Appendix D
Case Study for Analysis of Interior Flood Damage Reduction Measures, Napa River, Napa, California

D-1. Introduction

a. This case study presents part of the hydrologic engineering analysis results of interior flood damage reduction measures for the City of Napa, CA. It was conducted by the Hydrologic Engineering Center (HEC) for the Sacramento District Corps of Engineers. The objective of the hydrologic engineering analysis was to determine the minimum outlet facility associated with the proposed line-of-protection, the stage-frequency relationships for the without-project conditions, and the stage-frequency relationships for a range of gravity outlet and pumping station sizes and configurations for the interior areas.

b. This case study presents the results of applying the HEC-IFH program for evaluation of one of the several interior areas involved in the overall investigation. The case study includes a description of the study area, the Napa River proposed flood damage reduction project, interior area data and information, without-project conditions analysis for minimum facility analysis, minimum facility analysis, and stage-frequency for interior flood damage reduction plans. The Sacramento District was responsible for developing data for the without-project conditions, including stage-damage relationships, cost estimates of the flood damage reduction measures, and other data required to perform the economic analyses of each plan. The design requirements for conveyance systems, inlet and outlet works, and the economic analyses of project components are beyond the scope of the case study presented herein.

D-2. Description of the Study Area

a. The Napa River basin is located about 50 miles north of San Francisco, CA. The basin is about 50 miles long on a north-south axis, varies between 5 and 10 miles in width, and has a drainage area of about 426 sq miles (see Figure D-1). The north, east, and west limits of the basin are formed by portions of the north coast mountain range. The southern limit is bounded by San Pablo Bay.

b. The Napa River originates near Mount St. Helena and empties into the Mare Island strait that flows into the tidal marshland and sloughs of San Pablo Bay. The City of Napa is located in the lower third of the basin and has a population of about 60,000. Basin land use consists mainly of vineyards in the valley area north of the City of Napa and limited mixed use in the marshland or reclaimed tidal land south of the city.

D-3. Description of the Proposed Flood Damage Reduction Project

a. Napa River and Napa Creek. The current recommended plan for the City of Napa provides for protection against the 1-percent chance event from the Napa River and Napa Creek. The proposed plan consists of channel excavation, sheet-pile walls, concrete floodwalls, setback earthen levees, a bypass channel, and related environmental mitigation measures.

b. Interior area measures. The interior flood damage reduction measures will consist of replacing approximately 21 existing storm sewers in 8 interior areas with minimum gravity outlets through the Napa River line-of-protection. Additional outlet capacity by gravity or pumps will be provided where economically justified. The proposed improvements for Napa Creek consist of channel excavation only and, therefore, will not include interior measures. The case study presented here will describe the analysis of interior measures for one of the areas.

D-4. Interior Area Data and Information Assembly

a. General.

(1) Hydrologic data and other information required for the analysis of the interior area were assembled. They include data for both the interior and exterior (Napa River) areas. The information is applicable for any analytical method, but was specifically targeted for application of HEC-IFH. Appropriate information was assembled to permit analyses using continuous simulation analysis (CSA) with period-of-record historical data and hypothetical event analysis (HEA) with synthetic storm event data.

(2) CSA is attractive because it preserves the relationship between Napa River stages at interior outlet locations and interior area runoff. A drawback of CSA is the difficulty of defining rare flood events when only a relatively short period-of-record is available as is the case for the Napa area. Therefore, HEA was adopted for this study to define the full range of flood events. The stage-frequency relationships from HEA and CSA were compared to help substantiate the reasonableness of the HEA results. Hydrologic data and other required information are described as an analyst would assemble and enter the data into HEC-IFH. Data sets and module information are shown by including representative program screens as figures where appropriate.

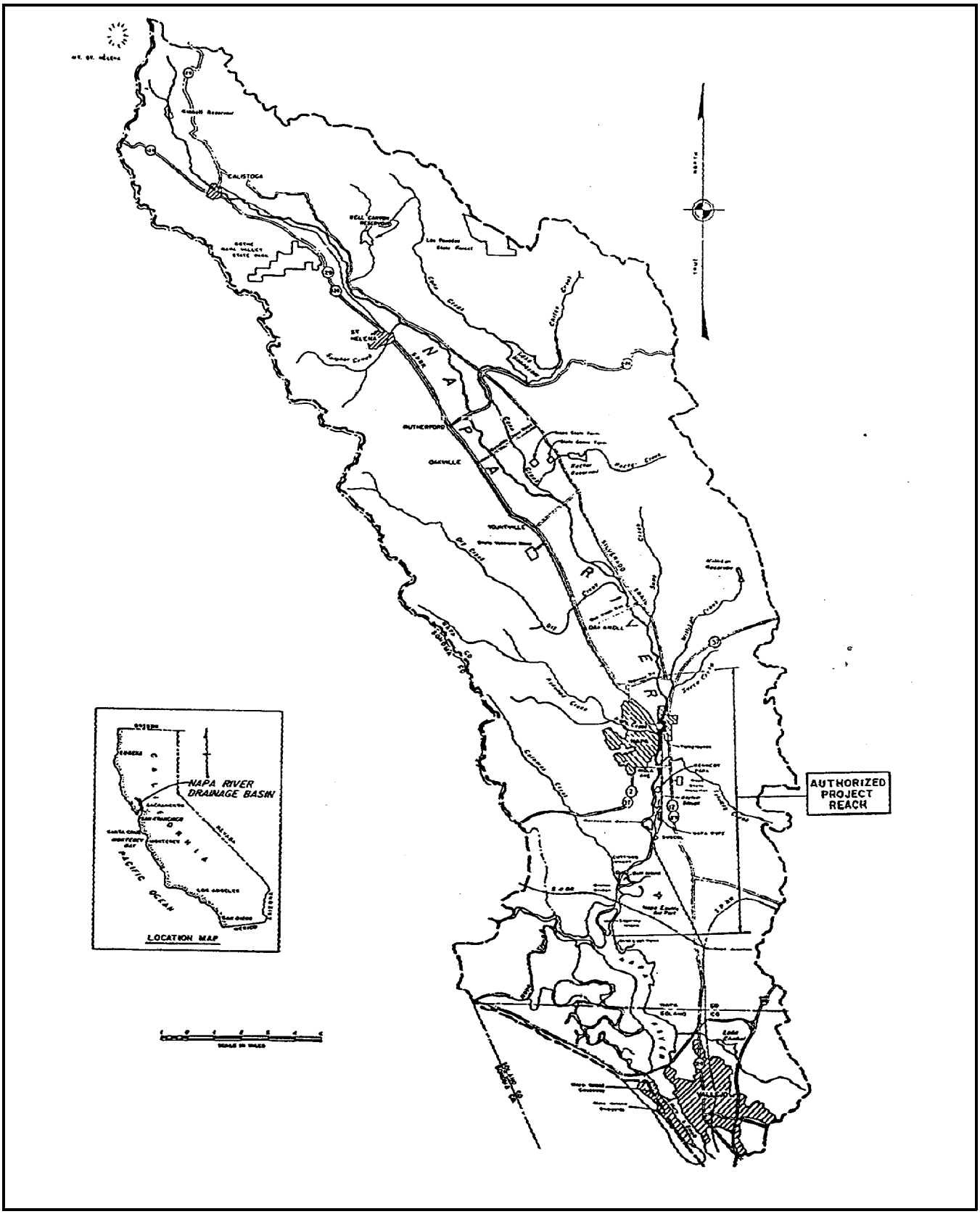

Figure D-1. Napa River basin

b. Rainfall data. Historical rainfall records were assembled for continuous simulation analysis (CSA) and hypothetical depth-duration-frequency relationships were developed for hypothetical event analysis (HEA).

(1) Historical rainfall records of nearby recording rain gauges were used to develop a continuous period-of-record rainfall record for Napa River interior areas. Recorded hourly incremental rainfall data were adjusted by the ratio of mean annual precipitation at the gauges to that for Napa River interior areas. A composite precipitation record for water year (WY) 1949 through WY 1989 was determined in this manner for use in CSA. The computed composite record was written to HEC-DSS and then imported into HEC-IFH. After importing the composite record, incremental rainfall can be plotted on a yearly, monthly, or daily basis. Figure D-2 shows daily total daily precipitation for WY 1986.

(2) Hypothetical frequency storm depth-duration-frequency relationships for general rain and local storms were developed from rainfall frequency data that were available for the Martinez 3S and Napa State Hospital gauges. Depths were adjusted by ratios of the mean annual precipitation (MAP) for the gauges and the MAP for the Napa River interior area estimated from a MAP isohyetal map. The adopted depth-duration-frequency rainfall relationships for a general rain storm are shown in Figure D-3. The development of precipitation data for computing exterior period-of-record discharge hydrographs is described in paragraph D-4*f*.

c. Delineation of interior areas.

(1) Interior areas were delineated based on alignment of the line-of-protection, minimum facility requirements, runoff topology, topography of local ponding areas, and present and potential future storm sewer and water collector/conveyance systems.

(2) Interior Area 5 is located on the right bank of Napa River just upstream from the mouth of Napa Creek (see Figure D-4). This 1.5-sq-mile area is bounded by the Napa River on the east, Highway 29 on the west, approximately Trancas Street on the north, and Napa Creek on the south. The area was divided into an upper and lower portion to accommodate the previously developed HEC-1 basin model. Runoff parameters and the existing storm sewer layout are described in subsequent sections.

d. Runoff characteristics.

(1) The Sacramento District developed a HEC-1 rainfall-runoff model for simulating historical flood events for Napa River interior areas during previous studies. The HEC-1 model used the kinematic wave technique for transforming rainfall to runoff. HEC-IFH does not use kinematic wave and therefore it was not possible to reproduce the modeling effort in HEC-IFH. It was important to preserve the timing of the interior runoff and the detail of the HEC-1 model because interior areas were divided into many subareas and reaches to

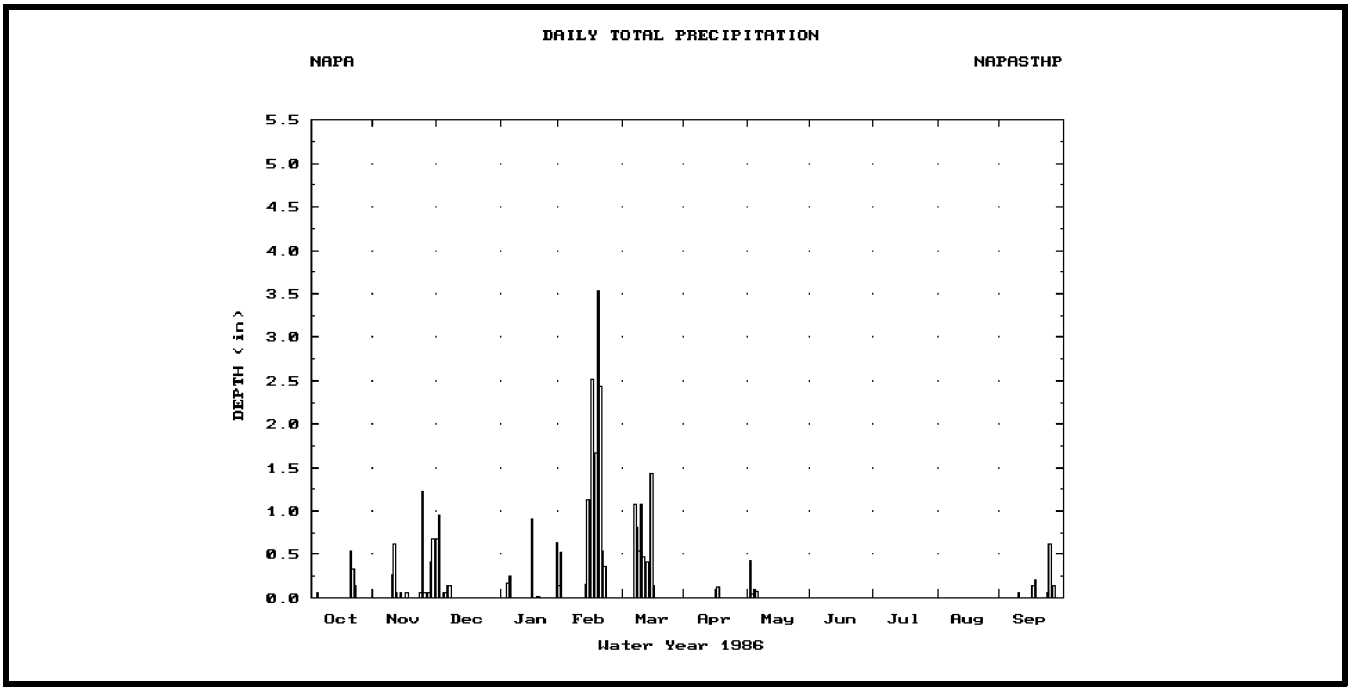

Figure D-2. Interior area composite historical precipitation data

HEA 01.04.00
Study ID NAPA
Module ID PRECHLOC

Basin Average Precipitation (PRECIP)

Enter Partial-Duration Rainfall Depth-Duration-Frequency Data

Duration	Rainfall Depth (in) for each Hypothetical Event						
	50%	20%	10%	4%	2%	1%	0.2%
5 minutes	0.15	0.20	0.25	0.30	0.32	0.36	0.45
15 minutes	0.27	0.38	0.46	0.56	0.62	0.69	0.85
1 hour	0.57	0.80	0.97	1.16	1.30	1.44	1.78
2 hours	0.82	1.16	1.39	1.66	1.87	2.07	2.55
3 hours	1.02	1.42	1.70	2.04	2.29	2.54	3.14
6 hours	1.50	2.12	2.53	3.03	3.40	3.76	4.67
12 hours	1.98	2.79	3.33	4.00	4.48	4.96	6.15
24 hours	2.45	3.44	4.12	4.95	5.56	6.14	7.60
2 days	3.12	4.51	5.42	6.63	7.49	8.33	10.48
4 days	4.03	5.77	6.94	8.38	9.44	10.45	13.01
7 days	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10 days	0.00	0.00	0.00	0.00	0.00	0.00	0.00

1Help 2PrtScr 3 4 5 6DOS 7 8 9 10Exit

Press <F10> to Save Data and Continue

Figure D-3. Interior area hypothetical precipitation data

represent sewered urban runoff. Therefore, the kinematic wave HEC-1 model was used with 1 in. of runoff to generate composite unit hydrographs for each interior area. Clark unit hydrograph parameters TC and R were estimated from these kinematic wave unit hydrographs using the parameter estimation capability in the HEC-1 program. These unit hydrograph parameters were used in HEC-IFH for computing runoff from the interior area during hypothetical event and continuous simulation analysis.

(2) The initial and uniform loss rate model was used for both CSA and HEA. There are no stream gauges in the interior area so calibration of runoff parameters was not possible. Other methods were used to ensure the reasonableness of the parameters as described below.

(a) For CSA, the initial loss was 0.4 in. and the uniform loss was 0.02 in. per hour. The monthly initial loss recovery rate for CSA was 0.04 in. per day. Test simulations with different initial loss recovery rates for CSA showed that peak interior runoff was not sensitive to this parameter. Examination of monthly precipitation, loss, and percent loss is possible in HEC-IFH and helps verify the reasonableness of selected loss rates (see Figure D-5).

(b) For HEA the adopted initial loss was 0.2 in. and the uniform loss was 0.02 in. per hour. These loss rates were held constant for all hypothetical events. These loss rates were consistent with those used by the district in previous studies and were considered reasonable for the highly urbanized areas. As expected, the HEA loss rates, which are representative of rare single events, are lower than the CSA rates. Peak interior runoff using the described adopted loss rate parameters was compared for CSA and HEA. Peak interior flow-frequency relationships for CSA and HEA are shown in Figure D-6 and compared closely for moderately rare events. This further substantiates the reasonableness of adopted parameters.

(3) No base flow was specified for either CSA or HEA. Base flow was considered to have little or no impact on peak runoff or volume for these small interior areas. Some runoff parameters for Interior Area 5 are shown in Figure D-7.

(4) No routing was used between the upper and lower subareas for Interior Area 5 due to the short travel time and the fact that the area is heavily sewered.

(5) The interior runoff computation time was 15 min for CSA and 5 min for HEA. The times of concentration for the upper and lower subbasins for Interior Area 5 were 0.79 and 1.1 hr, respectively. Accordingly, these time intervals were considered adequate to define the runoff hydrographs at the outlets.

Figure D-4. Napa Interior Area 5

CSA 01.04.00
Study ID NAPA
Plan ID PLAN5-3A

Hydrologic Analysis Summaries

Begin 01OCT1948/0015
End 30SEP1989/2400

K. Monthly Summaries - Average Monthly Rainfall

Month	Lower Sub-Basin			Upper Sub-Basin			Exterior Basin		
	Precip (in)	Losses (in)	Percent Loss	Precip (in)	Losses (in)	Percent Loss	Precip (in)	Losses (in)	Percent Loss
Oct	1.28	0.49	38.25	1.28	0.49	38.25			
Nov	3.37	1.09	32.30	3.37	1.09	32.30			
Dec	4.38	1.34	30.60	4.38	1.34	30.60			
Jan	5.02	1.47	29.21	5.02	1.47	29.21			
Feb	3.96	1.17	29.53	3.96	1.17	29.53			
Mar	3.43	1.20	34.90	3.43	1.20	34.90			
Apr	1.72	0.70	40.89	1.72	0.70	40.89			
May	0.41	0.25	61.46	0.41	0.25	61.46			
Jun	0.16	0.10	59.73	0.16	0.10	59.73			
Jul	0.06	0.03	43.31	0.06	0.03	43.31			
Aug	0.06	0.04	67.54	0.06	0.04	67.54			
Sep	0.38	0.19	49.00	0.38	0.19	49.00			

1Help 2PrtScr 3 4 5 6DOS 7 8 9Plot 10Exit

Press <F10> to Return

Figure D-5. Precipitation, loss and loss percent for Interior Area 5 - CSA

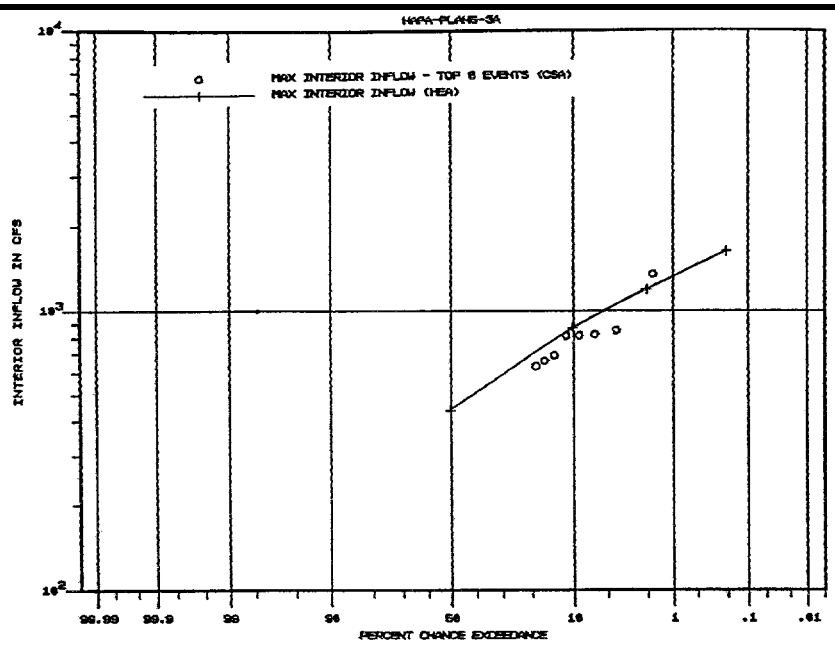

Figure D-6. Interior runoff discharge-frequency relationships - CSA and HEA

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CSA 01.04.00
Study ID  NAPA        [ Runoff Hydrograph Parameters (RUNOFF) ]

                          Enter Basin Runoff Data
Basin ID      A5L-CSA
    Lower area 5 - CSA                                 Month   Initial Loss Recovery

Basin Drainage Area (sq mi)              1.26          Oct        0.04      (in/day)
Percent of Drainage Area Impervious      20.0          Nov          0.04
                                                       Dec          0.04
Enter Monthly Base Flow Rates        Yes  No           Jan          0.04
                                                       Feb          0.04
Basin Infiltration Loss Data                           Mar          0.04
  Generalized Runoff Coefficients                      Apr          0.04
 [Initial-Uniform-Recovery Method]                     May          0.04
  No Losses Computed                                   Jun          0.04
                                                       Jul          0.04
Basin Unit Hydrograph Data                             Aug          0.04
 [Clark's Unit Hydrograph      ]                       Sep          0.04
  Snyder's Unit Hydrograph
  SCS Dimensionless Unit Graph                         Initial Loss (in)        0.40
  Enter Unit Hydrograph                                Uniform Loss (in/hr)     0.02

1Help  2PrtScr 3      4      5      6DOS   7      8      9      10Exit
                   Press <F10> to Save Data and Return
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Figure D-7. Runoff parameters - Interior Area 5, lower subbasin, CSA

e. Interior ponding area. Elevation-area relationships were delineated for each ponding area adjacent to the line-of-protection at the flow concentration points. Relationships were taken from elevation-area tables generated from computerized topographic data of the project area. Elevation-area data were entered into HEC-IFH, which automatically generates the storage values from end-area approximations. The minimum value was established from the lowest invert elevation to be analyzed for Interior Area 5. The maximum value was established from the highest stage anticipated in the analysis, which in this case is the top of the levee embankment at the line-of-protection. A portion of the pond elevation-area-storage relationship for Interior Area 5, as implemented in HEC-IFH, is shown in Figure D-8.

f. Exterior stage data. Exterior stage hydrographs were required to establish the exterior conditions for both CSA and HEA methods.

(1) Exterior stage data for period-of-record CSA include continuous stage hydrographs that represent the historic patterns of Napa River discharge at the outlet locations of each interior area. A continuous discharge hydrograph was developed for the exterior from rainfall-runoff analysis. Historical rainfall records of nearby recording and nonrecording rain gauges were used with the PRECIP program to develop a continuous, period-of-record, composite rainfall record for the Napa River basin. Runoff parameters for the exterior basin were derived by calibration with the computed SPF hydrograph, the estimated peak discharge of the February 1986 flood event, and the project design discharge-frequency curve for Napa River below Tulucay Creek. Computed exterior runoff hydrographs were used with Napa River rating curves to determine continuous exterior stage hydrographs during CSA. The rating curves were defined at the outlet locations based on project channel water surface profiles provided by the district. Rating curves were slightly adjusted so that the peak flow of each hypothetical flood hydrograph matched the water surface elevation from the water surface profiles for the corresponding event. Figure D-9 shows some runoff parameters for the exterior basin.

(2)(a) Hypothetical storm analysis was conducted using general rain 96-hr local storms centered over the interior for unblocked, low Napa River conditions. For hypothetical interior and exterior analysis the general rain 96-hr hypothetical storms were centered over both the interior area and the Napa River basin.

(b) Hypothetical storm flood hydrographs at the outlet locations of each interior area were developed from HEC-1 data sets provided by the district. The data used consists of an S-curve unit hydrograph rainfall-runoff model upstream of the Oak Knoll stream gauge and a kinematic wave model downstream to Imola Avenue in Napa. The hydrographs were determined by taking ratios of the SPF. These HEC-1 rainfall-

```
CSA 01.04.00
Study ID  NAPA                    Interior Pond (POND)

                    Enter Surface Areas for Computing Volumes

Storage Table ID  AREA5

Description
  Area 5 natural pond at Soscal Ave.
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Pond Elevation (ft)	Surface Area (ac)	Storage Volume (ac-ft)
-5.30	0.0	0.0
0.00	0.1	0.4
2.00	0.2	0.7
5.00	0.2	1.4
7.00	0.3	2.0
8.00	0.4	2.3
9.00	0.5	2.8
10.00	0.6	3.4
12.00	0.8	4.8
14.00	1.9	7.4
15.00	4.9	10.8
16.00	7.2	16.9
17.00	42.5	41.7

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

Figure D-8. Interior pond elevation-area-storage relationship for Interior Area 5

```
CSA 01.04.00
Study ID  NAPA          Runoff Hydrograph Parameters (RUNOFF)

                    Enter Basin Runoff Data
Basin ID     EXTUSNAP
    Exterior Basin US of Napa Creek

Basin Drainage Area (sq mi)            266.00
Percent of Drainage Area Impervious      2.0

Enter Monthly Base Flow Rates        Yes  No

Basin Infiltration Loss Data
  Generalized Runoff Coefficients
  [Initial-Uniform-Recovery Method]
  No Losses Computed

Basin Unit Hydrograph Data
  [Clark's Unit Hydrograph      ]
  Snyder's Unit Hydrograph
  SCS Dimensionless Unit Graph
  Enter Unit Hydrograph
```

Month	Initial Loss Recovery	
Oct	0.50	(in/day)
Nov	0.50	
Dec	0.40	
Jan	0.30	
Feb	0.30	
Mar	0.40	
Apr	0.50	
May	0.60	
Jun	0.80	
Jul	0.80	
Aug	0.80	
Sep	0.60	

Initial Loss (in)	4.00
Uniform Loss (in/hr)	0.02

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1Help   2PrtScr 3      4      5      6DOS   7      8      9      10Exit
                Press <F10> to Save Data and Return
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Figure D-9. Runoff parameters for the exterior basin - CSA

runoff models were used by the district to develop project discharge-frequency relationships for the Napa River. Therefore, the HEC-1 model-developed hypothetical flood hydrographs were used for exterior conditions during HEA. The flood hydrographs were imported into HEC-IFH and used with rating curves to compute exterior stage hydrographs at interior outlet locations during HEA. Figure D-10 shows a portion of the imported hypothetical flood hydrographs for the exterior basin.

g. Existing and proposed storm sewer design and configuration. The details of existing and any proposed storm sewer layout, and discharge design capacities, including elevation of the inverts, were required to define drainage areas, minimum facilities, gravity outlet inverts, pumping station on-off elevations, and design criteria for inlet and outlet works. Layout and design of existing and proposed storm runoff conveyance systems were obtained from the Napa Public Works Department. The information included storm sewer location, length, size, and invert elevation. These data were provided on an areal photo (1 in. = 100-ft scale) with 2-ft contour intervals. Interior Area 5 is well sewered and has several existing gravity outlets that cross the line-of-protection and/or convey portions of the runoff to the Napa River. The outlets are shown in Figure D-4 and are described in the following subparagraphs. Numbered outlets refer to the primary and secondary outlet locations as shown in the figure.

(1) A major storm sewer system runs easterly along Trancas Street and discharges into the Napa River via a 54-in. circular pipe just downstream from the Trancas Street Bridge. This outfall is above the upstream limit of the project and therefore will not be disturbed. The outlet invert is not subject to blockage from high river stages due to the relatively high outlet invert elevation. It was estimated by the City of Napa that this outfall would pass a maximum of 50 cfs into the Napa River during flooding. This was simulated in HEC-IFH by diverting this flow from the upper subbasin to the river (see paragraph D-4*k*).

(2) The next downstream major storm sewer is a 72-in. circular pipe that enters the river at the north end of the Lake Park leveed area, just east of the intersection of Soscol and Pueblo Streets. It serves a major portion of the upper subbasin under pressure flow. This outlet is just upstream from the upper limits of the flood control project and, therefore, will be left undisturbed. The capacity of this pipe was estimated to be 300 cfs and this flow was diverted from the upper subbasin to the river for HEA and CSA (see paragraph D-4*k*).

(3) The Lake Park/Edgewater leveed area and its associated existing gravity outlets and pump station are considered independently and are not part of the Interior Area 5 analysis.

(4) The location 5.0 overflow ditch and 42-in. pipe north of the confluence of Napa Creek and the Napa River system includes a 72-in. pipe that empties into an overflow ditch that enters the Napa River just upstream from the confluence of Napa Creek and Napa River. At the outfall there is a 42-in.

HEA 01.04.00
Study ID NAPA
Module ID EXHYPUSN

Exterior Stage (EXSTAGE)

Index Location

Enter/Import Exterior Discharge Hydrographs (cfs)

Time Interval 15MIN Number of Intervals 800

Da/HrMn	Hyp.Frq 50%	Hyp.Frq 20%	Hyp.Frq 10%	Hyp.Frq 4%	Hyp.Frq 2%	Hyp.Frq 1%	Hyp.Frq 0.2%	SPF
1/0015	81.	113.	139.	167.	191.	216.	296.	0.
1/0030	81.	112.	139.	167.	191.	216.	296.	0.
1/0045	81.	112.	139.	167.	191.	216.	296.	0.
1/0100	81.	112.	139.	167.	190.	216.	295.	0.
1/0115	81.	113.	139.	167.	191.	216.	296.	0.
1/0130	81.	113.	140.	168.	192.	217.	297.	0.
1/0145	82.	115.	141.	170.	194.	219.	301.	0.
1/0200	84.	117.	144.	173.	197.	223.	309.	0.
1/0215	86.	120.	147.	177.	202.	229.	322.	0.
1/0230	89.	124.	152.	183.	209.	237.	343.	0.
1/0245	92.	128.	158.	190.	217.	248.	370.	0.
1/0300	95.	134.	164.	199.	228.	261.	421.	0.
1/0315	100.	140.	172.	208.	240.	276.	471.	0.

1Help 2PrtScr 3 4 5 6DOS 7 8 9 10Exit

Position with <PgDn>, <PgUp>, <Dn>, <Up>, <Home>, <End>

Figure D-10. Portion of hypothetical flood hydrographs for exterior basin - HEA

circular pipe that runs beneath the overflow ditch. This outfall location is the flow concentration point for Interior Area 5 and was designated as the ponding area (see paragraph D-4*d*) and the primary gravity outlet location for this interior area.

(5) Additional existing outlets. There are three additional existing outlets that cross the line-of-protection and are to be replaced with new gravity outlets with drop inlets. They are all upstream from the primary gravity outlet and are designated and analyzed as secondary outlets for HEA and CSA. These outlets are described below:

(a) Location 5.1. One 24-in. pipe at Imperial Way.

(b) Location 5.2. One 18-in. pipe at North Bay Drive (to be replaced by a 24-in. drop inlet).

(c) Location 5.3. One 30-in. pipe at Lincoln Avenue.

There are a few small outlets that convey a minor portion of interior runoff from Interior Area 5 into Napa Creek from the left bank (north side). These outlets will not be cut off by the project because they are upstream from the Napa River tieback levee where channel excavation is the only project feature. The effects of these outlets were considered negligible in the analysis of Interior Area 5.

h. Field reconnaissance. Two field trips were made to locate outlet inverts and ditches that will be cut off by the line-of-protection, bridges, hydraulic structures, and floodplain channels and overbank areas. Several meetings were held with the Napa Public Works Department and Sacramento District to discuss existing and proposed storm conveyance systems and proposed interior features that would convey storm runoff through the line-of-protection.

i. Gravity outlets.

(1) The characteristics and configuration of typical new gravity outlets were defined to establish gravity outlet parameters and to develop rating curves for the outlets. This information included culvert length, size, etc., invert elevations and slopes of existing storm sewers, culvert type (box or circular, concrete or corrugated metal pipe, etc.), and entrance and exit configurations.

(2) The typical outlet through the line-of-protection was defined, after coordination and agreement with the study manager, as a concrete box culvert with a grated drop inlet. The outlet inverts of the drop inlets are established by the existing storm sewer inverts entering the drop inlets. Lengths of the box culverts were dependent on whether the line-of-protection consisted of a setback levee, sheet-pile wall, or concrete flood wall at the outfall. Slopes of the box culverts were set to maintain the slopes and outlet invert elevations of the existing outlets as close as possible. Required information was taken from project drawings provided by the district and existing storm sewer layouts provided by the City of Napa. Manual gate closure valves, as well as flap gates, will be included as part of each new outlet. The minimum head differential required for gravity flow was specified as 0.5 ft. No special gate closure requirements were established. A typical layout of a drop inlet box culvert at the primary location for Interior Area 5 is shown in Figure D-11.

j. Pumping Stations.

(1) Typical pumping station configuration and operation were determined through coordination with the district. Criteria for number of pumps and pumping station capacity were that each pumping station would have a total of three pumps, each having two-thirds of the total designated station capacity. Two of these pumps would be operated as needed and one would be for backup in case one of the other pumps went out of service. For example, a 300-cfs pumping station would include three (200-cfs or 90,000-gpm) pumps, two of which would be operating for a maximum possible station capacity of 400 cfs. Pump head-capacity-efficiency relationships were determined from pump performance curves provided by the district. Figure D-12 shows the relationships for a 200-cfs (90,000-gpm) pump unit.

(2) Pump on and off elevations were determined so that the pumps would come on to effectively reduce damaging stages and turn off when stages dropped below damaging levels. However, pumps should not cycle on and off over very short periods of time. Pump on/off elevations were determined based on the "zero damage" elevation and rate of rise for specific ponding areas for a specific interior area. Pump on/off elevations may need adjusting depending on the final design configuration of the pumping station. Preliminary on/off elevations for the two operating pump units for a 100-cfs station are shown in Figure D-13 and are based on a "zero damage" elevation of 14.0 ft for Interior Area 5.

k. Auxiliary flow. 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. As indicated in paragraph D-4*f*, the effect of the existing 54-in. and 72-in. pipes located upstream from the upper limits of the flood protection project was represented by a diversion from the upper subbasin in Interior Area 5. Specified diversions for Area 5 are shown in Figure D-14. Seepage was not considered a factor because the inundation time for the earthen embankments would be minimal and sheet-pile and concrete floodwalls along the line-of-protection would be extensively used.

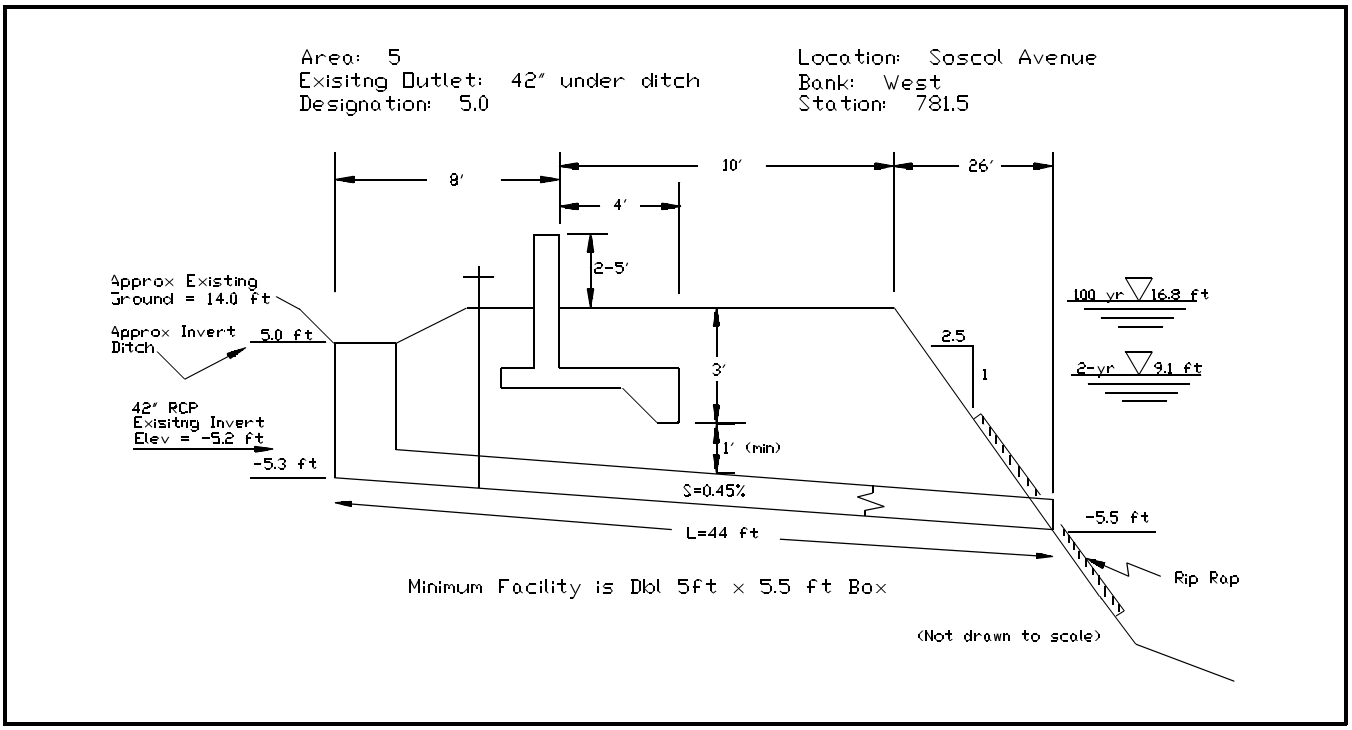

Figure D-11. Typical layout - new box culvert with drop inlet Area 5

HEA 01.04.00
Study ID NAPA

Pump Outlets (PUMP)

Enter Pump Unit Data

Pump Unit ID and Description PUMP200A 1-200 CFS (90,000 GPM) pump
Estimated* Head Loss (ft) 1.00 *Total Head = Static Head + Est Head Loss

Total Head (ft)	Capacity (cfs)	Efficiency (%)
0.00	200.5	50.0
10.60	200.5	72.0
12.00	196.1	74.0
14.00	191.6	78.0
16.00	184.9	80.0
18.00	180.5	82.5
20.00	176.0	85.0
22.00	171.6	85.7
24.00	164.9	85.5
30.00	0.0	0.0
0.00	0.0	0.0
0.00	0.0	0.0

Pump Start Elev (ft) 12.75
Pump Stop Elev (ft) 11.00

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

Figure D-12. Pump unit head-capacity-efficiency data

HEA 01.04.00
Study ID NAPA
Plan ID PLAN5-4A

Hydrologic Analysis Summaries

Begin 01/0005
End 07/0600

D. Analysis Input Summaries - Pump Station Data

PUMP Module ID PMOD100 100 cfs station (2-67 cfs pumps oper.)

Pump Number	Pump Unit ID	Maximum Capacity (cfs)	Pump Start Elevation (ft)	Pump Stop Elevation (ft)	Maximum Total Head (ft)
1	PUMP67A	66.8	12.75	11.00	30.00
2	PUMP67B	66.8	13.25	11.75	30.00
3					
4					
5					
6					
7					
8					
9					
10					

1Help 2PrtScr 3 4 5 6DOS 7 8 9 10Exit

Press <F10> to Return

Figure D-13. Pumping station data for Interior Area 5

HEA 01.04.00
Study ID NAPA

Auxiliary Inflow/Outflow (AUXFLOW)

Enter Diversion Rate for Upper Sub-Basin

Diversion Table ID AREA5U

Description
Outflow to Napa R via Pueblo & Trancas.

Runoff + Aux. Inflow (cfs)	Diverted Flow (cfs)
0.0	0.0
10.0	10.0
50.0	50.0
100.0	100.0
200.0	200.0
350.0	350.0
10000.0	350.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0

1Help 2PrtScr 3 4 5 6DOS 7 8 9 10Exit

Press <F10> to Save Data and Return

Figure D-14. Diversion rate for the upper subbasin - Interior Area 5

l. Water surface profile data. Water surface profiles for with-project conditions were developed by the district using the HEC-2 program. These profiles were used to determine rating curves for the Napa River at interior area outlet locations. The water surface profiles were also used to determine exterior stage transfer relationships for transferring the computed exterior stage at the primary outlet location to the secondary outlet locations. The rating curve for Napa River at the Area 5 primary location is shown in Figure D-15.

m. Stage-damage relationships. Representative stage-damage relationships for the interior areas at runoff concentration points are required for economic analysis and identification of interior plans that maximize net flood damage reduction benefits. Economic analysis is not part of this investigation; therefore, complete stage damage relationships were not required. The elevation where significant damage begins or "zero damage" was required in order to establish the size of the minimum facility and to set pump on/off elevations. These elevations were provided by the district.

D-5. Without-project Conditions Analysis for Minimum Facility Evaluation

a. General. The without-project analysis involves evaluation of conditions without and with the line-of-protection in place. Degrees of flooding 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 that the adopted minimum facility is in place and is described in paragraph D-6.

b. Napa River flooding without line-of-protection. The source of serious flooding in the City of Napa is the Napa River and to a lesser extent Napa Creek. The recommended flood damage reduction project protects the city from flooding up to the 1-percent chance flood for both the Napa River and Napa Creek. The basis for sizing the minimum facility is to assure that flooding from local storm runoff, when the Napa River and Napa Creek are below bank full, is not more frequent with the line-of-protection in place than without the line-of-protection in place.

c. Local runoff flooding without line-of-protection. Local flooding was evaluated without the line-of-protection in place, assuming the present storm sewer system in place, and Napa River and Creek below flood stage. Stage-frequency relationships for this condition were not developed due to lack of data. Storm sewer system design criteria for the City of Napa, for existing and new systems, were well-documented and were used to establish the target condition for the minimum outlet facility analysis. The first criterion used was that only minor street and gutter flooding should occur up to the 10-percent chance (10-year) flood event. Minor street and gutter flooding in this case is defined as not exceeding a depth that would result in flooding more than 10 ft from the street gutter. The second criterion was that no significant damage from flooding would occur in residential and commercial areas from floods up to the 4-percent chance (25-year) flood event.

HEA 01.04.00
Study ID NAPA
Module ID EXHYPUSN

Exterior Stage (EXSTAGE)

Enter Exterior Channel Rating Curve

Discharge (cfs)	Elevation (ft)
0.0	0.00
13800.0	9.00
19400.0	11.00
23500.0	12.50
28700.0	13.80
33000.0	15.10
37200.0	16.80
52100.0	19.00
0.0	0.00
0.0	0.00
0.0	0.00
0.0	0.00
0.0	0.00
0.0	0.00

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

Figure D-15. Exterior rating curve for Interior Area 5

This second criterion was interpreted that the interior stage resulting from the 4-percent chance event should not exceed the start of significant damage elevations determined by the district office. Based on the past performance of the existing sewer system and the overall reasonableness of the criteria, the storm sewer system design criteria were adopted for sizing the minimum facilities.

d. Assess future without-project conditions impacts. Future conditions that could affect Napa River interior area local runoff flooding were considered. Hydrologic and/or hydraulic conditions are not expected to significantly change over the project life and, therefore, no changes needed to be incorporated into the hydrologic and hydraulic analysis. The interior areas are fully urbanized, so future urbanization would have minimal effect on watershed runoff. Proposed and planned improvements in the existing storm sewer system, as described by the City of Napa, were evaluated and incorporated in the interior areas where appropriate. There were no planned changes to the existing storm sewer system in Interior Area 5.

D-6. Minimum Facility Analysis

a. General. The adopted minimum facility, sized according to the criteria described in paragraph D-5*c*, is a justified part of the line-of-protection. Stage-frequency relationships for the condition with the minimum facility in place become the condition without the minimum facility in place for evaluating potential interior flood damage reduction measures over and beyond the minimum facility. The residual damage with the minimum facility in place becomes the target for damage reduction of proposed additional interior flood damage reduction measures. As described previously, the minimum facility was sized to provide interior flooding relief so that during low exterior stages (unblocked gravity outlet conditions) the local interior area runoff will pass the design storm sewer outflow without an increase in interior stages over natural or without line-of-protection conditions.

b. Selecting the minimum facility for Interior Area 5. A series of analyses of gravity outlet capacities and configurations using local storm hypothetical events analysis (HEA) and assuming unblocked conditions were conducted using HEC-IFH. Physical characteristics of the gravity outlets were described in paragraph D-3*i*. A new plan was defined for each gravity outlet capacity to be evaluated and the interior stage-frequency relationship was developed for each outlet. Plan components as defined in HEC-IFH for one of the plans evaluated for Interior Area 5 are shown in Figure D-16. Stage-frequency relationships of gravity outlets were compared to the storm sewer design criteria described previously and the outlet size that came closest to meeting the criteria was selected. For Interior Area 5, the selected minimum facility was a double 5- by 5.5-ft box culvert. The "zero damage" elevation is 14.0 ft, and the 4-percent chance elevation based on the results of the HEA unblocked condition simulation is 13.55 ft. The stage-frequency relationship with the minimum facility in place is shown in Figure D-17. The 10-percent chance stage is below the criterion elevation for street flooding and therefore this minimum facility is adequate.

```
HEA 01.04.00
Study ID  NAPA                 Perform Interior Analysis

   Plan ID  PLAN5-1D   Description  Area 5 Min. Fac. 2-5X5.5 boxes-HEA unblk

                                 Module
          Module                  ID          Description
Basin Average Precipitation     PRECHLOC   General rain interior area hyp. precip.
Runoff Hydrograph Parameters    A5-HEA     Area 5 (U & L) runoff for HEA
Interior Pond                   POND5      Pond surface area-elevation for Area 5
Gravity Outlets                 OUTMOD5B   New Dbl 5X5.5 box at primary- Soscal Ave
Pump Data
Exterior Stage                  UNBLOCK    Low Napa River exstage (unblocked cond.)
Auxiliary Flow                  AREA5      Outflow to Napa R via Pueblo & Trancas

     ANNUAL series
     Computation Time Interval (e.g. 1HOUR, 1DAY, ...)    5MIN
     Number of Time Intervals                              1800

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Figure D-16. Plan components, minimum facility - HEA, unblocked

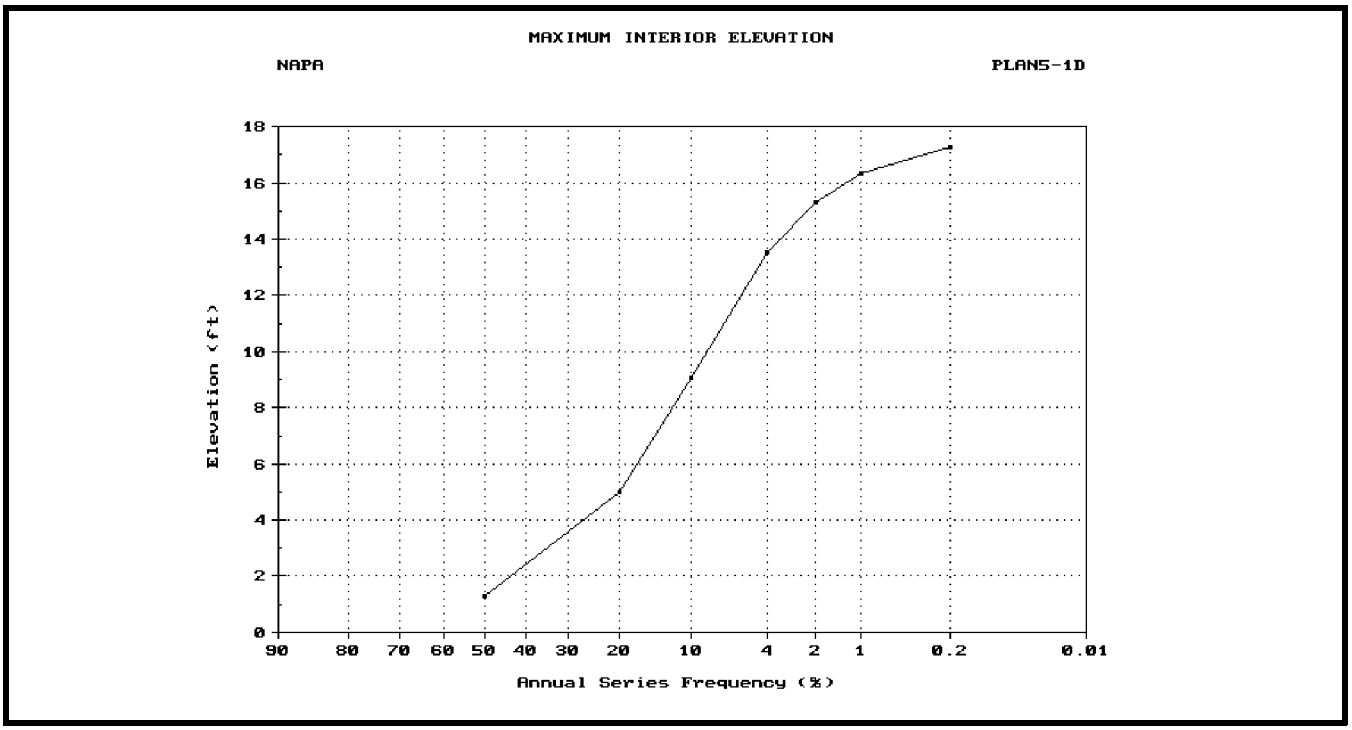

Figure D-17. Stage-frequency for minimum facility - Interior Area 5 - HEA, unblocked

c. Without-project condition stage-frequency relationship with the minimum facility in place.

(1) After the minimum facility was selected, it was evaluated using general rain hypothetical event analysis (HEA). A new general rain HEA plan (Plan 5-2A) was defined using precipitation depth-duration-frequency data for general rain events occurring over the Napa River watershed as well as the interior area. Exterior stages were computed from imported hypothetical flood discharge hydrographs and a stage-discharge rating for the Napa River at the interior area outlet as previously described. The results of the analysis were used to test the effectiveness of the minimum facility gravity outlet. HEC-IFH assessed local runoff flooding that occurs during blocked conditions (e.g., with general rain storms centered over the interior and exterior basin causing flooding on both the interior and exterior). The resulting stage-frequency relationship is shown in Figure D-18. Plan 5-1D is HEA with unblocked exterior conditions and Plan 5-2A is HEA with interior and exterior flooding conditions.

(2) Continuous simulation analysis (CSA) was performed using previously described period-of-record composite rainfall. The purpose of evaluating CSA in addition to HEA is to compare the resultant stage-frequency relationships. CSA captures the relationship between interior runoff and exterior stage, whereas HEA assumes interior and exterior flooding are coincident.

(3) Examination of CSA results for several historical events shows that interior and exterior flooding are typically coincident, as illustrated in Figure D-19 for the February 1986 event. An exception to this was the January 1973 event, where the 41-year record interior rainfall and resultant runoff occurred while Napa River stages were very low (see Figure D-20). Timing of the peak interior runoff and the maximum exterior stage is critical in the Napa study due to the small ponding area storage available. Due to this fact and the fact that the historical CSA shows that the peak interior runoff can occur before, after, or simultaneous to the exterior peak stage, HEA stage-frequency relationships were adopted for the evaluation of interior features. HEA captures the critical combinations of interior runoff and exterior stage that can occur, but are not always well-represented in the historical record. Figure D-21 shows a comparison of the stage-frequency relationships for CSA and HEA. The differences in stage are minor considering a 2-ft difference in stage (17.0 ft minus 15.0 ft) is equivalent to less than 0.25 in. of runoff from the interior area. The relatively good comparison between the relationships helps prove the reasonableness of the HEA-developed stage-frequency relationship. The HEA stage-frequency was adopted to establish the base plan or without-project condition stage-frequency relationships for evaluating additional interior flood damage reduction measures as described in paragraph D-7.

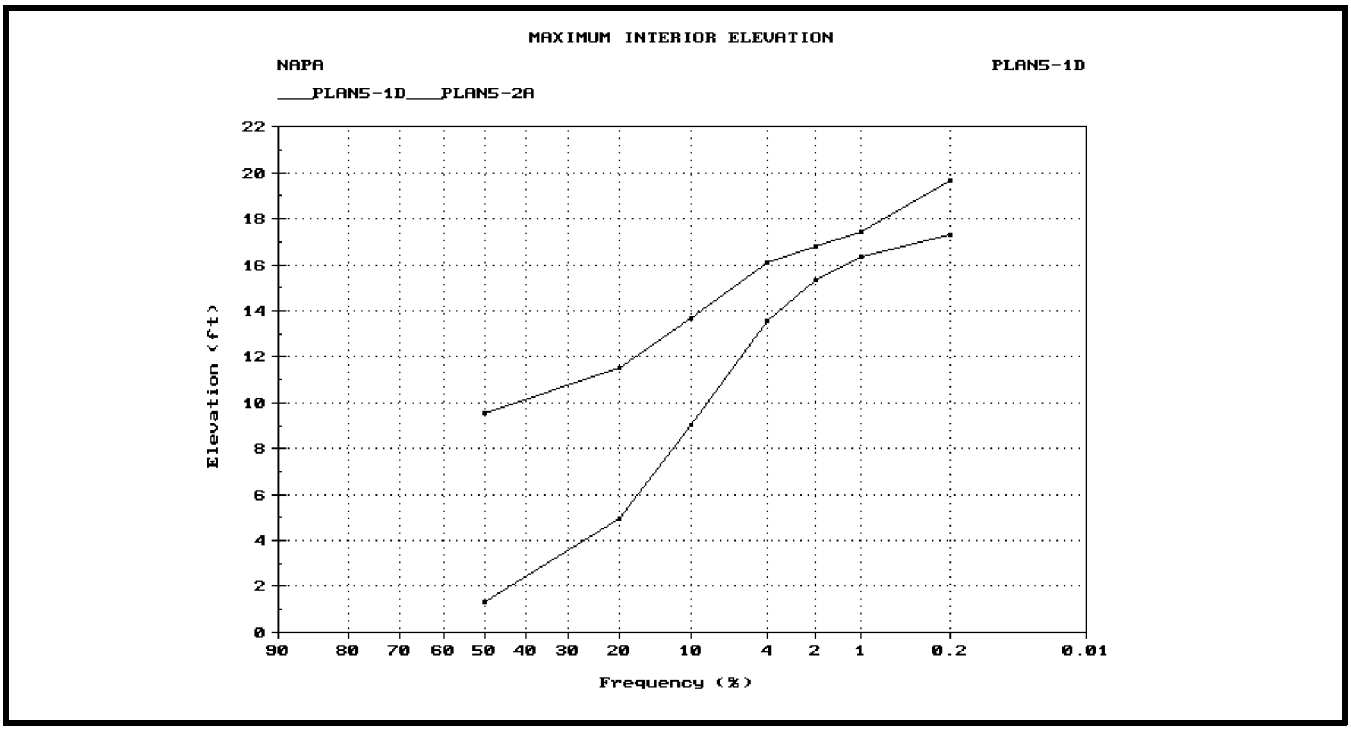

Figure D-18. Stage-frequency relationships - HEA unblocked and interior/exterior

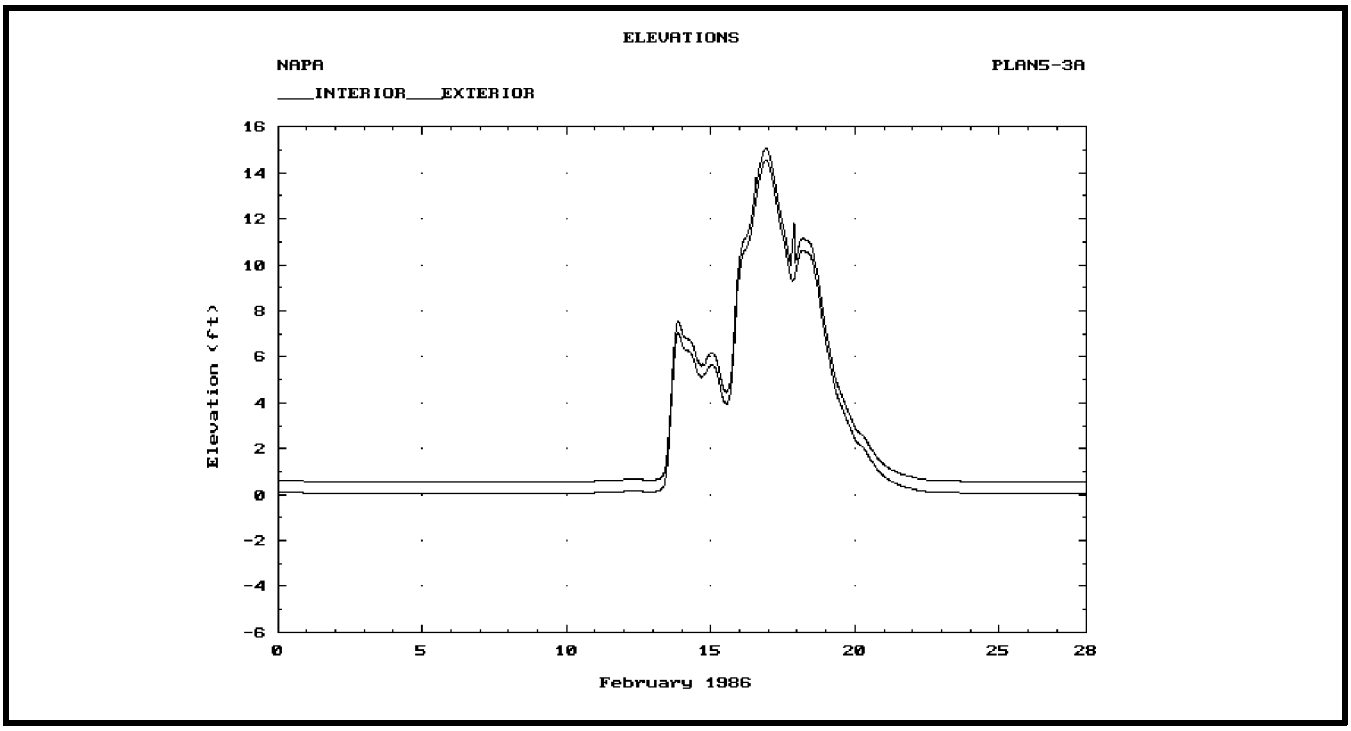

Figure D-19. Interior and exterior elevation - February 1986, CSA

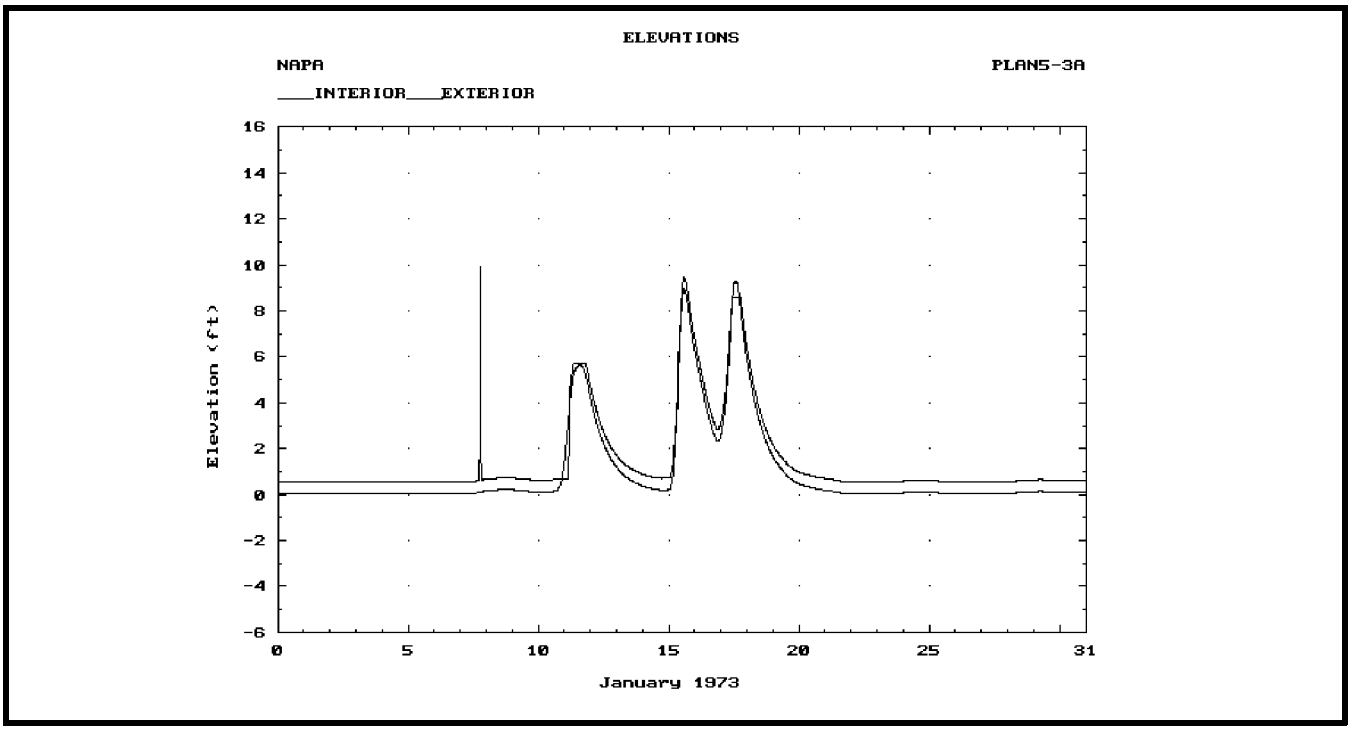

Figure D-20. Interior and exterior stages - January 1973 event, CSA

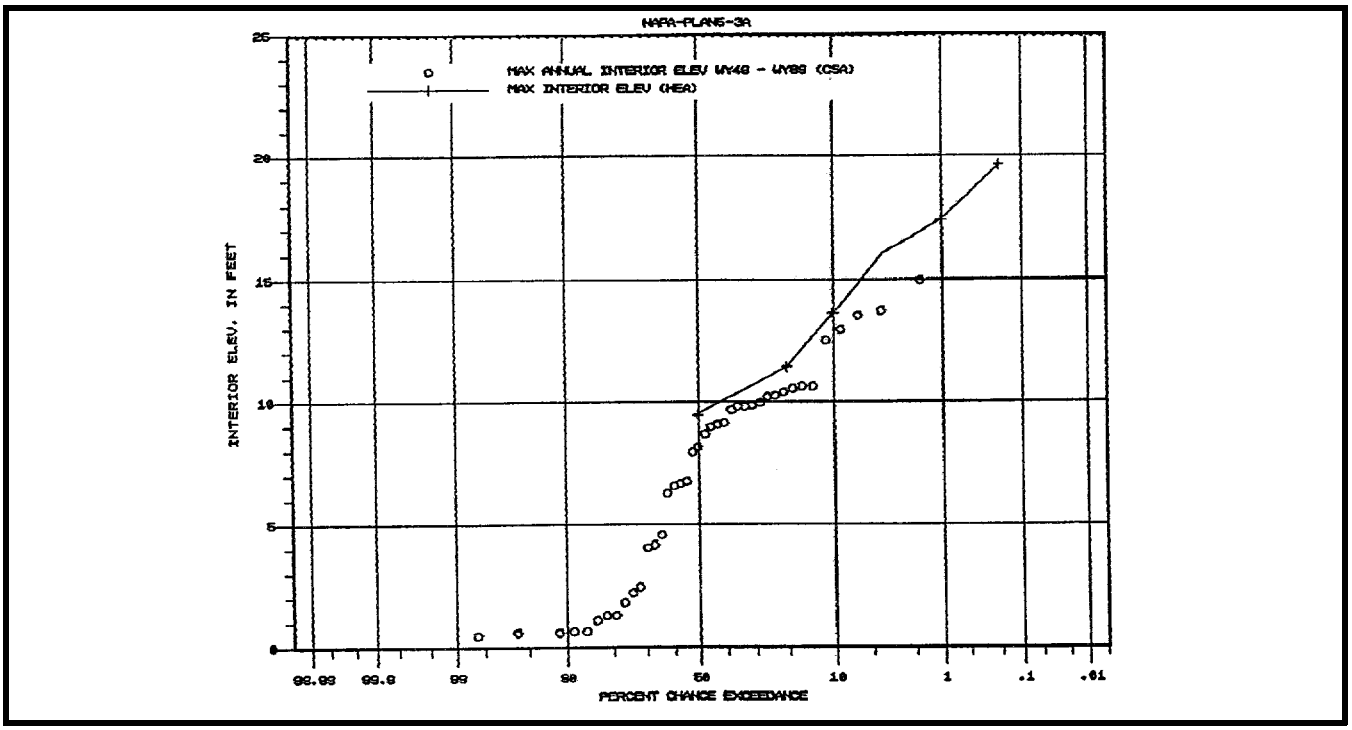

Figure D-21. Interior stage-frequency relationships for CSA and HEA - Area 5

D-7. Stage-Frequency for Interior Flood Damage Reduction Plans

a. General. The objective of this task is to develop stage-frequency relationships that can be used 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.

b. Stage-frequency relationships for additional gravity outlet capacity. New plans for evaluating additional gravity outlet capacity using data previously developed for the HEA with the minimum facility in place were defined. Only the gravity outlet data needed to be changed to define plans with a range of outlet sizes. Four or five gravity outlet configurations (modules), with one or more gravity outlets in addition to the minimum facility outlet, were defined. Each module represented an incremental increase in total outlet capacity. Several plans that incorporated the gravity outlet modules were defined and interior stage-frequency relationships were developed for each plan. The HEA results were adopted to establish a final stage-frequency relationship for each gravity outlet plan. These relationships will be used in the economic analysis to select an optimal plan. A plan summary for the four different Area 5 plans analyzed is shown in Figure D-22. Figure D-23 shows a comparison of the plan stage-frequency relationships.

c. Determine stage-frequency for added pumping capacity.

(1) General. The analysis for Area 5 shows that additional gravity outlet capacity is not effective, due to considerable coincidence between interior runoff and high exterior stages. Residual damages may be significant, and pumps may be justified. The same steps described for evaluating additional gravity outlet capacity are appropriate for evaluating added 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. At the time of this writing the preliminary economic optimal gravity outlet was selected as four 5- by 5-ft box culverts (Plan 5-C). HEA plans for Area 5 with the selected outlet and three different size pumping stations were defined and analyzed. The plan configurations are shown in Figure D-24 and the stage-frequency relationships are shown in Figure D-25. These relationships will be used to define the optimal pumping station size for interior Area 5.

HEA 01.04.00
Study ID NAPA

Comparison of Plans

A. Plan Summary

Plan ID	Type of Series	Storm Area (sq mi)	Storm Duration (hr)	Area of Primary Grav.Out (sq ft)	Min Pump Start Elev. (ft)	Min Pump Stop Elev. (ft)	Total Pump Capacity (cfs)
PLAN5-2A	ANNUAL	266.00	96.00	55.00	0.00	0.00	0.0
PLAN5-2B	ANNUAL	266.00	96.00	72.00	0.00	0.00	0.0
PLAN5-2F	ANNUAL	266.00	96.00	90.75	0.00	0.00	0.0
PLAN5-2C	ANNUAL	266.00	96.00	100.00	0.00	0.00	0.0
PLAN5-2D	ANNUAL	266.00	96.00	126.75	0.00	0.00	0.0

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Figure D-22. Summary of plans for evaluating additional outlet capacity - HEA

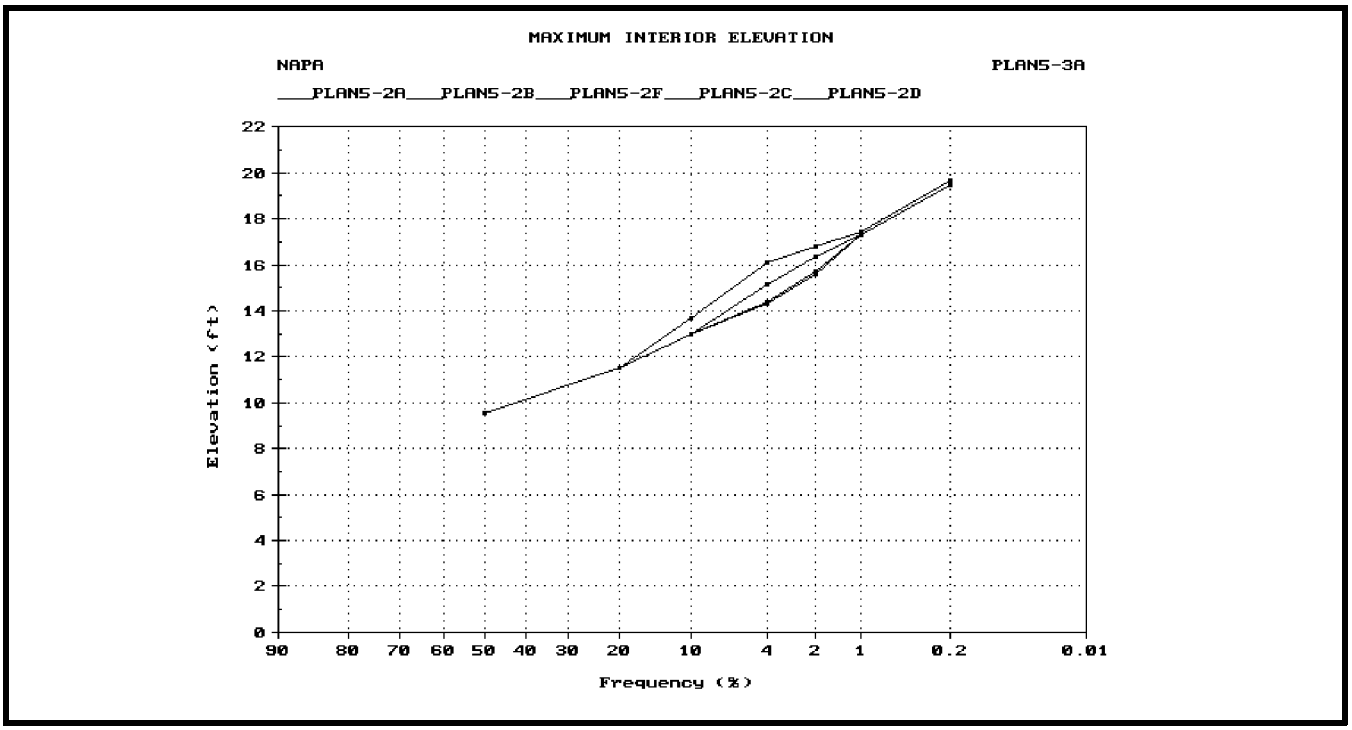

Figure D-23. Stage-frequency relationships for a range of gravity outlet sizes

HEA 01.04.00
Study ID NAPA

Comparison of Plans

Plan No.	Plan ID	Plan Description
1	PLAN5-2C	Area 5 - 4-5X5 Boxes - HEA int/ext
2	PLAN5-4A	Area5 4-5X5 w/100 cfs pump - HEA int/ext
3	PLAN5-4B	Area5 4-5X5 w/200 cfs pump - HEA int/ext
4	PLAN5-4C	Area5 4-5X5 w/300 cfs pump - HEA int/ext
5		
6		
7		

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Figure D-24. HEA plans for evaluating pumping capacity

HEA 01.04.00
Study ID NAPA

Comparison of Plans

B. Maximum Interior Elevation-Frequency

Plan ID	Peak Elevation (ft) vs. Percent Chance Exceedance							
	50%	20%	10%	4%	2%	1%	0.2%	SPF
PLAN5-2C	9.54	11.51	13.01	14.33	15.62	17.29	19.49	0.00
PLAN5-4A	9.54	11.51	13.01	13.80	15.05	16.48	19.15	0.00
PLAN5-4B	9.54	11.51	13.00	13.56	14.52	15.93	18.79	0.00
PLAN5-4C	9.54	11.51	12.99	13.54	14.15	15.54	18.57	0.00

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Press <F10> to Return

Figure D-25. Stage-frequency relationships for evaluating pumping capacity

d. Nonstructural measures. Temporary evacuation, relocation, flood proofing, and other nonstructural measures that reduce susceptibility to damage, as well as the increase in available storage, will be evaluated by the district and considered in the final recommended plan.

e. Final plan selection. Other social, institutional, and environmental issues, including the management of future development, and flood warning and preparedness programs, will need to be evaluated in the final plan selection for each interior area.