetical storm runoff hydrographs.

(a) Enter local hypothetical storm depth-duration-frequency data for defining the PRECIP module for hypothetical event analysis (HEA).

(b) Enter appropriate rainfall-runoff and routing parameters, if any, to define RUNOFF module.

(2) Develop normal depth rating for the interior runoff approach to the Napa River. Napa River is assumed to be low and, therefore, there will be no backwater effect.

(3) Define a plan using the precipitation and runoff data and exercise HEC-IFH to compute interior runoff hydrographs. The program computes the interior area runoff and routes the runoff to the area outlet for each hypothetical event. Peak flow is displayed for each hypothetical storm frequency.

(4) Determine interior stage-frequency relationship. The peak flow for each hypothetical storm runoff event will be used with the normal depth rating to determine the maximum interior elevation for each event. The stage-frequency curve will be derived graphically.

d. Local runoff flooding, with line-of-protection and no outlets. This analysis assumes the line-of-protection is in place and the local conveyance systems to the Napa River are blocked by the line-of-protection. It becomes the without line-of-protection condition for the minimum facility analysis and represents an upper bound for the stage-frequency relationship with the minimum facility in place. Stage-frequency relationships including the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent chance exceedance interior runoff events are developed for each interior area. The analysis is the same as described for the without line-of-protection condition, except the runoff will now pond behind the line-of-protection.

(1) Enter appropriate elevation-area relationship and interior ditch rating, if required, to define the ponding area adjacent to the line-of-protection POND module.

(2) Define a new plan using HEA and exercise HEC-IFH to compute interior stage-frequency relationship. The program computes the interior area runoff and routes the runoff to the ponding area where it is stored assuming no outlet to the Napa River. The program displays the maximum interior elevation for each hypothetical event and a graphical fit stage-frequency curve.

e. Assess future without-project conditions impacts. Assess future conditions effects on Napa River interior area local runoff flooding. The effect may well be minimal. 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. The analysis will derive a set of future condition stage-frequency relationships for the conditions described in paragraphs C-1-4*b*, C-1-4*c*, and C-1-4*d*.

(1) Identify future development. From future land use planning information obtained during the preliminary investigation phase, identify areas of future urbanization or intensification of existing urbanization.

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

(b) Storm drainage requirements of the community (storm sewer design frequency, onsite detention, etc.)

(c) Other considerations and information.

(2) Select future years in which to determine project hydrology.

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

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

(3) Adjust model hydrology parameters for all areas affected by future land use changes.

(a) Unit hydrograph coefficients reflecting decreased time-to-peak and decreased storage.

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

(c) Routing coefficients reflecting decreased travel times through the watershed's hydraulic system.

(4) Operate hydrologic models, including HEC-IFH using local storm HEA, and determine revised discharge-frequency and/or stage-frequency relationships throughout the watershed for future without-project conditions.

C-1-5. Minimum Facility Analysis - Without-project Conditions for Evaluating Interior Measures

a. General. The minimum facility of the individual interior areas will be justified as part of the line-of-protection. The stage-frequency relationships for the with-minimum-facility-in-place condition becomes the without condition for evaluating potential interior flood damage reduction measures. The residual damage with the minimum facility in place is thus the target for damage reduction of implemented interior flood damage reduction measures. The minimum facility should provide interior flood relief such that during low exterior stages (gravity conditions) the local interior area runoff will pass the design storm sewer outflow without an increase in elevation over natural or without line-of-protection conditions. Flood stages with the minimum facility in place should not be significantly higher than stages for less frequent flood events assuming it can be established that these less frequent flood events have and will occur when the Napa River is below pre-project flood stage.

b. Evaluate range of minimum facilities. The minimum facility will normally include gravity outlets but may include pumps if the coincidence of flooding between the interior and exterior is high. For example, the Napa River is high enough to block gravity outlets, but is below pre-project flood stage and flooding occurs in the interior from local runoff. The sequence will be to evaluate a series of gravity outlets; then pumps, if required. The physical characteristics of the gravity outlets should be established prior to the analysis and refined as the analysis proceeds. The analysis should be performed for the range of hypothetical frequency events.

(1) Analyze series of gravity outlet capacities and configurations using local storm hypothetical event analysis and assuming unblocked conditions. The analysis is the same as that for the local flooding with the line-of-protection in place (Section C-1-4), except gravity outlets through the line-of-protection are incorporated.

(a) Define 3 or 4 gravity outlet configurations (modules) of increasing capacity. Outlet sizes should encompass the largest storm sewer size or ditch capacity at the line-of-protection.

(b) Define a new plan for each gravity outlet capacity to be evaluated and, using local storm HEA, exercise HEC-IFH and determine the interior stage-frequency for each outlet.

(2) Compare stage-frequency relationships of gravity outlets with the storm sewer design event and with the local area flooding stage-frequency relationships both with (no outlet) and without the line-of-protection in place.

(3) Select minimum facility. The minimum facility is selected to assure that expected flooding and associated damages from the local, interior area with the line-of-protection in place are no worse than flooding from the local area (not including the Napa River) and associated damages were before the line-of-protection was in place.

(4) Perform analysis for all interior areas and for expected future conditions. The expected future condition hydrologic parameters are incorporated and the analysis is repeated using the selected minimum facility. If the selected facility is not efficient to assure that local flooding with the

line-of-protection and the minimum facility in place will not be worse than what would be expected in the future without the project, upgrade the selected minimum facility accordingly.

c. Develop without-project condition stage-frequency relationship with the minimum facility in place. After the minimum facility is selected, it is evaluated using continuous simulation analysis and general rain hypothetical event analysis. The results of the analysis can be used to test the effectiveness of the minimum facility gravity outlet by assessing local runoff flooding that occurs during blocked conditions. Results of the analysis establish the base plan or without-project condition stage-frequency relationships for evaluating additional interior flood damage reduction measures as described in Section C-1-6.

(1) Define Continuous Simulation Analysis (CSA) plan using HEC-IFH that incorporates period-of-record interior area rainfall, existing condition runoff characteristics, existing interior ponding area, and the selected minimum facility, seepage, and period-of-record exterior stages at the interior area outlet.

(a) Define PRECIP module for CSA. Historical, period-of-record rainfall data for representative recording and non-recording gauges are used. The data are generally retrieved from NWS magnetic tapes or from available CD ROM and stored in an HEC-DSS file where they can be imported directly into HEC-IFH. Gauge weightings are specified for determining basin average precipitation.

(b) Define rainfall, runoff, pond, and outlet parameters. Existing condition rainfall-runoff and routing (RUNOFF module) parameters, ponding area characteristics (POND module), and the minimum facility are defined for CSA in the same manner as previously described for HEA.

(c) Define exterior stage (EXSTAGE module) data for CSA. Historical, period-of-record discharge, or stage hydrographs for main river gauges are obtained from available electronic media and stored in an HEC-DSS file for direct importing to HEC-IFH. Napa River period-of-record stage hydrographs at each interior outlet location are determined by one of the following methods, each of which can be accomplished using HEC-IFH.

- Exterior stage from historical, period-of-record stage hydrographs. Typically, the gauge data (index location) will need to be transferred to interior area outlets (primary and secondary) locations by incorporating transfer functions that relate index stage to primary and secondary outlet locations. These transfer relationships are developed from water surface profiles and are used by HEC-IFH to determine the exterior stage at the outlets for each time period during pond routing computations.

- Exterior stage from historical period-of-record discharge hydrographs. Typically, discharge hydrographs are more readily available than stage hydrographs. If discharge hydrographs are employed, a rating curve is incorporated which is used to convert flow to stage at the index locations. The stages are transferred to primary and secondary outlet location as described above, if required.

- Exterior stage from computed period-of-record discharge. If recorded stages or flow are not available, discharge hydrographs can be computed from rainfall-runoff analysis. Flow is converted to stage and stage transferred to the outlet locations as described above, if required.

- San Pablo Bay impact on exterior stage for CSA. If it is determined that tidal fluctuations in the San Pablo Bay influence the stages at the interior area outlet locations, a family of rating curves for each interior outlet that gives Napa River stage based on Napa River flow and stage in San Pablo Bay is required. These relationships are developed by determining water surface profiles for various stages in the bay. Analysis period San Pablo Bay stages are also required and could be obtained from historical data or generated based on known tidal cycles. These data are used by HEC-IFH to determine the appropriate exterior stage at the gravity outlet for each time period in the analysis.

(d) Define seepage (AUXFLOW module) data for seepage inflow from the Napa River to the interior ponding area, if appropriate. A relationship between differential head (the exterior stage minus the interior stage) and seepage inflow is defined and incorporated. No seepage occurs when the interior stage is equal to or greater than the exterior stage. Data are developed based on field measurements or empirical information.

(2) Exercise HEC-IFH using the developed CSA data modules and specify either a partial duration or annual series frequency analysis. Results will include a graphical fit interior stage-frequency relationship.

(3) Examine the periods of local flooding (Napa River below pre-project flood level) and determine the extent of local flooding caused by blocked gravity outlet conditions. If flooding resulting from this condition is considered worse than pre-project local flooding, the minimum facility may require the addition of a pump to alleviate induced flooding. In this case, pumping capacity would need to be evaluated using the CSA plan data. See Section C-1-6 for evaluating pumping capacity.)

(4) Define a new general rain HEA plan using HEC-IFH that incorporates precipitation depth-duration-frequency data for

general rain events occurring over the Napa River watershed as well as the interior area. Exterior stages will be computed from rainfall-runoff analysis and an appropriate stage-discharge rating for the Napa River at the interior area outlet. San Pablo Bay tidal effects on hypothetical exterior stages will be incorporated using coincident frequency analysis, if required.

(a) Define a new precipitation data set (PRECIP module) using HEA by assembling general rain depth-duration-frequency storm data for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent chance exceedance events occurring over the local interior areas as well as over the Napa River watershed.

(b) Define rainfall, runoff, pond, outlet, and seepage parameters. Existing condition rainfall-runoff and routing (RUNOFF module) parameters, ponding area characteristics (POND module), the minimum facility, and seepage are defined in the same manner as previously described.

(c) Exterior stages for each hypothetical event are computed discharge hydrographs and a specified rating. The discharge hydrographs are computed from rainfall-runoff analysis as described above.

(d) San Pablo Bay impact on exterior stage for general rain HEA. If it is determined that tidal fluctuations in the San Pablo Bay influence the stages at the interior area outlet locations, it may be appropriate to develop a bay elevation-duration relationship and use coincident frequency analysis to account for the bay effect on the stage-frequency curve.

(5) Exercise HEC-IFH using the developed HEA data modules. Results will include a graphical fit interior stage-frequency relationship. This curve will help to determine if rare combinations of events are being captured in the continuous simulation analysis and will help shape the final without-project condition stage-frequency relationship.

(6) Final stage-frequency relationships. Make appropriate adjustments to the CSA stage-frequency relationship based on the results of the without line-of-protection and with line-of-protection and no outlet plans developed from local storm HEA and the results from the general rain HEA.

(7) Future without-project condition stage-frequency relationships with the minimum facility in place. Repeat above CSA and HEA incorporating expected future condition hydrologic parameters and develop future condition stage-frequency relationships.

C-1-6. Formulation and Comparison of Interior Flood Damage Reduction Plans

a. General. The objective of this task is to formulate a set of flood damage reduction plans for each interior area. The condition with the line-of-protection and the selected minimum gravity outlet in place becomes the without-project condition for evaluating additional features such as additional gravity outlets, pumping stations, additional ponding area storage, and nonstructural measures. The first step is to find the economic optimal size and configuration for additional gravity outlet capacity with the minimum facility in place. The second step is to identify the economic optimal pump capacity, assuming that the minimum facility and the optimal gravity outlets are in place. The third step is to explore trade-offs of pumping capacity versus ponding area storage and would include evaluation of nonstructural measures to increase nondamaging ponding area storage. Finally, the conceptual feasibility of other flood damage reduction actions such as flood warning-preparedness and institutional arrangements would be evaluated. The district and HEC will work closely together in the plan formulation and comparison process. The following paragraphs describe the procedures in more detail and show how both continuous simulation and hypothetical event analyses can be applied.

b. Determine economic optimal gravity outlet capacity.

(1) Stage-frequency relationships.

(a) Define new plans for evaluating gravity outlets using data previously defined for the CSA with the minimum facility in place. Existing condition rainfall (PRECIP module), runoff and routing (RUNOFF module) parameters, ponding area characteristics (POND module), minimum facility (GRAVITY module), and seepage (AUXFLOW module) are the same as used for the CSA analysis of the selected minimum facility.

(b) Assemble outlet characteristics for several standard size outlets and develop composite rating curves for each using HEC-IFH.

(c) Develop five or six gravity outlet configurations (modules) with one or more gravity outlets in addition to the minimum facility outlet, each module representing an incremental increase in total outlet capacity.

(d) Exercise HEC-IFH, and using CSA, develop several plans which incorporate the gravity outlet modules, described above, and determine interior stage-frequency relationships for each plan.

(e) Define new plans, and using HEA, assemble general rain depth-duration-frequency storm data for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent chance exceedance events occurring over the local interior areas as well as over the Napa River watershed, and determine the interior stage-frequency relationships for each plan. The analysis is similar to that described for the general rain HEA of the minimum facility but will include analysis of several plans incorporating the additional gravity outlet capacities defined in (c) above. The relationships will help determine if rare combinations of events are being captured in the continuous simulation analysis. These relationships will also help establish the upper end of the graphical curve determined in (d) above.

(f) Define additional plans using HEA and local storm depth-duration-frequency data for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent chance exceedance events occurring over the interior area with unblocked conditions on the Napa River. Determine the interior stage-frequency relationships for each plan. This relationship will help to determine if rare combinations of events are being captured in the continuous simulation analysis and may help to shape the final stage-frequency relationships.

(g) After examining the results of the continuous and hypothetical event analyses, adopt a final stage-frequency relationship for each gravity outlet plan.

(h) Develop future condition stage-frequency relationships by repeating the described steps using expected future hydrologic condition data, if appropriate.

(2) Determine equivalent expected annual damages (EAD) for each gravity outlet plan.

(a) The district will provide cost estimates of various sized gravity outlets and stage-damage relationships by damage category for existing and potential future conditions.

(b) EAD for each plan will be determined using the developed stage-frequency relationships, the stage-damage relationships, and HEC's EAD program.

(c) A plan comparison array including residual equivalent EAD, expected annual inundation reduction benefits, average annual costs, and net benefits will be developed identifying the economic optimal plan. This plan will most likely become the base plan for evaluating additional measures.

c. Determine economic optimal pumping capacity.

(1) General. If the analysis for determining the economic optimal gravity outlet indicates that gravity outlets are very effective (considerable peak runoff attenuation from ponding and little coincidence between interior runoff and high exterior stages), there would be little residual flood damages with the selected outlet in place. If gravity outlets are shown to be ineffective and residual damages are significant, pumps may be justified. The same steps described for evaluating additional gravity outlet capacity are appropriate for identifying the economic optimal pumping capacity. Some differences in the analysis are described below.

(2) Base condition. The base condition for evaluating pumping capacity is with the minimum facility and, most likely, the economic optimal gravity outlet configuration in place. Several plans are evaluated against the base plan, each with an incremental increase in pumping capacity.

(3) Pump operation criteria. Pump on and off elevations must be determined so that the pumps come on to effectively reduce damaging stages and turn off when stages drop below damaging levels. However, pumps should not cycle on and off over very short periods of time. Therefore, "on" elevations are usually set below flood stage and "off" elevations are usually set 1 to 2 ft below "on" elevations. "On" and "off" elevations can also vary by season (monthly) if appropriate. Two or more pump units make up a pumping plant or station. Several units that can be used for backup and which can be operated in phases to step up total capacity usually prove to be more effective than a few large-capacity pumps.

(4) Type of events and analyses. CSA, general storm HEA, and local storm HEA with blocked gravity conditions would be performed to derive final existing and future condition stage-frequency relationships, as described above, for the gravity outlet plans.

d. Evaluation of increased storage capacity. It is prudent to investigate the trade-offs between pumping capacity and ponding area storage capacity. Pumps are expensive and an increase in storage capacity will typically allow reduction in required pumping capacity. There are several measures that can be evaluated, including increasing the physical size of the ponding area and implementing nonstructural actions that will reduce the damage for a given ponding stage.

(1) Increasing the size of ponding areas. The potential for excavating larger ponding areas should be explored, if physically possible. The sensitivity of ponding area size versus pumping capacity can be readily determined using HEC-IFH. The plan with the identified economic optimal gravity outlet and pumping station would be the base plan for determining if excavation is feasible.

(2) Nonstructural measures. Temporary evacuation, relocation, flood proofing, and other nonstructural measures

that reduce susceptibility to damage (and increase available storage) should be evaluated. Residual damages for evaluated plans would be revised based on new stage-damage relationships resulting from implementing the nonstructural measures.

e. Final plan selection. Other social, institutional, and environmental issues, including the management of future development, and flood warning and preparedness programs, would also need to be evaluated in the final plan selection for each interior area. HEC will assist the district in this evaluation, if desired.

C-1-7. Technology Transfer

a. Study report. A study report that documents the Napa River interior flood analysis will be prepared. The text of the report will generally follow the topics in Sections C-1-4, C-1-5, and C-1-6 of this plan, and a discussion of the results, including tables and figures.

b. HEC workshop. A 1 or 2 day workshop will be conducted at HEC for district staff covering the Napa River interior flood analysis using the HEC-IFH, and EAD programs. It is intended that materials developed for this workshop will be used in future HEC PROSPECT courses on interior flood hydrology.

PROPOSAL FOR HEC ASSISTANCE TO THE SACRAMENTO DISTRICT FOR ANALYSIS OF INTERIOR FLOOD DAMAGE REDUCTION MEASURES, NAPA RIVER, CA

A. Resource Requirements.

Task Description	Person-Days
1. Preliminary Investigation Assistance	2
2. Data Assembly Assistance	5
3. Without-Project Analysis	10
4. Minimum Facility Analysis	15
5. Analysis of Flood Damage Reduction Measures	
a. Stage-frequency for gravity outlets	10
b. Stage-frequency for pumping station(s)	10
c. Formulation of alternative plans	20
d. Plan comparison and evaluation	5
6. Study Documentation and Technology Transfer	20
7. Coordination/Meetings with District Office	10
TOTAL	107

Estimated total cost at $600.00/day = $64,200.00

Use $65,000.00

(Note: Cost includes secretary, reproduction, etc.)

B. Schedule of Work. (See attached schedule)

Figure C-1. HEMP for Napa, CA (Continued)

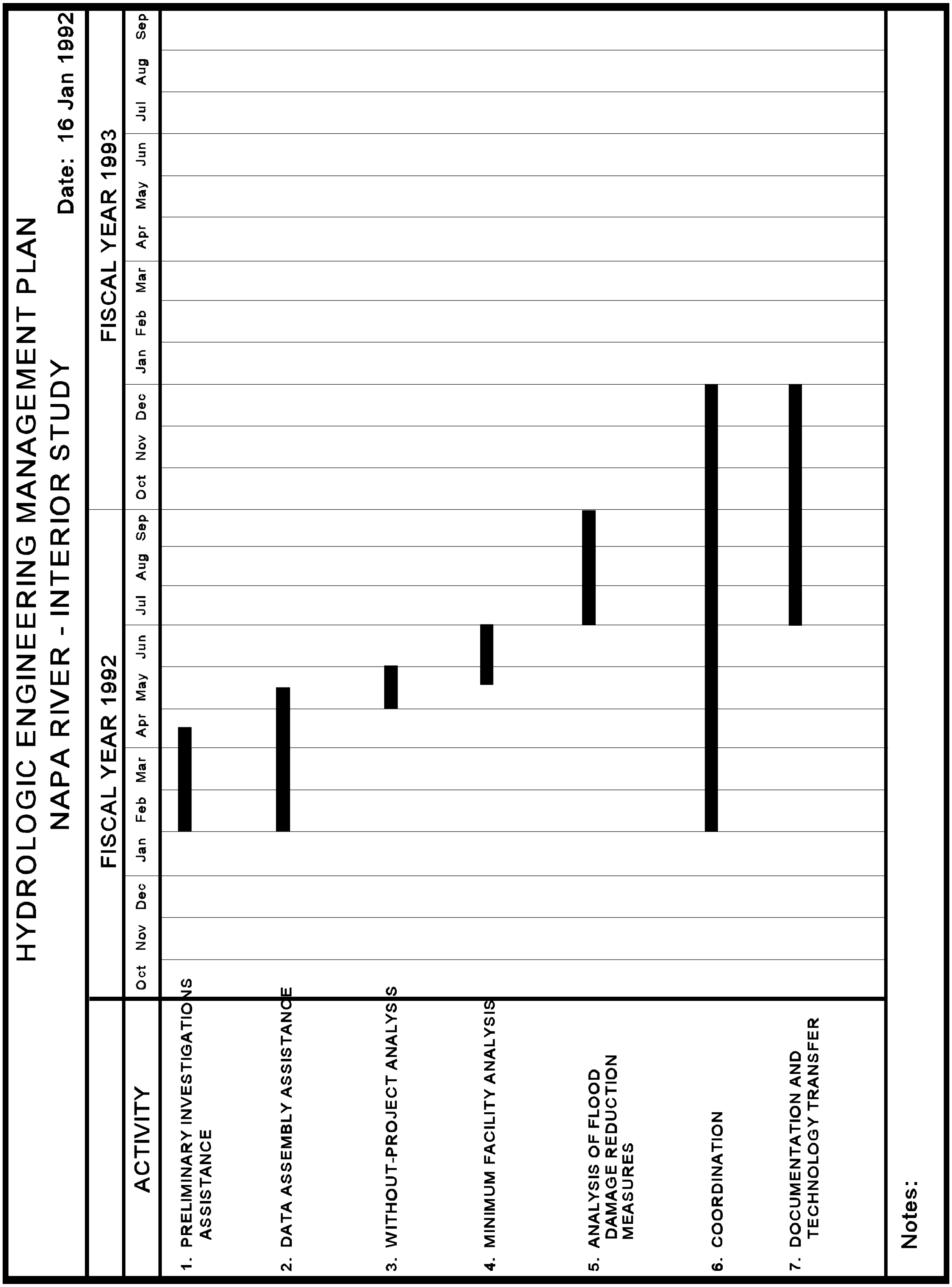

Figure C-1. (Concluded)