Overview of the Flood Damage Analysis Program (HEC-FDA)

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Abstract

The Hydrologic Engineering Center (HEC) has developed a next generation Flood Damage Analysis computer program (HEC-FDA) for formulating and evaluating flood damage reduction plans. The program streamlines the study process following functional elements of a study involving coordinated study layout, hydrologic engineering analysis, economic analysis, and plan formulation and evaluation. The program has the capability to quantify uncertainty in discharge-frequency, stage-discharge, geotechnical levee failure, stage-damage functions, and incorporate these uncertainties into economic and performance analyses of alternative flood damage reduction plans. Plans are evaluated by expected annual damage associated with a given analysis year or the equivalent annual damage over the project life of the plan. Information on the flood risk performance is also included in the results. Output includes tables and selected graphics of information by plan, analysis year, stream, and damage reach for the plan. Results of the various plans may also be compared. The program design is consistent with federal and Corps of Engineers policy and technical requirements. The program operates on Windows NT and 95, and Unix-based computer operating systems.

Introduction

The Corps of Engineers requires use of risk-based analysis procedures for formulating and evaluating flood damage reduction measures (USACE, 1996). Procedures developed are now applied to ongoing Corps studies. They quantify uncertainty in discharge-frequency, stage-discharge, stage-damage functions and incorporate it into economic and performance analyses of alternatives. The process applies Monte Carlo simulation (Benjamin et al., 1970.), a numerical-analysis procedure that computes the expected value of damage while explicitly accounting for the uncertainty in the basic functions.

The HEC-FDA program was initially released early in 1997 as a “pre-release version. Since that time development and improvements have continued. New program capabilities since the original release include inflow vs. outflow relationships for regulated frequency functions, and interior vs. exterior relationships, non-linear

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geotechnical failure criteria, and wave overtopping for levee analysis. The capability for entering structural floodplain inventory data in a table or spreadsheet type form has also been added. The program data base has been restructured allowing the import and export of economic data.

The HEC-FDA program is designed to expedite the Corps plan formulation and evaluation technical analysis for flood damage reduction studies. The program streamlines the study process following functional elements of a study involving coordinated study layout, hydrologic engineering analysis, economic analysis, and plan formulation and evaluation. The main program window shown on Figure 1 illustrates the program menu that facilitates the definition of study information following these functional elements. The program is used continuously throughout the planning process as the study evolves from the base without-project conditions analysis through the analysis of alternative plans for reducing flood damage.

Figure 1. HEC-FDA Main Program Window

Study Layout and Configuration

The HEC-FDA program application requires coordinated effort from the various interdisciplinary elements involved in the study. The study configuration, hydrologic engineering, and economic analysis information for the study are developed and specified. All study information is stored under a study directory. Study Configuration information is common with all elements of the study and therefore, should be the first information defined.. Once defined, most of the data remains constant throughout the progression of the study. The study streams, damage reaches, analysis years, and plans are defined under Configuration. See Figure 2. The study information is referenced so that water surface profile stationing, damage reach definition, and structure locations are consistent with stream stationing.

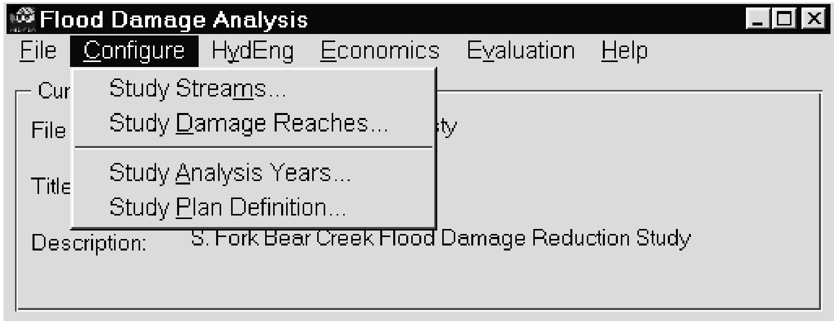
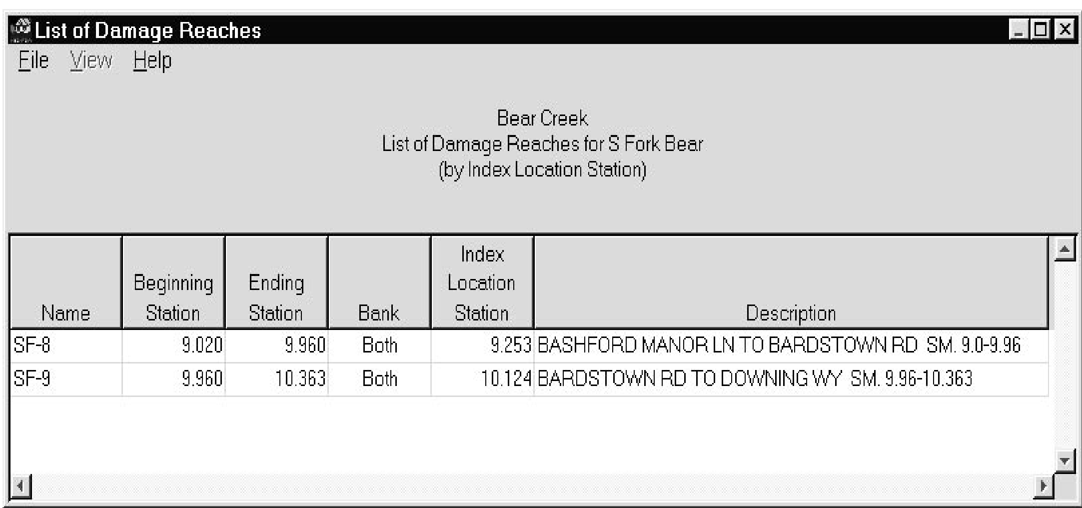


Figure 2. Configure Menu

One of the important elements of study configuration information is the definition of study damage reaches. Damage reaches are spatial floodplain areas. They are used to define consistent data for plan evaluations and to aggregate structure and other potential flood inundation damage information by stage of flooding. A damage reach is defined by the beginning and ending stations (river mile, kilometer, etc.) along the stream and can extend into the floodplain to include the largest flood deemed reasonably possible. Damage reaches are unique to a stream. They are integral to both the hydrologic engineering and economic analyses. Figure 3 shows a list of defined study damage reaches.



Name	Beginning Station	Ending Station	Bank	Index Location Station	Description
SF-8	9.020	9.960	Both	9.253	BASHFORD MANOR LN TO BARDSTOWN RD SM. 9.0-9.96
SF-9	9.960	10.363	Both	10.124	BARDSTOWN RD TO DOWNING WY SM. 9.96-10.363

Figure 3. List of Study Damage Reaches

Hydrologic Engineering

General. Hydrologic engineering analyses are required for defining hydrologic engineering relationships for the specific study setting. Required hydrologic engineering data for plan evaluation are typically water surface profiles, discharge- or stage-probability functions with uncertainty, stage-discharge (rating) functions with uncertainty, and data describing levees, including data that describe flooding characteristics associated with them. These data are developed for each plan, analysis year, stream, and damage reach that have been defined as part of the study configuration. The data is defined in the HEC-FDA program by selecting hydrologic engineering (**HydEng**) from the main program window and are described in the order that the elements appear on the menu. See Figure 4.

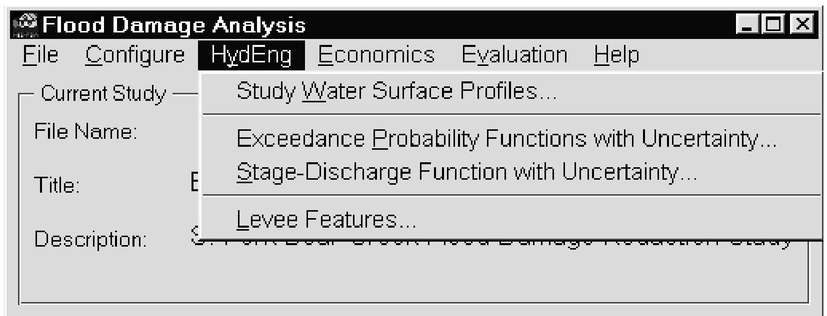
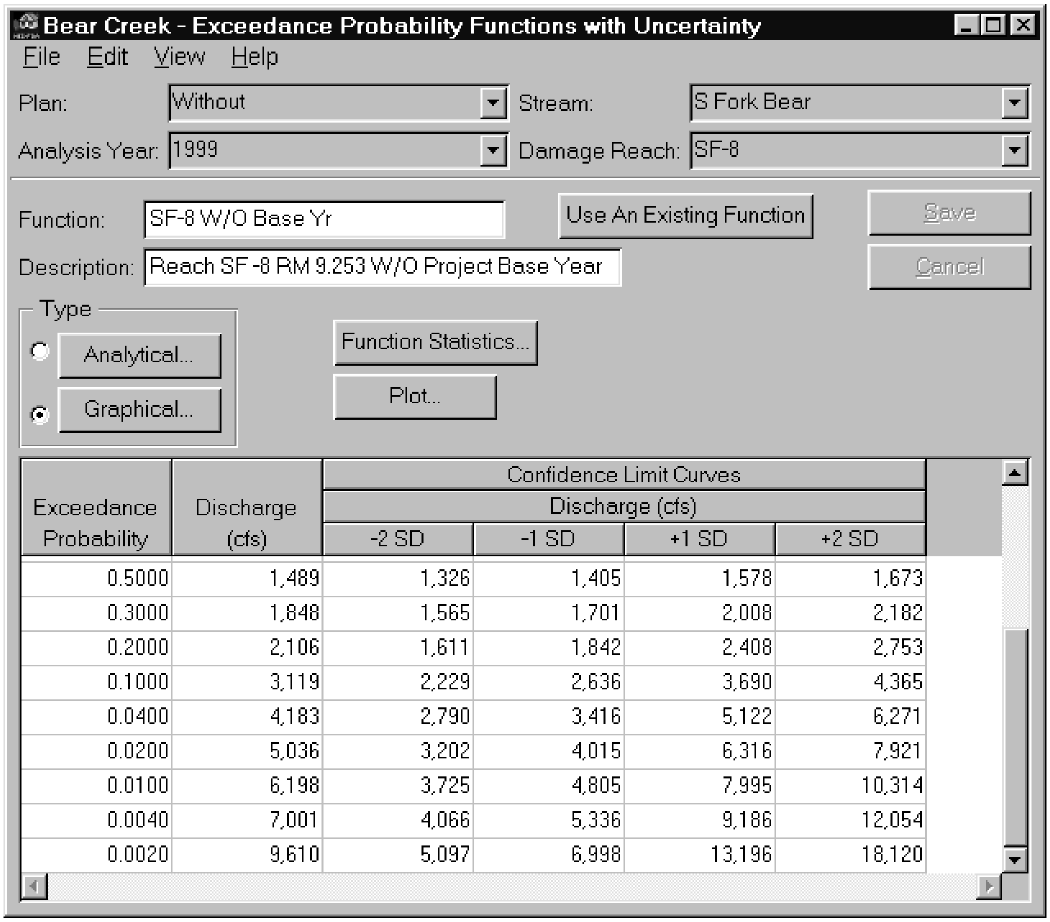


Figure 4. Hydrologic Engineering Elements

Water Surface Profiles. Water surface profiles are required to aggregate stage-damage-uncertainty functions at damage reach index locations. They are also used in development of the stage-discharge functions. The profile data are normally imported from stream hydraulics programs such as the HEC River Analysis System package (HEC-RAS). The data may also be entered manually. The HEC-FDA program requires specific water surface profiles for the 50-, 20-, 10-, 4-, 2-, 1-, .50-, and .20- percent chance exceedance frequency flood events.

Exceedance-Probability Functions. The derivation of exceedance-probability functions is dependant on data availability. For gaged locations and where analytical methods are applicable, the HEC-FDA program uses procedures defined by the Interagency Advisory Committee on Water Data (1982). Uncertainties for discrete probabilities are computed using the non-central *T* distribution. For ungaged locations, the cumulative discharge-frequency is adopted from applying a variety of approaches (Water Resources Council, 1981). The adopted function statistics are then computed similar to gaged locations. The equivalent record length is specified based on the perceived reliability of the information. Regulated discharge-frequency, stage-frequency, and other non-analytical or graphical frequency functions require different methods. An approach referred to as order statistics (Morgan et al., 1990) is used to compute the cumulative frequency and uncertainty relationships for these situations. Figure 5 shows an example frequency screen of HEC-FDA with tabulated results and Figure 6 shows a plot of the frequency function with uncertainty.



Exceedance Probability	Discharge (cfs)	Confidence Limit Curves Discharge (cfs) -2 SD	-1 SD	+1 SD	+2 SD
0.5000	1,489	1,326	1,405	1,578	1,673
0.3000	1,848	1,565	1,701	2,008	2,182
0.2000	2,106	1,611	1,842	2,408	2,753
0.1000	3,119	2,229	2,636	3,690	4,365
0.0400	4,183	2,790	3,416	5,122	6,271
0.0200	5,036	3,202	4,015	6,316	7,921
0.0100	6,198	3,725	4,805	7,995	10,314
0.0040	7,001	4,066	5,336	9,186	12,054
0.0020	9,610	5,097	6,998	13,196	18,120

Figure 5. Graphical Exceedance-Probability Function with Uncertainty

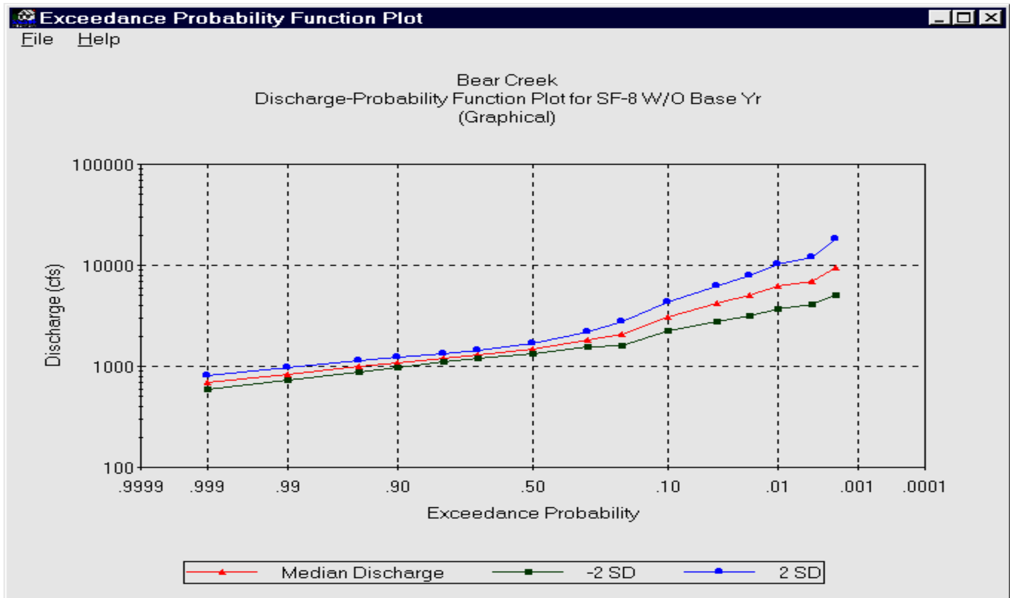


Figure 6. Plot of Exceedance-Probability Function

Stage-discharge Functions. Stage-discharge or rating functions are defined by observed data or computed water surface profiles. The relationships and uncertainty are entered directly into HEC-FDA for both types. Probability density functions of errors may be normal, log normal, triangular, or uniform. For observations, uncertainty is calculated from deviates of the best fit cumulative rating function. Computed profiles are required for ungaged locations and modified conditions. For these, the corresponding water surface profile data set provides eight discharge-stage ordinate values plus the invert for zero discharge as initial definition of the rating at the damage reach index station locations. Additional points may be added to define the function. Figure 7 shows a plot of the rating with uncertainty.

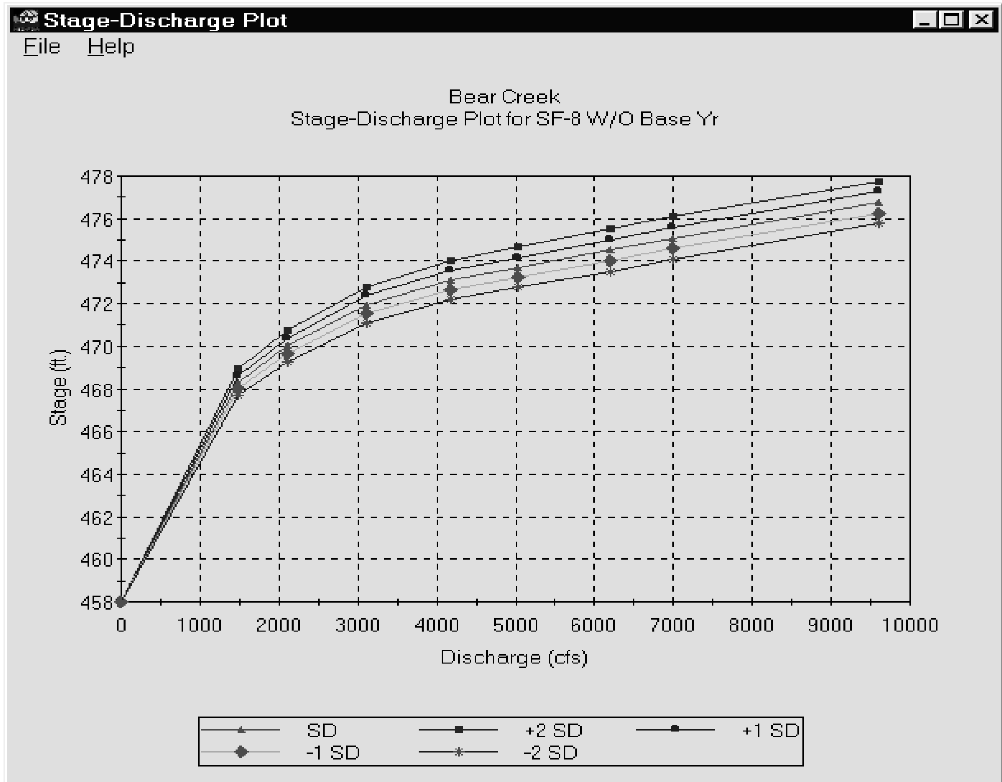


Figure 7. Stage-Discharge Plot

Levee Features. Under Levee Features, the user specifies levee size and failure characteristics, interior versus exterior stage relationships associated with the levee, or wave overtopping criteria. The levee, floodwall, or tidal barrier characteristics are entered and other relationships are defined depending on whether the levee is subject to geotechnical failure or wave action (overtopping) which may cause flooding. A levee or floodwall is defined by selecting the appropriate Plan, Year, Stream, and Reach in the Levee Feature window. The elevation of the levee or floodwall is entered in the appropriate field (Figure 8).

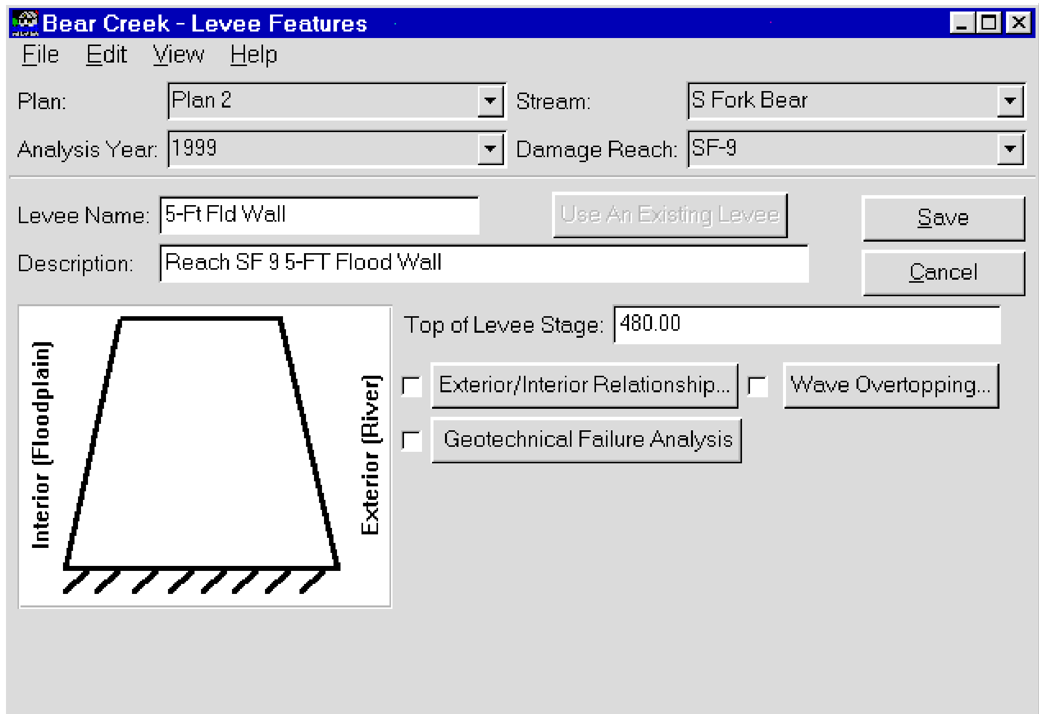


Figure 8. Levee Features

As can be seen on the Levee Features window (Figure 8), other data that describe the characteristics of levees and floodwalls and how they affect flooding can be specified. These features are briefly described. Detailed descriptions of these features are included in the program User's Manual.

(1) *Exterior-Interior Relationship* - The purpose of this feature is to define a relationship between the stage on the river or exterior side of the levee vs. the stage in the flood plain or interior side of the levee. This relationship is necessary if water that overtops the levee from the river side will not reach the same level as the top of the levee in the flood plain. This may be due to floods that result in stages near the top of the levee overtopping in a safe, controlled manner, as designed or flood hydrograph volume is not sufficient to fill the flood plain to the stage equal to the top of the levee. In either case, the relationship must be developed from hydrologic or hydraulic analyses external to the HEC-FDA program. If the relationship is not specified, the assumption is that the flood plain fills to the stage in the river (represented by the rating curve for the reach) for all events that result in stages that cause levee failure or are above the top-of-levee.

(2) *Geotechnical Failure Analysis*. A relationship between water elevation on the river or exterior side of the levee vs. the probability of levee failure may be specified, if appropriate. This may be necessary for existing non-federal levees or older levees that may have deteriorated and can no longer be assumed to hold water to the stage initially

intended. The relationships are developed from geotechnical analysis according to existing geotechnical guidance.

(3) *Wave Overtopping*. Wave Overtopping Analysis allows the user to account for effects of wave overtopping when analyzing levees, floodwalls or tidal barriers. A wave height versus still water stage relationship is specified. Still water stage corresponds to the exterior stage-discharge or stage-frequency function specified for the reach. The uncertainty of wave height is defined by specifying one of several error distribution types. When a levee or floodwall is subjected to wave action, a portion of the wave may overtop depending on whether the wave strikes the structure. The volume of water that spills over the levee or floodwall is dependent on the effective overtopping height. Wave overtopping relationships may be used to account for these factors. A relationship between effective overtopping height and resulting interior stages can also be specified. These relationships are developed outside the HEC-FDA program using wave overtopping analyses and overtopping volume versus interior stage characteristics.

Economics

General. Economic analysis aggregates stage-damage-uncertainty functions by damage category, damage reach, stream, plan and analysis year using the structure inventory data and water surface profiles. These functions are used in the plan evaluation. Figure 9 shows the information the is defined under Economics.

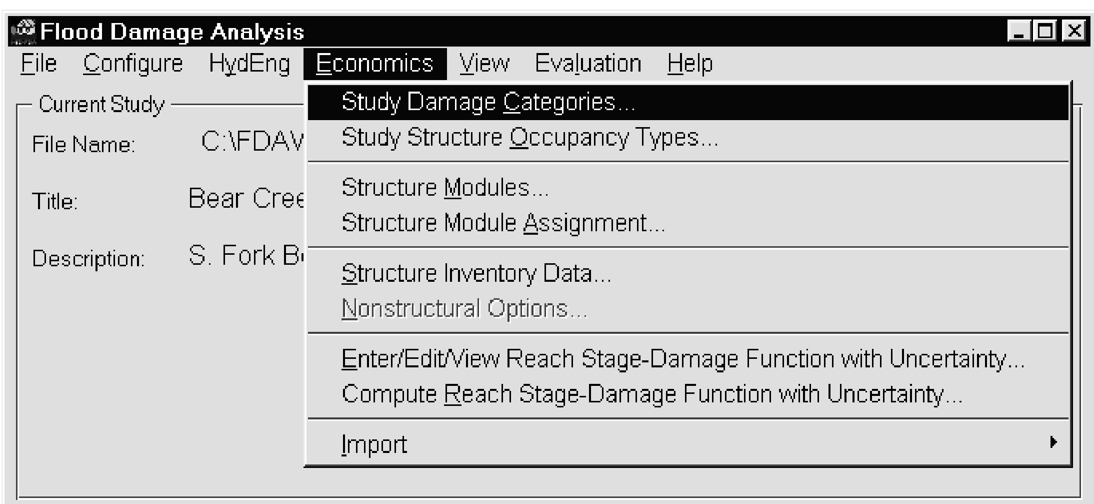


Figure 9. Defining Economic Data

Damage Categories. Damage categories are used to consolidate large number of structures into specific groups of similar characteristics for analysis and reporting.

Depth-Damage Functions. Depth-damage functions define the percent of the structure damage for a range of flood stages at a structure. The percent-damage is multiplied by the structure value to get a unique depth-damage function at the structure. The zero depth is assumed to coincide with the stage (elevation) of the first floor. The depth-percent damage functions are input directly or imported from external files.

Structure Inventories. Inventories of floodplain structures are performed to develop structure attribute information on unique or groups of structures relevant to flood damage analysis. The information is entered and stored in HEC-FDA for subsequent calculations to produce stage-damage-uncertainty information at the damage reach index locations. Structure attributes include the following: location addresses, stream station and/or coordinates; reference stages; damage category and depth-percent damage function assignments; structure and content values, and uncertainty parameters. Data can be entered in a table or "spreadsheet" type form, if desired. The data may also be imported from external files. An illustration of some of the information included in structural inventory is included on Figure 10.

Bear Creek - Structure Inventory

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	Stream Station	Structure Value ($1,000's)	Content Value ($1,000's)	First Floor Stage (ft.)	Damage Category Name	Structure Occupancy Type	Structure Module Name	Stream Name	Bank	Damage Reach Name
399	9.900	73700.00	36850.00	476.99	COMM	30S_30C_	Base	S Fork Bear	left	SF-8
402	9.750	241.50	120.75	476.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
403	9.730	237.40	118.70	476.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
404	9.710	344.40	172.20	477.00	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
405	9.690	232.30	116.15	476.75	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
406	9.660	232.30	116.15	476.81	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
407	9.640	344.40	172.20	475.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
408	9.620	232.30	116.15	475.63	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
409	9.600	294.50	147.25	475.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
410	9.580	232.30	116.15	476.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
411	9.565	237.40	118.70	476.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
412	9.500	240.50	120.25	476.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
413	9.475	355.60	177.80	474.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
414	9.450	281.20	140.60	472.00	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
415	9.420	303.70	151.85	472.25	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8
416	9.380	470.80	235.40	472.50	APT	A2S_A2C_	Base	S Fork Bear	left	SF-8

Figure 10. Structural Inventory Data Table

Stage-damage Functions. Stage-damage-uncertainty functions are required for each damage category, damage-reach, plan and analysis year. They may be entered directly or computed and aggregated to the index location based on the structure inventory attributes and specifications and associated water surface profiles. A plot of the stage-damage function with uncertainty is shown on Figure 11.

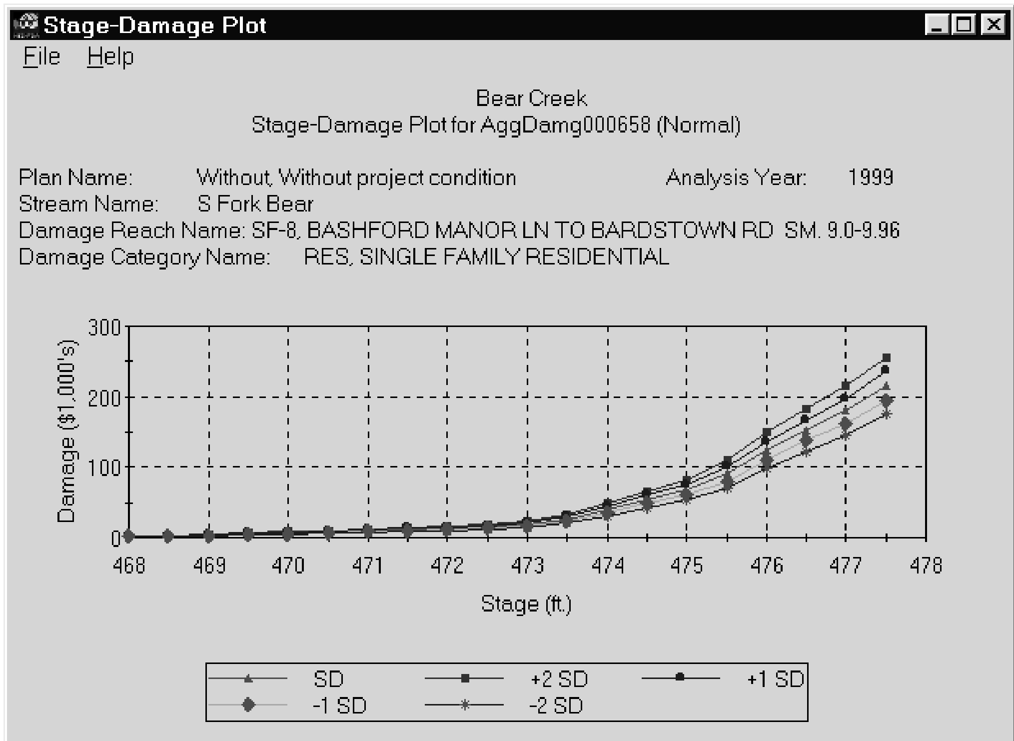

Figure 11. Stage Damage Function with Uncertainty

Evaluation

Evaluation is where HEC-FDA performs computations for specified plans and output results are available for viewing. The analyses are performed using Monte Carlo simulation to numerically integrate the large number of possible combinations of damage-frequency functions associated with defined uncertainties in the frequency, stage and damage functions. Figure 12 shows study evaluation options. Under evaluation you specify the type of analysis to be performed. The choices are to view a study status report (Figure 13), conduct analysis by plans for a specific analysis year, conduct analysis of equivalent annual damage, or view study results, if analyses have been completed.

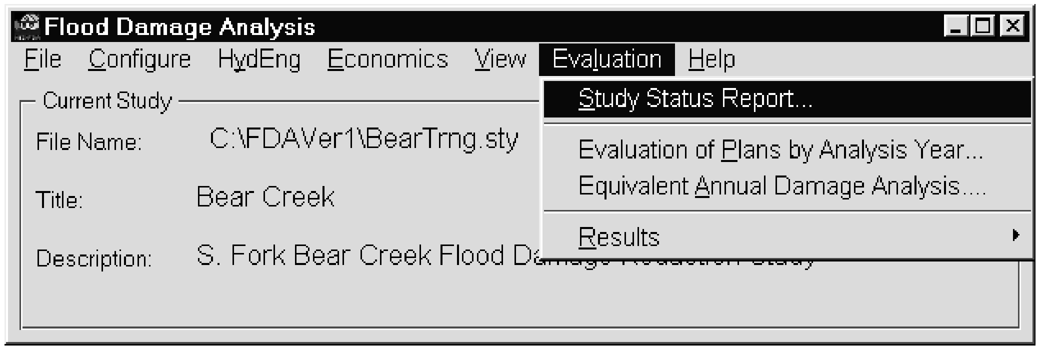

Figure 12. Study Evaluation Options

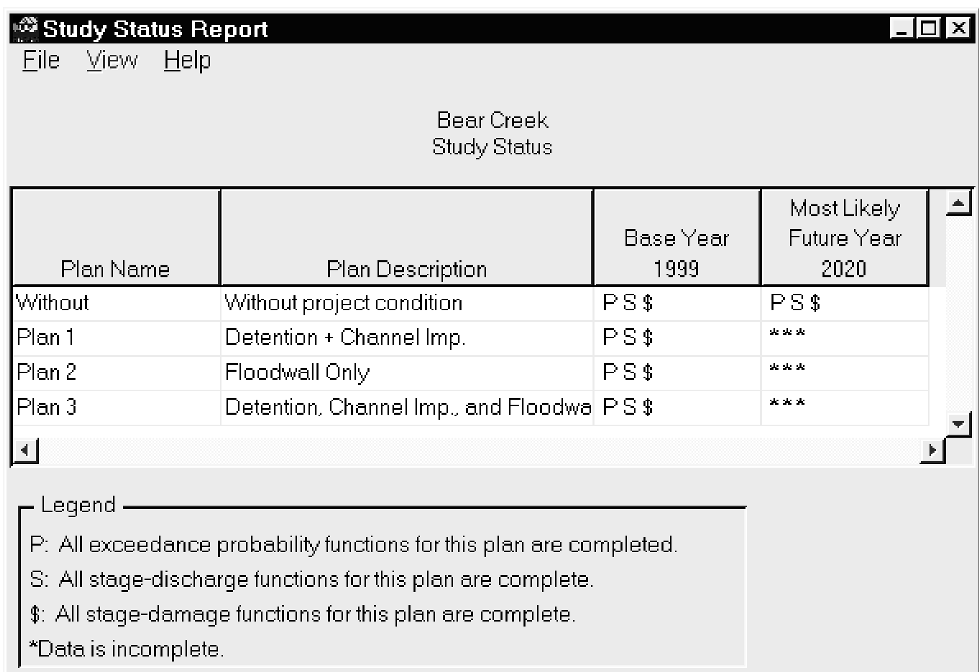

Figure 13. Study Status Report

Results

Information on the flood risk performance and expected annual damage is included in the results. Output includes tables and selected graphics of information by plan, analysis year, stream, and damage reach for the entire plan. Plan comparisons may also be performed. The choices under Results are displaying reports of (1) expected annual damage by analysis year, (2) equivalent annual damage, or (3) project performance. Figure 14 shows these options.

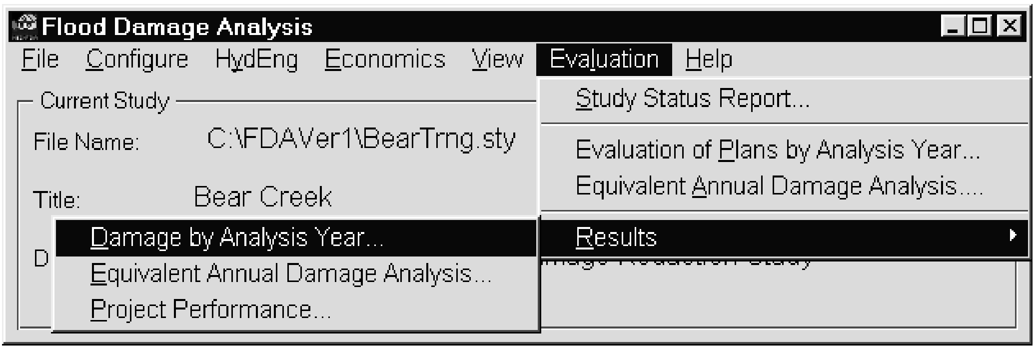

Figure 14. Study Analysis Results options

<u>Expected Annual Damage by Analysis Year</u>. When this option is selected, the window shown on Figure 15 appears and the analyst can select the desired combination of analysis results he or she wants in the report. An example output report for an analysis of several alternative levee plans for a damage reach is shown in Table 1.

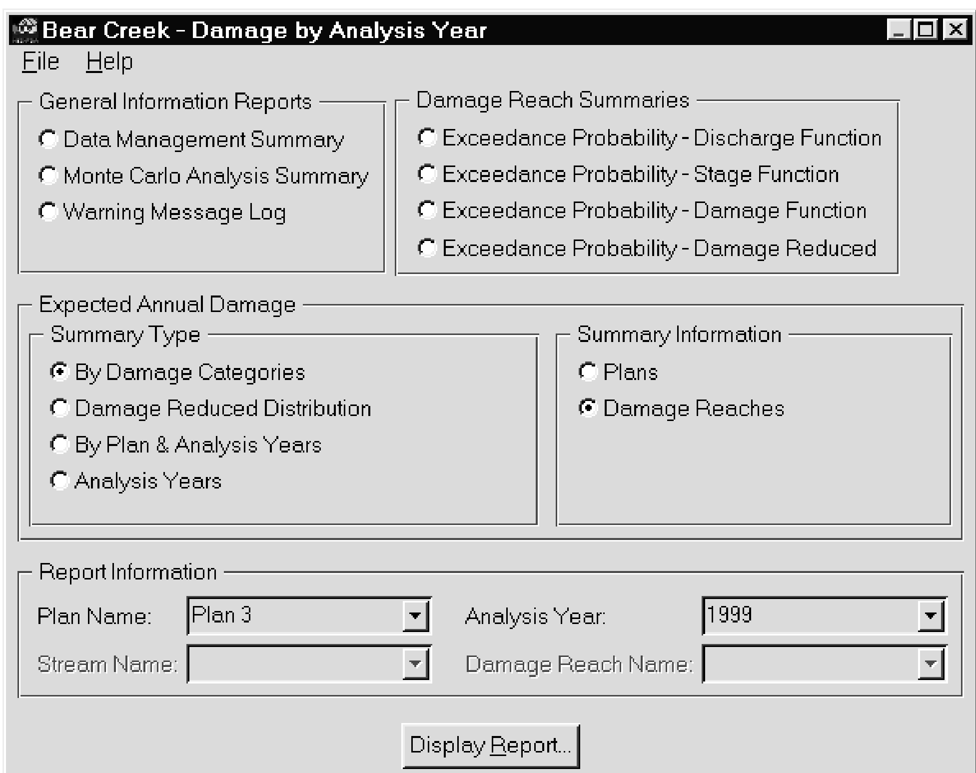

Figure 15. Damage by Analysis Years report Options

Table 1
Expected Annual Damage by Plan

Plan Name	Plan Description	Expected Annual Damage ($1000)		
		Without Project	With Project	Damage Reduced
Without	Without Project	78.3	--	--
Plan 1	16.5' Levee	78.3	72.9	5.4
Plan 2	19.1' Levee	78.3	63.1	15.2
Plan 3	21.9' Levee	78.3	49.1	29.2
Plan 4	23.0' Levee	78.3	43.1	35.2
Plan 5	24.0' Levee	78.3	30.2	48.1
Plan 6	25.5' Levee	78.3	26.6	51.7
Plan 7	26.0' Levee	78.3	23.1	55.2
Plan 8	27.0' Levee	78.3	17.4	60.9

Project Performance. Project or plan performance is a measure of the hydrologic efficiency of a flood damage reduction plan. Performance is measured in terms of risk of flooding in any year, over a specified number of years, or if a specific hypothetical or historical event occurs. Risk-based analysis is used to determine plan performance. The options for performance results reports are illustrated on Figure 16. Performance is based on exceedance or non-exceedance of a target stage which can be specified by the analyst based on residual flood damage for a specific event. Performance results can be displayed based on reaches for a single plan or for all plans and reaches. An example of some of output for plan performance associated with the various levee sizes is shown in Table 2.

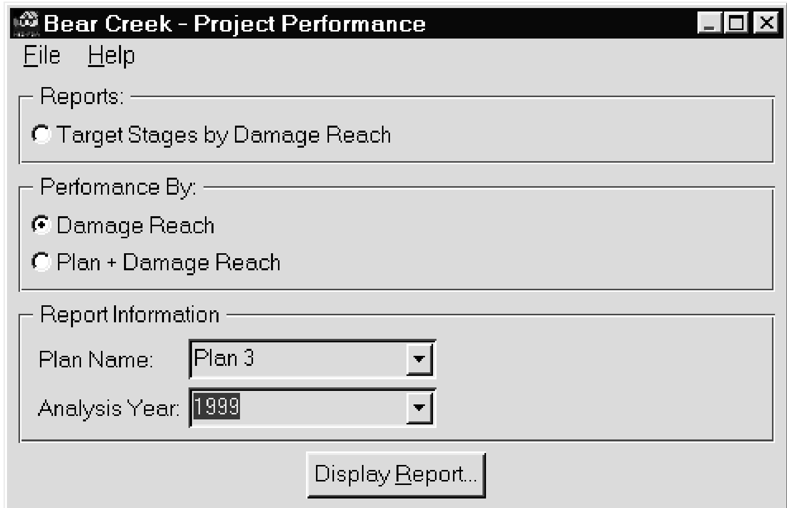

Figure 16. Project Performance Report Options

Table 2
Plan Performance

Plan Name	Plan Description	Target Stage	Expected Annual Stage Exceedance Probability	Long-term Risk in Percent for Indicated Years			Conditional Annual Percent Chance Non-Exceedance for Indicated Events		
				10	25	50	4%	1%	.2%
Without	Without Project	15.1	0.059	46.0	78.5	95.4	16.9	0.0	0.0
Plan 1	16.5' Levee	16.5	0.043	35.5	66.6	88.9	49.1	0.3	0.0
Plan 2	19.1' Levee	19.1	0.023	20.5	43.6	68.2	92.7	9.5	0.0
Plan 3	21.9' Levee	21.9	0.012	11.4	26.2	45.5	99.5	48.8	0.5
Plan 4	23.0' Levee	23.0	0.010	9.2	21.4	38.2	99.8	64.4	1.6
Plan 5	24.0' Levee	24.0	0.008	5.6	13.5	25.1	100.0	87.0	12.9
Plan 6	25.5' Levee	25.5	0.005	4.8	11.6	21.9	100.0	91.1	19.0
Plan 7	26.0' Levee	26.0	0.0045	4.1	9.9	18.7	100.0	94.1	26.8
Plan 8	27.0' Levee	27.0	0.0029	2.8	6.9	13.3	100.0	97.7	45.6

Conclusions

The HEC-FDA program provides comprehensive state-of-the-art analysis capabilities for formulating and evaluating flood damage reduction that includes risk-based analysis procedures. The program has a modern user interface and operates on multiple platforms. Computational procedures and output reports are consistent with Federal and Corps of Engineers policy and technical element regulations. Version 1.0 release is scheduled for early December 1997. The release will include a user's manual.

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