Chapter 5
Analysis of Interior System Flood Damage Reduction Measures

5-1. Overview

a. This chapter describes the formulation and evaluation of a set of flood damage reduction plans for interior areas. The condition with the line-of-protection and the selected minimum facility becomes the without-project condition for evaluating additional features. If the line-of-protection is in place, the existing system is the without condition for analysis of enhanced interior facilities. The enhanced facilities may include additional gravity outlet capacity, pumping stations, ponding area storage, and nonstructural measures. Figure 5-1 conceptually shows an interior system with gravity outlets and pumps.

b. The criteria specified in the "Planning Guidance Notebook" (ER 1105-2-100) and EM 1110-2-1413, are principal references for analysis of interior systems. The application of continuous record and hypothetical event analytical procedures using HEC-IFH is detailed in this chapter. More detailed examples of its application are provided in the case example studies described in Appendices D and E.

5-2. Without-project Conditions

a. General. Existing and future without-project conditions analyses are required to determine the value of implementing flood damage reduction measures. The initial hydrologic engineering goal is to define the flood hazard, performance, and operation procedures of the existing without-project condition. Observed event information is important to define these characteristics and validate the analysis results. The continuous simulation and/or hypothetical event options of HEC-IFH may be used in the analyses depending on the information available and the nature and complexity of the interior and exterior system.

b. Storm sewer design and configuration. If the levee and minimum facilities are in place, the layout, planned changes, design discharges, and invert elevations of existing and potential future storm sewer systems must be considered as part of the with- and without-project conditions for the interior analysis. See section 4-4*b*.

c. Existing without-project conditions.

(1) The existing without-project condition used in the evaluation of interior flood damage reduction measures is the initial focus. The line-of-protection and minimum facilities are assumed in place, as described in Chapter 4 and EM 1110-2-1413. The analysis is the same as that for the minimum facility except now the dependence and coincidence of interior and exterior flooding must be considered. This is instead of just the unblocked outlet condition used to size the minimum facility for most studies. Input data and analysis would essentially be the same as described in Chapter 3. The existing without-project conditions plan is described in HEC-IFH by the PRECIP, RUNOFF, POND, EXSTAGE, GRAVITY (minimum facility) modules, and perhaps the AUXFLOW and the PUMP modules.

(2) The HEC-IFH analysis results should be validated from several perspectives. Historic events (stage-frequency, durations, coincidences, etc.) may be analyzed and the model calibrated to observed and reasonable results. The percent runoff for historic and hypothetical frequency events and monthly recovery rates for continuous record analysis must be reasonable, as should other factors such as gravity flow, seepage and general operation and performance. The results should be carefully inspected and the flood hazard (stage-frequency, depth and extent of flooding, duration, warning time, etc.), performance, and operation of the system clearly defined. Performance includes how the interior system responds for a range of events and conditions. Operation should closely approximate that presently used in a physical and institutional sense. This normally is the gravity outlet but includes pumps if they presently exist.

d. Future without-project conditions.

(1) Hydrologic engineering analysis of future without-project conditions typically involves urbanization effects on watershed runoff. The process includes identification of areas for the most likely future urbanization or intensification of existing urbanization from future land use planning information obtained during the preliminary investigation phase. This includes types of land use and conveyance system changes. Conveyance system changes refer to the storm drainage and authorized flood control projects likely to be implemented by locals. Other future alternate land use conditions may be assessed if necessary. The future years in which to determine project hydrology are normally specified by the study manager. Generally, the start of project operation or base year (existing conditions may be appropriate), and some year during the project life (often the year when land use planning information is available) are selected.

(2) The HEC-IFH plan for future without-project conditions normally consists of the existing conditions plan with changes only to the runoff and perhaps routing characteristics defined in the RUNOFF module. Runoff would relate to urbanization effects on the unit hydrograph and loss rates. Routing changes might be related to alterations in the conveyance channel prior to entering the lower ponding area or encroachment into the natural storage remote from the line-of-protection. Other changes could also occur depending on the study area and any projected flood damage reduction measure enhancements.

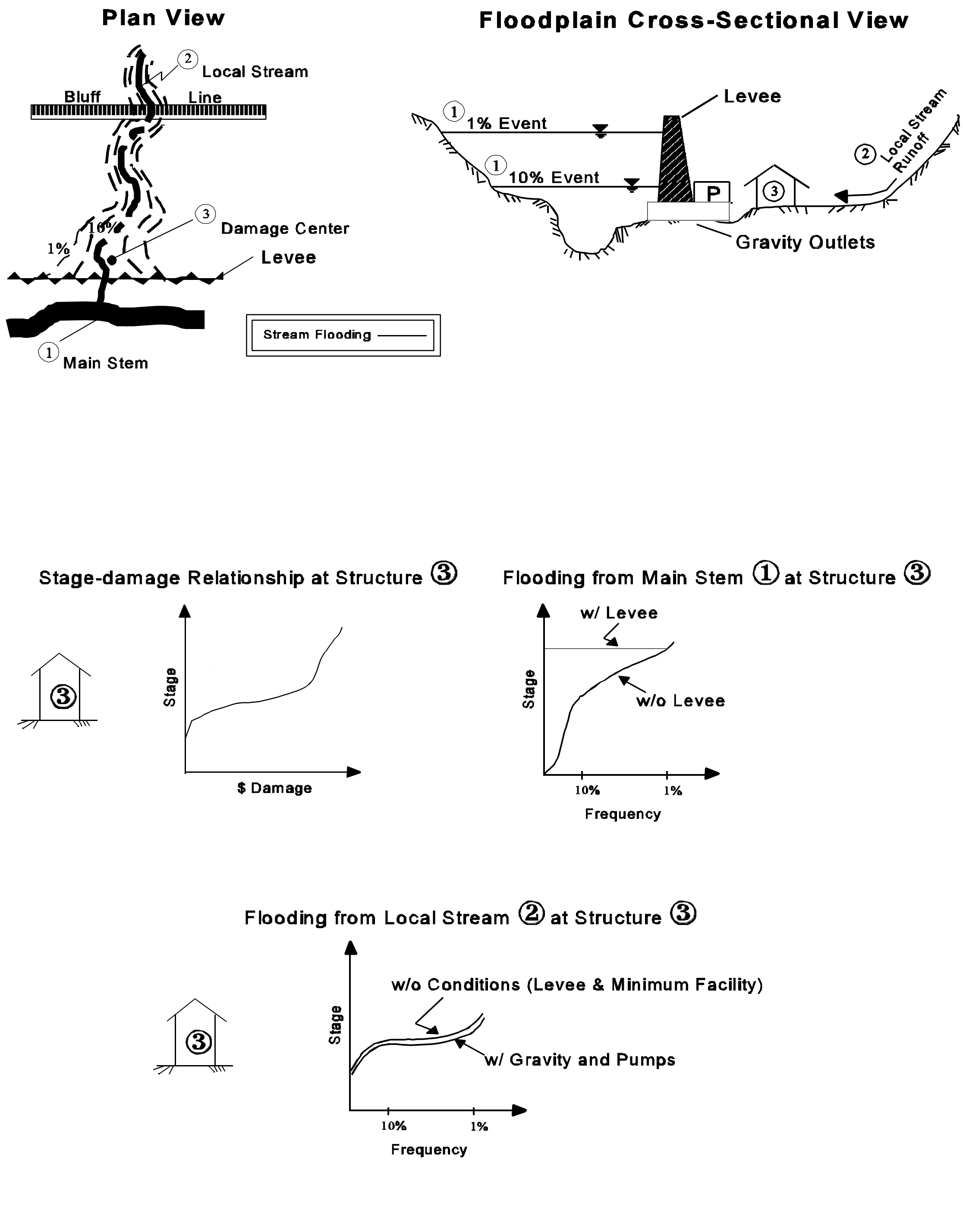

Figure 5-1. Interior system with gravity outlets and pumps

5-3. Flood Damage Reduction Measures

a. General. A range of potential flood damage reduction measures and performance standards should be addressed in the study of interior areas. These measures may be structural or nonstructural in nature. Emphasis here is on gravity outlets, detention or ponding at or near the line-of-protection, and pumping stations since they represent primary flood damage reduction measures for interior areas. A comprehensive array of other measures combined into plans should also be investigated.

b. Gravity outlets.

(1) Gravity outlets are defined as culverts, conduits, or other openings that permit discharge of interior waters through the line-of-protection. The size of the gravity outlet is based on the economic, environmental, and social aspects associated with the outfall ditch, gravity conduit, and ponding area analyzed as a collective system. The size selection must be based on the functional operation of the outlet for a range of expected events and not on a single design event. Where possible, gravity outlets should be located at or near where the line-of-protection intersects the natural or existing conveyance system or detention area, called the primary location. It is normally more feasible to provide one large gravity outlet than several smaller ones. This may require an interceptor system along the line-of-protection.

(2) Most gravity outlets are corrugated metal or reinforced concrete pipes, or reinforced concrete box culverts. Guidance in EM 1110-2-3104 states that reinforced concrete pipe should be used exclusively for urban levees and agricultural levees where substantial loss of life and/or property can occur due to embankment failure at the outlet location. For agricultural levees where no substantial loss of life and/or property can occur, corrugated pipe with a protective coating may be used. In those cases, fill heights of levee embankment must be less than or equal to 3.66 m (12 ft) above the pipe invert, and pipe diameters cannot exceed 0.914 m (36 in.). Corrugated pipe between 0.914 and 1.52 m (36 and 60 in.) may be used if service conditions are investigated in detail and safety requirements are satisfied. Corrugated pipe with a diameter greater than 1.52 m (60 in.) should never be used. Some new gravity outlet pipes are made of reinforced fiberglass and polyethylene that do not rust and have very low flow resistance.

(3) Gravity outlets should have a sufficient invert elevation and slope to minimize siltation in the outlet. An exterior stage-exceedance duration table or plot can help pick an invert in which the exterior stage is below the invert most of the time. HEC-IFH can determine and plot a stage-exceedance duration table, if continuous simulation data are available. Likewise, the invert must be low enough to flow full before interior depth reaches damage elevation.

(4) The type of inlet chosen defines the entrance loss coefficient, which affects the design headwater elevation. Chapter 6 of the HEC-IFH user's manual lists these coefficients for both corrugated metal pipes and concrete pipes and box culverts. Inlet designs using a headwall and wingwall or a precast concrete or corrugated end section give lower loss coefficients and therefore greater flow capacity. Sometimes, in locations where large debris can reach the inlet, a debris retarder or trashrack is needed.

(5) The gatewell for the gravity outlet is normally located on the riverside of the line-of-protection (see Figure 5-2). This is done so that if problems in the gravity outlet under the line-of-protection occur, the gate can be closed and exterior water cannot enter the protected area. Hydrostatic pressure through a break or separation in the outlet will not jeopardize the stability of the earth levee or floodwall above it. Many Districts also provide flap gates at the discharge end of the gravity outlet to prevent backflow into the interior area when the outlet is open. Interior water could still flow into the exterior any time the interior ponding elevation exceeded the exterior.

(6) Gravity outflow rating curves are normally required to assess the outflow conditions of the major outlets. Rating curves should be developed for primary gravity outlets but may be combined for secondary outlets. Interior area discharge rating curves for gravity outlets are determined for a range of low to high tailwater conditions. Chapter 3 overviews the gravity outlet input data for HEC-IFH and Chapter 6 of the HEC-IFH user's manual describes the GRAVITY module concepts in detail.

(7) Existing gravity outlet operation criteria should be obtained from the agency responsible for operating the interior system. Analysis of modified operation procedures is part of the plan formulation process. The normal operational procedure is to release water in an attempt to follow the lowering of the interior stages while maintaining a small positive head. The lag time between interior and exterior peak stages may be a critical factor in the operation specification. Detention storage near the line-of-protection can reduce the capacity needed for outlets. Conveyance channels must be sized to assure that flows are conveyed to gravity outlets. The ditch rating curve option of the POND module may be used to approximate controlled inflow to the gravity outlet at the primary location.

Staff gauges are usually placed on both sides of the line-of-protection to effectively operate the gravity outlets. These gauges show the water surface elevation on each side of the line-of-protection and thus give the differential head between the inlet and outfall sides of the gravity outlet. When the exterior stage reaches a specified staff gauge stage or elevation, the gravity outlet gates are closed to prevent backwater flowing into the interior and to maintain the necessary storage in the ponding area. This elevation is called the gate closing elevation.

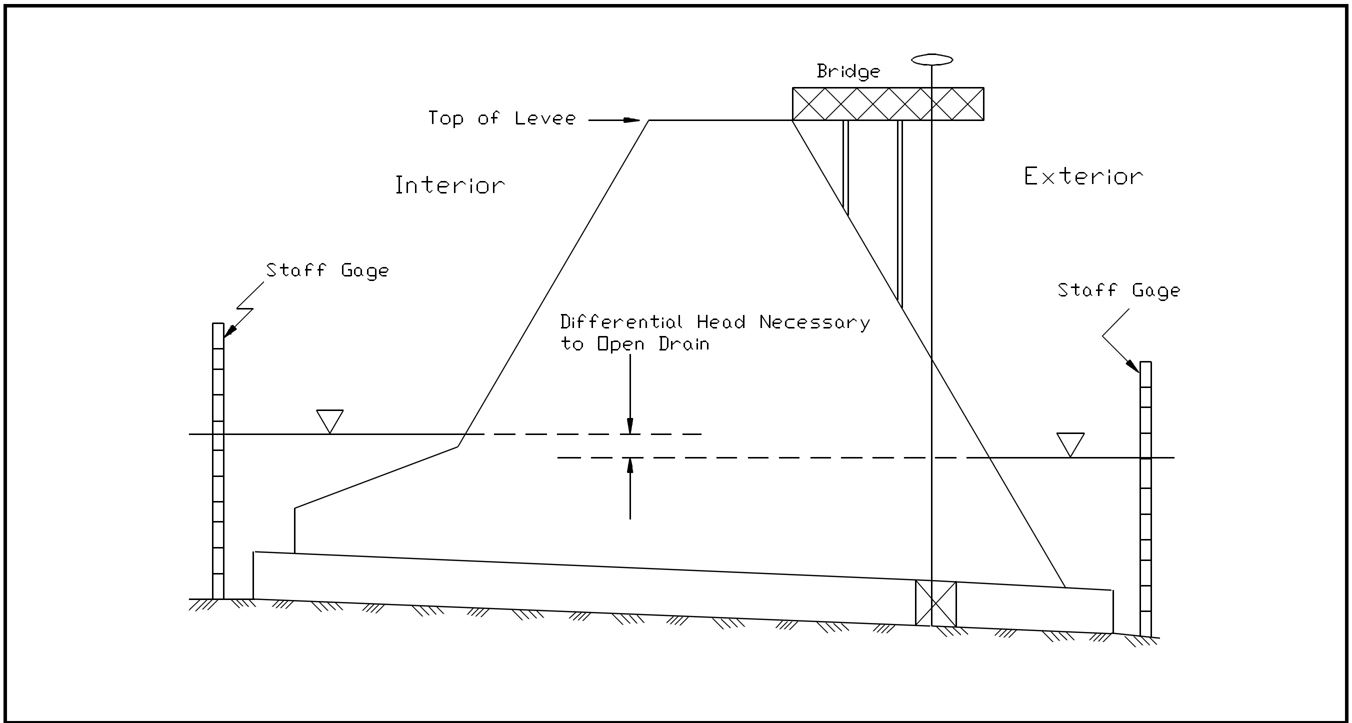

Figure 5-2. Gravity outlet concepts

Anytime the interior elevation is higher than the exterior, the gate could be opened to allow flow out of the interior until the differential becomes zero.

c. Pump stations.

(1) Pumps are designed to lift storm water and other interior flows over or through the line-of-protection to the exterior river, lake, or coastal areas as shown in Figure 5-3. Pump stations operate to reduce peak stages and duration of ponding when flow through gravity outlets is precluded or impeded by high exterior stages. Consideration should be given to setting these elevations so that the pumps may be operated at least once or twice annually for maintenance and testing purposes. Pumps may be used for storm runoff, groundwater and seepage, water accumulated from overtopping waves, and mixed flows with sanitary sewage.

(2) Pump stations are generally considered after analysis of gravity outlets and detention storage, since the initial and continuous operations, maintenance, and power costs of the stations are commonly significantly greater than other measures. For areas where interior and exterior flooding are highly dependent (high likelihood of blocked gravity outlets coincident with interior flooding), pumping may be the only means to significantly reduce interior flood stages. For areas with independent interior and exterior flood conditions, where coincident flooding is not likely, pumping facilities may not be required.

(3) Pump stations are typically located adjacent to the line-of-protection. Normally a larger capacity station is more desirable than several smaller ones. Gravity outlets may be offset if located near pump stations where significant direct flow access to both the pump and gravity outlets is unavailable.

(4) As with gravity outlets, pump stations should have staff gauges on both sides of the line-of-protection, unless the gravity outlet already has staff gauges. Pump start elevation should be set such that all pumps are in operation before the start of interior damage. The sequencing of the pumps is dependent on the approach channel's ability to deliver adequate water; therefore, an approach channel rating curve is required. The pump stop elevation is set below the damage elevation and although not necessarily tied to the channel rating curve, pumping should not continue if the capacity is not delivered by the channel. If the pump stop elevation is set too low, the sump would have to be lowered to maintain sufficient water depth over the impeller. A significant cost increase would occur in this situation.

(5) The pumping station should be aligned to allow direct flow patterns into the forebay from the conveyance channel or detention areas. The key, therefore, is to design the station with an evenly balanced flow distribution in the approach channel or pipe. A long straight approach of about 100 m (several hundred feet) is recommended as well as a straight approach through the station inlet into the sump area. A trashrack is located at the

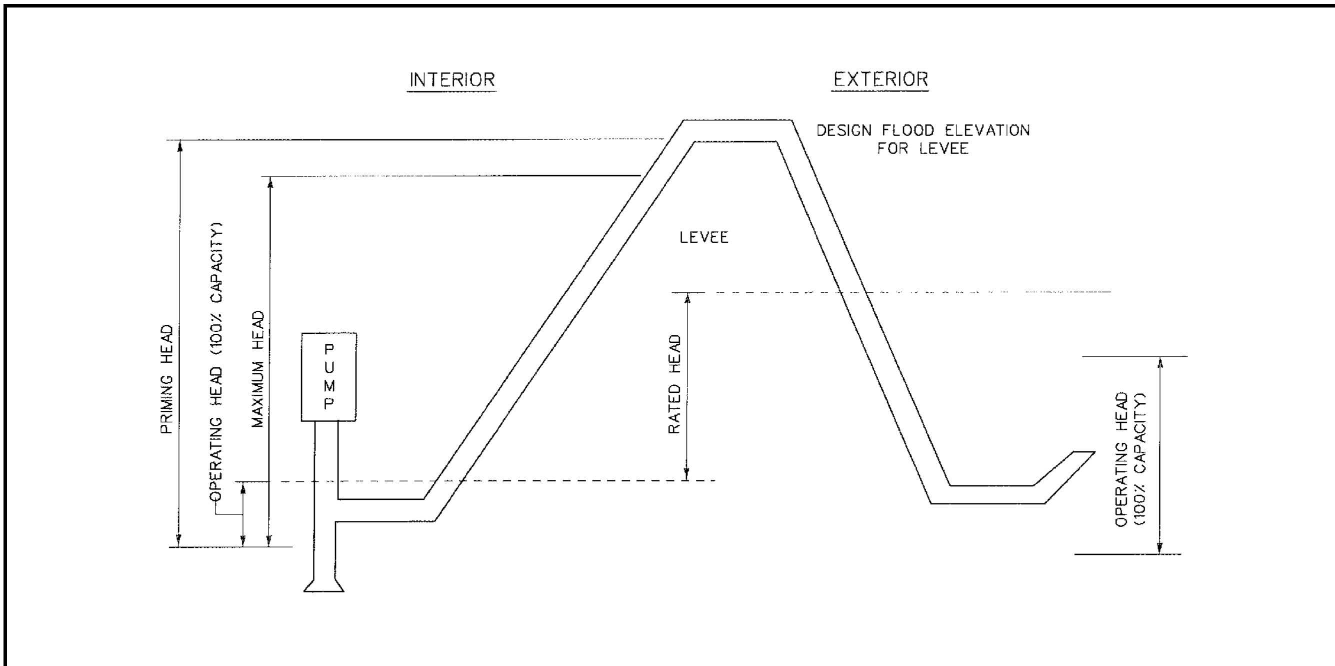

Figure 5-3. Pump station concepts

inlet to the station and should be designed to pass flow into the sump with a minimum of head loss and flow disturbance. For open channel approaches, reversing the invert slope away from the station, if practical, is done to minimize siltation and pumping station dewatering problems. The ability to maintain an even flow distribution minimizes vortex formation. If an unacceptable vortex forms during pump operation, it could eventually damage the impeller and pump bearings.

(6) The pumping station selection is part of the planning process. The feasibility of pumping stations is based on economics and other considerations. In general, the without-pump condition (with gravity outlets and detention storage implemented) must show adverse effects under present and the most likely future condition. Implementation of a pumping station must reduce the adverse effects sufficiently to justify the construction and operation of the facility. Finally, it must be demonstrated that the implementation of a pumping station is the most effective means of reducing the adverse effects.

(7) The feasibility study should investigate the general characteristics of the pumping station that might include number and type of pumps, and on-off elevations to the detail necessary for plan evaluation and selection. These and other features are finalized and detailed in the design phase. The number and types of pumps are determined to provide the total capacity developed in the planning study. Pump on-off elevations are specified. Pumping heads for efficiency and starting assumptions are specified for various combinations of interior and exterior stage conditions. Figure 5-3 shows key pump characteristics. The operating head, 100 percent efficiency, and maximum head are used to define the pump characteristics and efficiency used in planning and design studies.

(8) Additional hydraulic information besides the pump capacity is required. Various pumping heads needed for mechanical design are shown in Figure 5-3 and are described below.

(a) The priming head is the difference between the lowest pump start elevation and the center line of the discharge pipe at its highest point.

(b) The operating head considers the full range of interior and exterior elevations for pump operation. The operating head, also called the total head, is the sum of the estimated head losses and the static head. The estimated head loss is the summation of all the head losses for the pump discharge system, including friction loss, pipe bend loss, etc. The static head is the exterior river elevation minus the interior elevation at the pumping station. The data input to HEC-IFH for each pump unit analyzed gives the operating head information for a pumping unit at various flow capacities.

(c) The high head condition is the difference between the lowest stop elevation and the highest exterior elevation.

(9) First or operation floor elevations of pumping stations should be, as a minimum, at or above ground level to provide convenient access to equipment, to eliminate need for protection

against groundwater, and to simplify the ventilation of the operation areas. The consequence of exceeding pump design stage must be evaluated. Pumping and gravity outlet effects on exterior stages and operation of other downstream gravity outlets should be considered in locating, sizing, and designing the pumping station.

(10) The pumping station capacity in urban areas is generally determined by the physical performance of the facility and its effect on flood damage reduction, costs, and environmental and social factors. Station capacities in rural (agricultural type damage) areas are selected based on economic optimization.

d. Detention areas adjacent to line-of-protection.

(1) The use of detention areas can significantly reduce gravity outlet and pumping station size and costs. A detention basin may also increase the reliability of the system by providing additional time for appropriate operation before damaging water levels occur. A detention area may be natural or excavated sumps, or induced temporary ponding on vacant areas, streets, and parks. Only a few areas are typically available or selected. An interceptor system to collect and convey runoff along the line-of-protection is generally required.

(2) Topography, existing conveyance patterns, and land use usually govern the approximate locations of detention areas. Detention areas are normally located adjacent to the gravity outlet or pumping station, but may be remote from these facilities, connected by appropriately sized channels.

(3) In urban settings, application of nonstructural measures to surrounding structures may be warranted. This is done to gain incremental storage versus increased capacity of gravity outlet or pumping facilities. Detention basins can be designed to be environmentally attractive and contribute to community social goals in urban areas when used as parks and open spaces during periods not needed for runoff storage. Management of the functional integrity of the detention basin by preventing development encroachment and subsequent loss of storage capacity is critically important. Local agency agreements should specify requirements for maintenance of detention basin functional integrity throughout the project life.

e. Intercepting sewers and pressure conduits.

(1) These conveyance systems interconnect two or more existing sewers or channels within the line-of-protection for conveying their flows to gravity outlets, pumping stations, or pressure conduits, for combined discharge through the line-of-protection. Interceptor systems are designed to minimize the number of gravity outlets, pumping stations, and pressure conduits.

(2) Pressure conduits are pipes or closed conduits designed to convey interior flood waters through the line-of-protection under internal pressure. The inlet to the pressure conduit must be at a higher elevation than the river stage against which it functions. Some pressure conduits may serve as discharge lines for pumping facilities. The use of pressure conduits reduces the contributing interior runoff area and the magnitude and volume of flood waters that must be handled by other flood damage reduction measures.

(3) Detention storage adjacent to the line-of-protection is defined in the POND module of HEC-IFH. The elevation-area relationship is entered and the corresponding storage values calculated by the program. A ditch rating curve may be used to represent a channel link between the detention storage and primary outlet at the line-of-protection and thus govern the discharge to the outlet. Future conditions where the detention storage is encroached and thus reduced are modeled by adjusting the elevation-storage relationship appropriately. Sensitivity analysis of potential future development effects could be performed in this manner. Similarly, enhanced flood protection involving several excavation plans for the detention storage area may be readily evaluated.

f. Physical measures remote from line-of-protection. These measures are traditional structures such as channels, diversions, interior levees, and storage reservoirs remote from the line-of-protection. Their functional capability is therefore the same as with any other planning or design investigations involving flood loss reduction measures. Consequently, only the interrelationship with other specific interior measures will be emphasized. For the most part, the evaluation of these measures is performed outside HEC-IFH with the resulting time series hydrographs imported into HEC-IFH using the AUXFLOW module. Conversely, the HEC-IFH ponding area stages may be used as starting water surface profile elevations in the sizing studies of measures remote from the line-of-protection.

(1) Conveyance channels reduce flood losses for damage centers remote from the line-of-protection and collect and transport runoff and other interior waters to gravity outlets, pumping stations, and pressure conduits. Where possible, channels should follow natural drainage and conveyance routes. When this is not possible, consideration should be given to locating channels near and parallel to the line-of-protection. Channels may be required in combinations with detention basins to connect with gravity outlets or pumping stations. Channels may also be needed as exterior connections from the outlet works of gravity or pressure conduits or pumping stations to the river, lake, or ocean. The planning task is to approximately size and locate the channel system. The design task is to perform design in terms of size, location, gradient, and auxiliary control features of erosion protection and grade control.

(2) Diversions are used to transfer all or portions of the runoff from one location to another. They may collect flow for pressure conduits, transfer flow out of the basin (reduce the contributing area), and collect flow from areas to gravity outlets and pumping stations, thereby requiring fewer facilities. They may be designed to permanently alter conveyance systems or to operate only for discharges above (and below) certain values. Diversions may be operated as part of a coordinated system. They may also be used to bypass flow around damage centers.

(3) Remote detention basins (reservoirs) have characteristics similar to those described for detention basins adjacent to the line-of-protection. Bottomland detention basins may be natural sinks, oxbow lakes, or excavated sumps, or may be formed by levees. Hillside or bluff basins are really conventional reservoirs. Implementation of the remote basins may regulate flow to reduce the size of downstream interior flood loss reduction measures. Damage reductions at several downstream locations may be achieved, in contrast to local protection works that are effective only at their individual damage center. Detention basins may also retain sediment from the hillside or bluff areas and thus eliminate it as an interior area problem.

(4) Interior levees and walls along conveyance channels may be implemented as local interior protection features. These barriers are normally lower in height than the conventional main levees and thus failure is less likely to result in catastrophic loss. If the barriers are of sufficient height, and damage potential from failure is great, they are considered the same as the main line levees or walls. The interior levees may create secondary interior flooding problems that must be considered, though the magnitude would likely be minor. Implementation of these measures must meet criteria defined by "Flood Plain Management" (ER 1105-2-100) and other existing federal policy. Flood forecasting emergency-preparedness plans should be an integral part of implementation of interior levees and walls to reduce the potential for loss of life and property when the situation warrants.

g. Measures that permanently modify damage susceptibility of existing structures.

(1) Several types of nonstructural measures are designed to permanently modify damage potential of existing structures. They include: flood proofing (seals, earthen dikes, and walls), raising existing structures, and relocating of occupants and/or structures (damage potential) from the specified threatened area. The measures are designed to modify the damage potential of an area. They are typically implemented on a localized scale (such as a neighborhood) as opposed to structural and other types of nonstructural measures that often are designed to function for larger areas.

(2) Flood proofing and raising of structures to target elevations protect structures and their contents until the design limits are exceeded. These measures, applied to individual or small groups of structures, are generally less environmentally disruptive than structural alternatives. The measures do not reduce damage to vital services (i.e., water, gas, power), streets, bridges, and landscaping, and only slightly reduce the social impact and disruption associated with flood events. Seals, walls, and dikes are often significantly less reliable than other permanent measures.

h. Measures that manage future development.

(1) Management of future development reduces losses by requiring floodplain development and activities to be operated or located in a specific manner commensurate with the flood hazard. Land use development can be controlled by regulations such as zoning ordinances, building codes and restrictions, taxation, or the purchase of land in fee or by the purchase of a flood easement. Structures not precluded from floodplain locations by these measures may locate on the floodplain if constructed and maintained to be compatible with the recognized flood hazard.

(2) Regulatory actions and land acquisition can also cause new use of the floodplain. The measures are attractive from the perspective of managing development to reduce the future damage potential of the area and use of the floodplain for compatible purposes.

(3) Measures that manage future development are generally compatible with implementation of other structural and nonstructural measures. Regulatory actions may be incorporated as part of the agreements with local agencies or the local sponsor. For example, implementation of regulatory policies to preserve the storage and functional integrity of detention basins over the life of the project may be employed.

(4) The HEC-IFH analysis of the impact of implementing these measures and actions is performed similar to that for other alternatives. An exception is the most likely future condition development assumptions, which may be adjusted to reflect the management policies.

i. Flood forecasting-emergency preparedness plans.

(1) Flood emergency preparedness plans are flood emergency management actions and activities that reduce flood losses, minimize social disruption, and assist in recovery and reoccupation of flooded areas. The measures should not be considered instead of other feasible permanent structural or nonstructural alternatives due to their temporary nature and uncertain reliability during flood episodes. Preparedness plans, however, should be considered as interim measures until other flood loss reduction measures are implemented; as companions to, or enhancements of, such other measures; and as a means of

minimizing the risk of loss of life, flood damage, and social disruption if other methods are not feasible.

(2) Flood forecasting-emergency preparedness plans are generally compatible with other structural and nonstructural flood reduction measures. Implementation is more frequent in urban interior areas than in agricultural interior areas. Flood forecasting-emergency preparedness actions are usually feasible even if other structural and nonstructural measures are not.

(3) The HEC-IFH analysis results provide information on the flood hazard (frequency, stage, duration, and extent of flooding) that may be used directly in evaluation of flood warning-preparedness systems or in conjunction with other programs such as those used to compute water surface profiles. The implementation of flood warning-preparedness programs for interior systems may enhance the operation for large and complex systems, but will primarily improve the response so that more damage reduction may occur. The potential for loss of life is normally not a factor for interior systems due to typically shallow flooding, but would be for design exceedances for the line-of-protection.

5-4. Interior Analysis Using HEC-IFH

a. General.

(1) The formulation and evaluation process of interior flood damage reduction measures must be conducted within the framework of Corps guidance and regulations. The details of the hydrologic engineering and other analyses are study dependent. There is, however, an analysis progression that is applicable for most interior studies.

(2) The initial step is to determine the existing and future without-project conditions. The second step is to determine the configuration and feasibility for additional gravity outlet capacity assuming the minimum facility is in place. The third step determines the design and configuration of additional pump capacity, assuming that the minimum facility and the gravity outlets are in place. The next step explores tradeoffs of pumping capacity versus ponding area storage and includes evaluation of nonstructural measures to increase nondamaging ponding area storage. For studies with large and complex systems, such as many urban settings, traditional evaluation of flood damage reduction measures remote from the line-of-protection is often necessary. Finally, the feasibility of other flood damage reduction actions such as flood warning-preparedness and institutional arrangements would be evaluated. The following paragraphs describe the procedures and how both the continuous simulation and the hypothetical event analyses capabilities of HEC-IFH can be applied. Chapter 3 overviews the data entry and the general procedures for HEC-IFH applications. Appendices C, D, and E present a detailed strategy, and two case examples detailing the HEC-IFH analysis procedures, respectively.

b. Without-project conditions. Analyses of the existing and future without-project conditions are performed as previously described in Section 5-2.

c. HEC-IFH gravity outlet analysis. The following is a series of steps that may be used as a guide to tailor the gravity outlet analysis to a specific study. The goal is to determine the appropriate size and configuration of gravity outlets.

(1) Define new plans for evaluating gravity outlets using modules for CSA or HEA with the minimum facility in place. Existing condition rainfall (PRECIP module), runoff and routing parameters (RUNOFF module), ponding area characteristics (POND module), minimum facility (GRAVITY module), and seepage (AUXFLOW module) are from the CSA analysis of the selected minimum facility.

(2) Assemble outlet characteristics for several standard size outlets and develop composite rating curves for each using HEC-IFH. Alinement, invert elevations, number and size of outlets, and entrance and exit configurations are important considerations.

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

(4) Run HEC-IFH using the CSA option and develop several plans that incorporate the gravity outlet modules and determine interior stage-frequency relationship for each plan. A maximum annual interior elevation versus frequency plot comparing plans is illustrated in Figure 5-4.

(5) Test the additional capacity with the HEA-generated balanced storms over the interior and exterior basins for selected frequencies and determine the interior stage-frequency relationship for each plan if interior and exterior flooding can be highly coincident. The relationships help determine if rare combinations of events are being captured in the CSA. These relationships will also help establish the upper end of the graphical stage-frequency relationship.

(6) If the interior and exterior flooding can be independent and noncoincident, define additional plans using HEA and local storm depth-duration-frequency data for a range of exceedance frequency events occurring over the interior area for unblocked gravity outlet conditions. Determine the corresponding stage-frequency relationships for each plan. This relationship helps determine if rare local events are being captured by the CSA and helps define the frequency relationships.

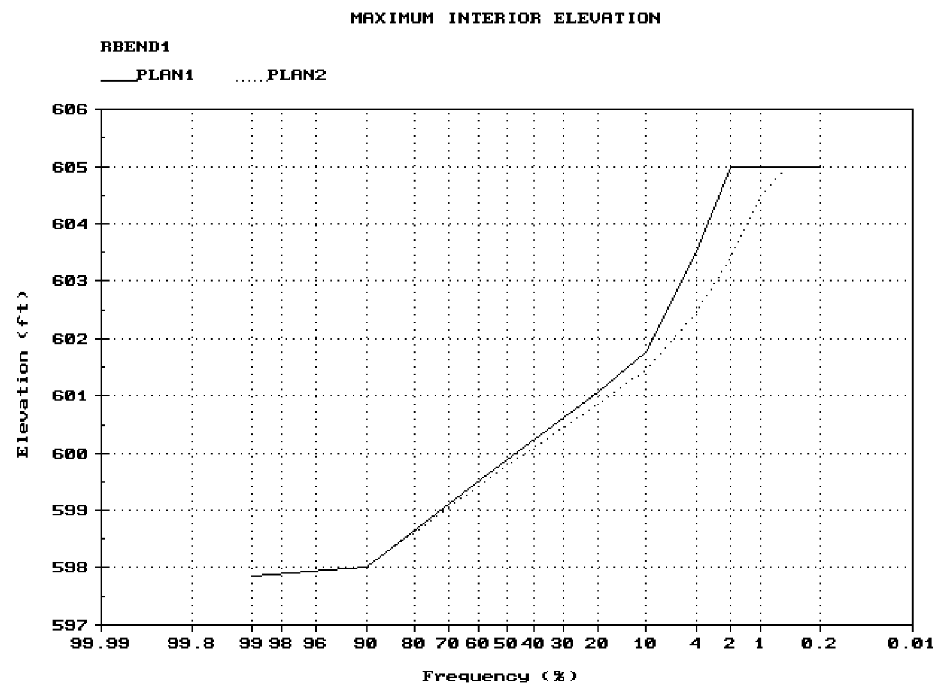

Figure 5-4. Plan comparison of stage-frequency relationships

(7) After examining the results of the CSA and HEA analyses, adopt a final stage-frequency relationship for each gravity outlet plan.

(8) If appropriate, develop future condition stage-frequency relationships by repeating the above process using the most likely and other (if required) future hydrologic conditions.

d. Selection of gravity outlets. The following are steps that may be used to determine the gravity outlet capacity at the primary location. Secondary outlet locations may use a less rigorous procedure if the locations are not critical.

(1) The HEC-IFH results should be reviewed for reasonableness. The gravity outlet should be sized such that the interior stage essentially follows the receding limb of the exterior stage hydrograph with consideration of the operating head differential. HEC-IFH's output results can show this graphically.

(2) An economic analysis is normally required for primary outlet locations to determine the NED (USACE 1990a) gravity outlet size. The cost engineering team member provides cost estimates of each gravity outlet HEC-IFH plan and the economist will provide stage-damage relationships by damage category for existing and potential future conditions. The expected annual damage for each plan is determined by the study economist using the developed stage-frequency relationships and the stage-damage relationships.

(3) A plan comparison array including residual equivalent expected annual damage (EAD), expected annual inundation reduction benefits, average annual costs, and net benefits is developed to identify the economically optimal plan. A similar table is shown for pumping station sizing in the next section. Other information on the flood hazard reduction, operation requirements, performance for a range of events and conditions, environmental and other factors should be considered in determining the recommended gravity outlet plan. This plan should be the base plan for evaluating additional measures. Normally the economically optimum plan is chosen.

e. Pumping station analysis overview. Pumping stations may not be attractive if the gravity outlets are effective in reducing the flood damage and if there is little coincidence between interior runoff and high exterior stages. Often, however, additional gravity outlets are not justified and significant residual damage exists. If most of the damage is from blocked conditions, pumps may be the only effective means of evaluating interior flood waters. The same general application steps for HEC-IFH used for additional gravity outlet capacity are appropriate for determining the economic optimal pumping capacity. Some differences and pumping station analysis considerations are described in the following paragraphs.

(1) The base condition for evaluating pumping capacity is with the selected gravity outlet configuration in place. Several pumping station plans are evaluated against the base plan, each with an incremental increase in pumping capacity.

(2) The pump operation criteria must be defined. Pump-on and pump-off elevations must be determined so that the pumps operate prior to the start of damages. Pump-on elevations are usually set below flood stage with pump-off elevations usually set at 0.3 to 0.6 m (1 to 2 ft) below pump-on elevations. If a levee stability problem exists when the exterior river reaches a certain stage, the pump-off elevation must be set for a higher stage. Two or more pump units generally make up total pumping capacity. Several units that can be operated in phases to step up to the total capacity may be more effective than one or two large-capacity pumps. Pump cycling can become a problem with a few large pumps and limited conveyance capability to the pumping station. Limited flow delivery capacity to the station or flow surges in sewer systems or at locations close to an upper basin with a very short time of concentration can cause cycling problems. Varying the capacity of the pump units and the on-off elevations minimizes pump cycling times.

(3) HEC-IFH can use up to ten pumping units for each interior pumping plan specified by the PUMP module. All pumping units are assumed to be located at the primary outlet location. The PUMP module input is summarized in Chapter 3 for CSA, and in Chapter 7 of the HEC-IFH user's manual. The operating data entered for the CSA and HEA is slightly different. For CSA, different values of pump start and stop may be defined for each calendar month of the year. For HEA, a single pump start and stop elevation is defined for use during the entire analysis.

(4) The CSA and HEA may both be used to evaluate the pumping station design and to derive the existing and future with-project conditions stage-frequency relationships for the pumping plans.

f. Economic analysis of pumping station plans. The following paragraphs describe the procedures for performing the economic analysis of pumping stations.

(1) The cost engineering team member provides cost estimates of several pumping station plans or sizes as were specified and evaluated. The stage-damage relationships previously provided by the economist are still applicable.

(2) An economic analysis is required for all pumping stations to determine the NED (USACE 1990a) pump capacity. The cost engineering team member provides cost estimates of each pumping station analyzed using HEC-IFH and the economist provides stage-damage relationships by damage category for existing and potential future with-project conditions. The expected annual damage for each plan or pumping station capacity is determined by the study economist using the computed stage-frequency relationships and the stage-damage relationships.

(3) The operation and maintenance costs of pumping stations are significant and an important factor, especially from the local sponsor's standpoint. HEC-IFH provides data such as the maximum pump head and the average annual days pumped. These data are evaluated by the electrical/mechanical engineer to determine electrical or fuel costs, and to assist in pump selection.

(4) A plan comparison array as shown in Table 5-1 is developed to aid in identifying the economically optimal or NED plan. The data for benefits and annual costs for each plan versus pump station capacity are then plotted to pick the economically optimal plan as illustrated in Figure 5-5. Other environmental, social impacts, performance, operation, and safety information

Table 5-1
Economic Evaluation of Pumping Station Capacity

Plan	Expected Annual Damage ($1000)	Average Annual Benefits ($1000)	Average Annual Cost ($1000)	Average Net Benefits ($1000)	B/C Ratio
Levee + Minimum Facility	952	-	-	-	-
Plus 80 m^3/s (100 cfs) pump	632	320	400	-80	0.80
Plus 155 m^3/s (200 cfs) pump	328	624	510	+114	1.22
Plus 230 m^3/s (300 cfs) pump	185	767	650	+117	1.18
Plus 385 m^3/s (500 cfs) pump	46	906	980	-74	0.90

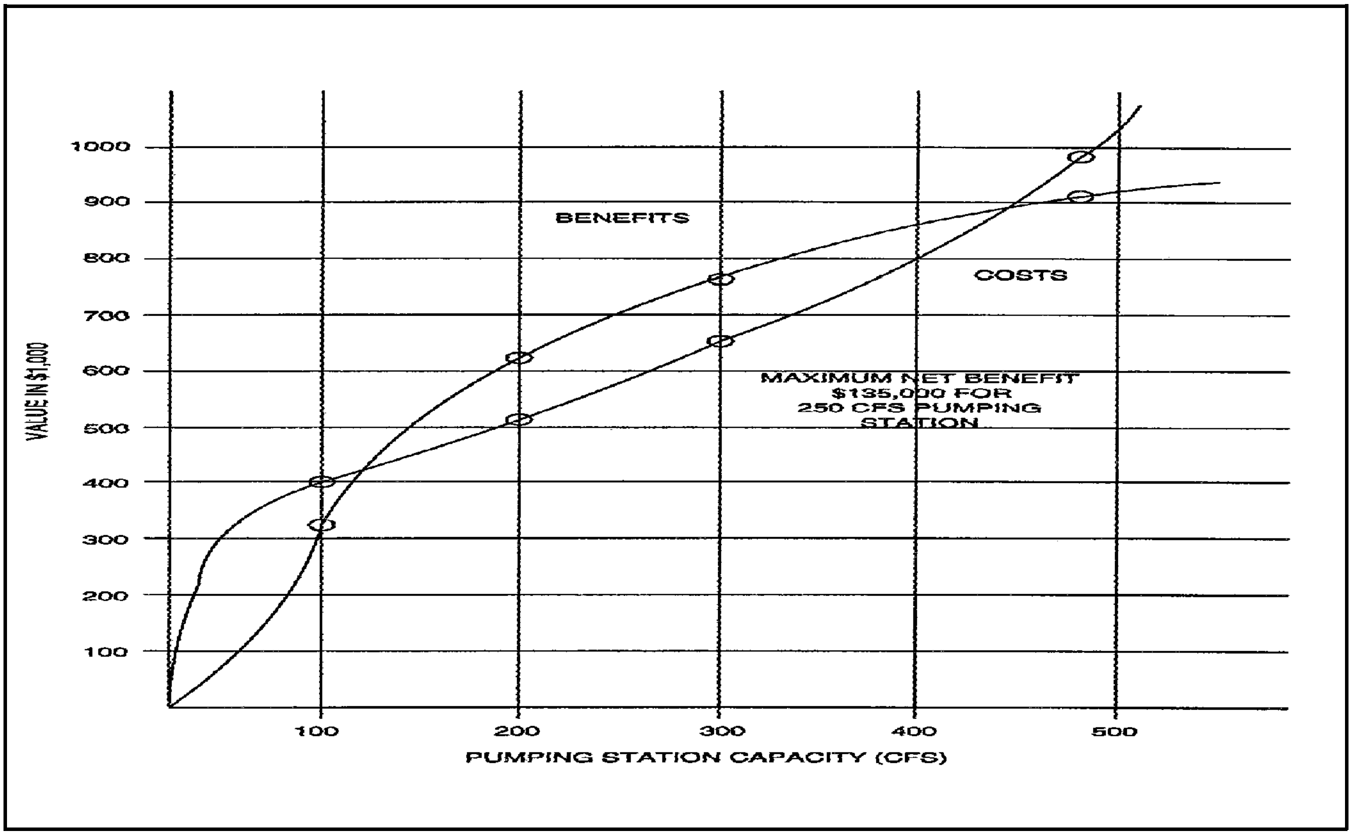

Figure 5-5. Pump station benefit-cost curve

should be developed and used to assist in determination of the appropriate pumping station capacity. The economically optimal plan is the recommended plan in agricultural areas and for most urban areas.

g. Evaluation of increased detention storage capacity.

(1) It is prudent to investigate the tradeoffs between pumping capacity and ponding area storage. Pumps are expensive and an increase in storage capacity will typically allow reduction in required pumping capacity. Several measures can be evaluated, including increasing the physical size of the ponding area and nonstructural actions that will reduce the damage for a given ponding stage.

(2) The sensitivity of ponding area size versus pumping capacity can be readily determined using HEC-IFH. The plan with the identified economically optimal gravity outlet and pumping station would be the base plan for determining if excavation is feasible.

(3) Temporary evacuation, raising existing structures, permanent relocation of structures and/or occupants, floodproofing, and other nonstructural measures that reduce susceptibility to damage (and increase available storage) should be evaluated. Floodproofing, raising, and relocation measures are generally more economically justified than structural measures when only a few structures are involved. Similarly, implementing nonstructural measures to a few structures to permit increasing the size of a detention basin may be more attractive than increasing the size of gravity outlets or pumping stations. Residual damages for evaluated plans would be revised based on new stage-damage relationships resulting from implementing the nonstructural measures.

(4) Other social, institutional, and environmental issues, including the management of future development, and flood warning and preparedness programs, would also be evaluated in the final plan selection.

5-5. Comparison of Plans

One important aspect of HEC-IFH is the ability to generate results from different plans and to compare them directly. The effects of different conditions or assumptions can be quickly evaluated. Up to seven different plans may be selected for comparison using HEC-IFH. Each plan is produced by performing the interior analysis using various combinations of the modular input data. HEC-IFH allows the user to display the results of the specified plans side-by-side in a report called Plan Comparison Summaries. For Continuous Simulation Analyses, eight summaries arranged into four categories are available. Figure 5-6 illustrates the plan comparison summary menu and the eight summaries that are available. For hypothetical event analyses, four plan summaries are available as shown in Figure 5-7. Chapter 13 of the HEC-IFH user's manual lists all the data values that can be specified for both types of analyses. The most important comparison is generally the peak elevation versus the percent chance exceedance frequency event. The minimum facilities plan can easily be compared with another plan having additional gravity capacity or with several plans having various pumping capacities. A tabular comparison of maximum interior elevation versus frequency is illustrated in Figure 5-8 and a screen plot of that same data is shown in Figure 5-9. By looking at the comparisons, a perspective is gained on the effectiveness of additional gravity drains or pumping capacity. This comparison data can then be given to the economist for an economic assessment of the flood damage reduction benefits produced by the various plans to determine which plans are viable features.

5-6. Plan Performance

After the selection of the NED plan, the HEC-IFH program should be operated for both CSA and HEA events using the selected components to verify the desired functional results. By comparing the NED plan results with other plans, the residual impacts of floods with volumes larger than the NED plan can handle can be determined. Also, if a specific ponding area size is required, the impacts of encroachments can be analyzed and the local sponsor can be made aware of the consequences of not maintaining this feature. The consequences of a pump unit failing during an event should also be evaluated.

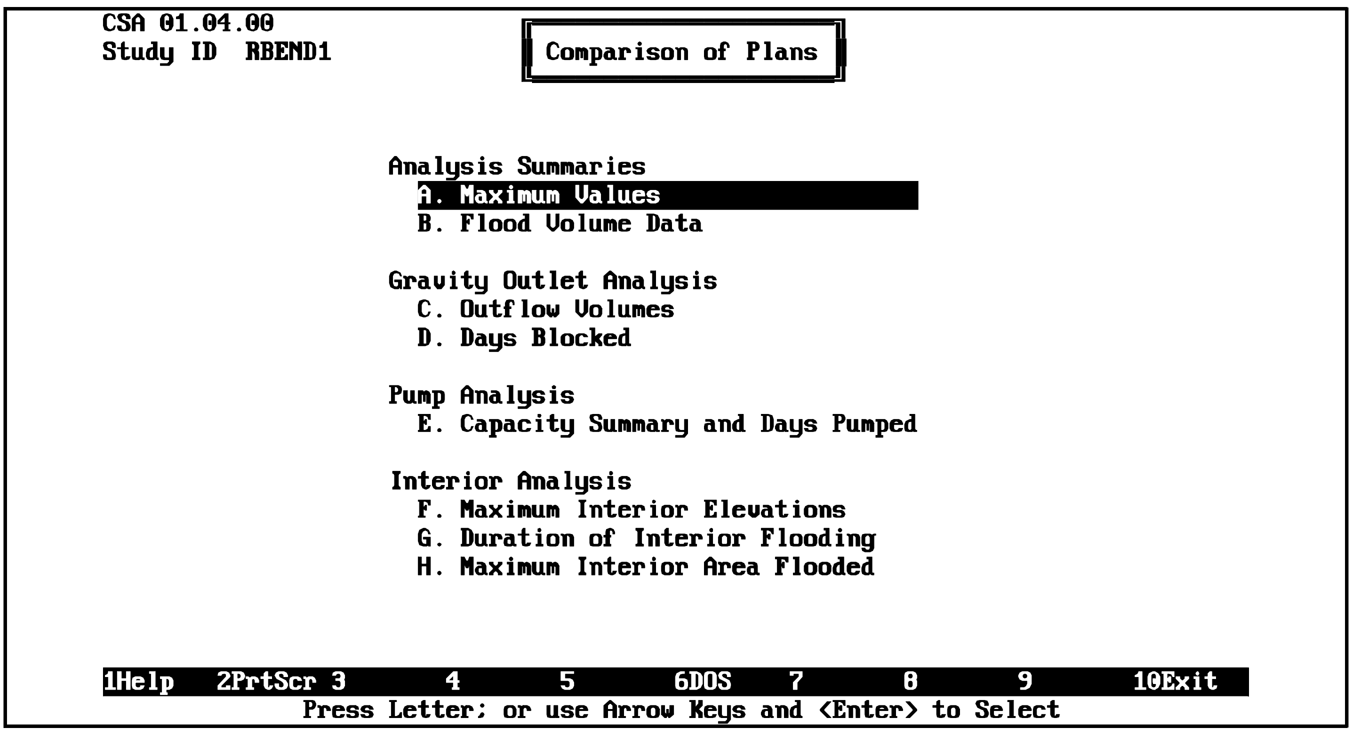

Figure 5-6. Continuous simulation plan comparison summary menu

HEA 01.04.00
Study ID RBEND1

Comparison of Plans

Select Option:

A. Plan Summary
B. Maximum Interior Elevation-Frequency
C. Maximum Interior Area Flooded-Frequency
D. Maximum Total Interior Inflow-Frequency

Press Letter; or use Arrow Keys and <Enter> to Select

Figure 5-7. Hypothetical event plan comparison summary menu

CSA 01.04.00
Study ID RBEND1

Comparison of Plans

F. Interior Analysis - Maximum Interior Elevations

Plan ID	Area Prim. Grav. (sqft)	Total Pump Cap. (cfs)	Peak Elevation (ft) vs. Percent Chance Exceedence Frequency Event						
			50%	20%	10%	4%	2%	1%	0.2%
PLAN1	16.0	0.0	599.88	601.06	601.75	603.50	605.00	605.00	605.00
PLAN2	16.0	200.0	599.79	600.85	601.46	602.47	603.40	604.49	605.00

1Help 2PrtScr 3 4 5 6DOS 7 8 9Plot 10Exit
Press <F10> to Return

Figure 5-8. Maximum interior elevation-frequency summary

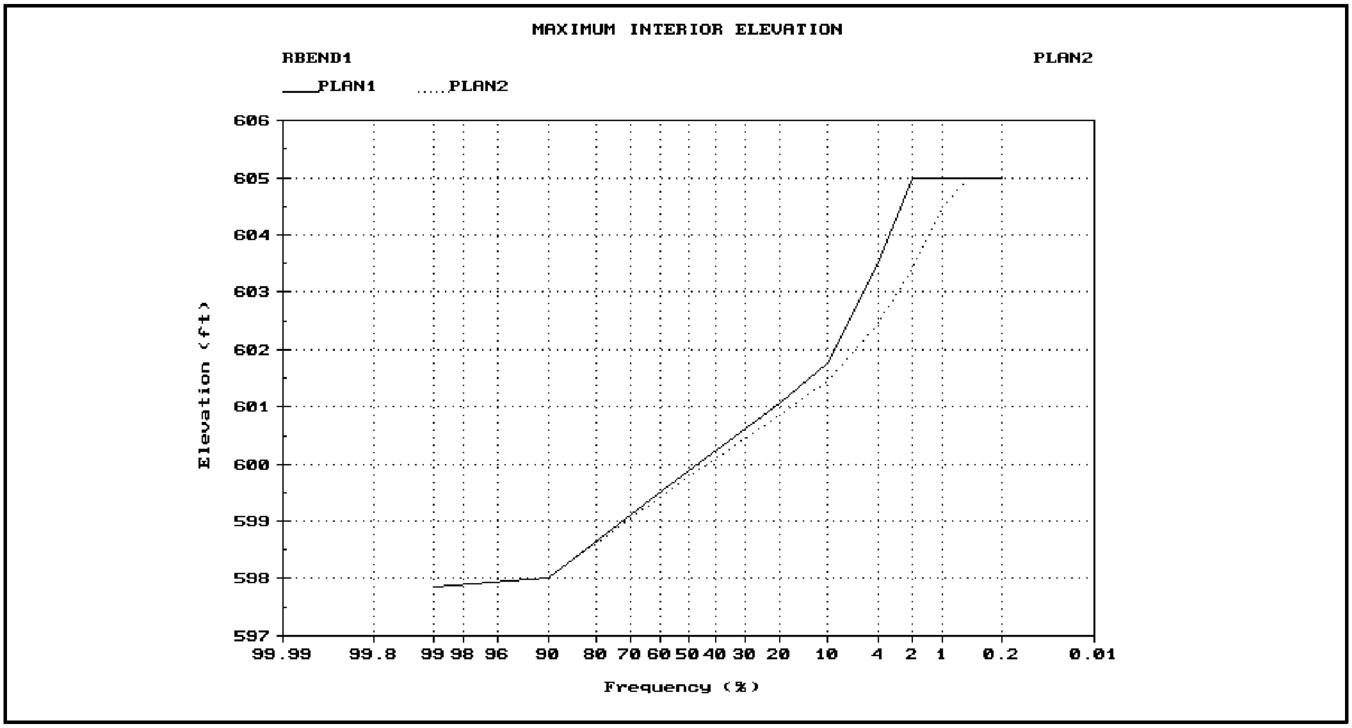

Figure 5-9. Maximum interior elevation-frequency plot