RISK BASED ANALYSIS OF FLOOD DAMAGE REDUCTION ALTERNATIVES FOR THE UPPER DES PLAINES RIVER IN NORTHEASTERN ILLINOIS

by

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ABSTRACT

Risk based analysis is evolving within the Corps and is being phased into all Corps planning and design studies. A risk based analysis has been applied to a flood damage reduction, draft feasibility study for the Upper Des Plaines River, a large watershed in northeastern Illinois. The HEC-FDA risk and reliability format was used to evaluate the feasibility of several flood damage reduction measures by evaluating the engineering and economic performance of each alternative. Results from the analysis have provided a comprehensive comparison of the flood damage reduction alternatives and the expected benefits accrued by location and damage category. In addition, the reliability of the flood damage reduction alternatives has been ascertained at various locations along the river.

STUDY SETTING

The Des Plaines River originates in Racine and Kenosha Counties in southeastern Wisconsin where the basin is primarily agricultural. The river enters Illinois in Lake County, flowing southward through urbanized Cook County to Riverside, Illinois (Figure 1). Beyond Riverside, the river curves to the southwest eventually merging with the Chicago Sanitary and Ship Canal, the DuPage River and the Kankakee River near Joliet, Illinois and forms the Illinois River. Except for the upper reaches in Wisconsin and northernmost Illinois, most of the study area is densely populated with considerable development in areas adjacent to the river's floodplain. Despite the highly urbanized character of much of the project area, the river has many natural, scenic, and recreational characteristics including riparian woods along 34 percent of its length.

The Des Plaines River is a primary drainage feature in northeastern Illinois. The river valley can be as wide as one mile, with the river channel itself on the order of 200 to 250 feet wide. From Wisconsin to the junction of the Des Plaines River and the Chicago Sanitary and Ship Canal the average river slope is approximately 1.3 feet per mile. The watershed is aligned primarily along a north south axis with a length of 82 miles and an average width of 9 miles. The drainage area of the watershed at Riverside, including the Salt Creek tributary, is 630 square miles. The length of the river is approximately 70 miles from the headwaters in Wisconsin to the study limits in Riverside, Illinois. Within this limit there are 4 mainstem United States Geological Survey (USGS) gaging stations with records ranging from 37 years at Russell to 83 years at Riverside - see Figure 1.

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The Upper Des Plaines River is subject to severe overbank flooding due to inadequate channel capacity to carry peak flows during major storm events. Flooding impacts homes, commercial and industrial sites, public and municipal sites, transportation network, cemeteries, golf courses and other recreation and open space areas. Average annual flood damages are estimated at $21,407,000. The feasibility study is aimed at evaluating and recommending flood damage reduction alternatives including 11 detention facilities totaling 9,540 acre-feet, 5 levees totaling over 6 miles in length, and other non-structural alternatives (Figure 1).

RISK AND RELIABILITY AS RELATED TO A FLOOD STUDY

Imperfect knowledge of the "true" nature of the hydrology and hydraulics in an area creates uncertainty in the design of flood control projects and in the determination of their reliability. Risk-based analysis provides a method to explicitly quantify the uncertainties associated with the primary relationships required in flood damage reduction projects:

1) Hydrology: flood discharge versus flood frequency,
2) Hydraulics: flood stage versus flood discharge, and
3) Economics: flood damage versus flood stage.

Risk based analysis methods provide statistical information on the reliability of predicted flood levels and the probability of those levels being exceeded. In addition, a risk based analysis provides a measure of the engineering and economic performance of proposed projects. The risk and reliability analysis for the Upper Des Plaines River study was performed following current Corps guidelines and using the current Corps of Engineer's Hydrologic Engineering Center's (HEC) flood damage analysis program, HEC-FDA (USACE, 1996a). Both HEC and the Corp's Institute for Water Resources (IWR) were contracted by the Chicago District for assistance in developing the basin-wide risk and reliability analysis for the Upper Des Plaines River. The analysis followed the general guidelines presented in the current EM 1110-2-1619 (USACE, 1996b) and the strategy developed by the Chicago District and representatives from HEC and IWR. The primary data required to carry out the risk-based reliability analysis are:

1) A best estimate of discharge-frequency curves along the river,
2) A best estimate of stage-discharge rating curves along the river,
3) A best estimate of stage-damage relationships along the river and,
4) A statistical description of the uncertainty inherent in these three relationships.

<u>DAMAGE REACH BREAKDOWN</u>

In accordance with the HEC-FDA format, the Upper Des Plaines River 70 mile study limit was subdivided into 27 damage reaches. Each damage reach was defined by an upstream and downstream river mile as well as an index node. Individual damage reaches along the 70 mile long study limit ranged from 0.2 to 10.4 miles in length. All hydrologic and hydraulic characteristics of the damage reach are defined at a chosen index node within the damage reach. Economic characteristics, such as stage-damage relationships, are aggregated over the entire reach length and total reach damages are then defined at the representative index node.

The 27 damage reaches were chosen with regard to locations of existing gaging stations, locations of large flow changes due to tributaries, state, county and municipal boundaries, locations of proposed detention facilities and at existing and proposed levee locations. At each proposed levee site two damage reaches were necessary; one to define characteristics of the protected (with levee) river bank and one to define characteristics of the unprotected river bank. In the case of a ring levee, all structures that physically shared the same bank, yet were not protected by the ring levee, were relocated to the unprotected bank in the HEC-FDA model.

DISCHARGE-FREQUENCY AND UNCERTAINTY

A flood discharge-frequency analysis provides an estimate of probability for different magnitudes of flood events. Discharge-frequency curves were taken from the HEC-1 (USACE, 1990a) baseline hydrologic model which was calibrated to the adjusted discharge-frequency curves at the four mainstem gages (based on an annual series and the expected, not computed, probability). The discharge-frequency relationships along the mainstem river were then imported to the HEC-2 (USACE, 1990b) hydraulic model for the development of synthetic water surface profiles. Through statistical methods the uncertainty in the discharge-frequency estimates was quantified with a consideration of the quality of data used to produce the adopted curves. Primarily, this is dependent on the availability of gages on the river, the number of years of record at those gages and the quality of the model calibration to these gages.

Results from the baseline condition (without project) HEC-2 hydraulic analysis were imported into HEC-FDA to define the discharge-frequency relationship at each of the river miles corresponding to the 27 index nodes. Development of the uncertainty about the discharge-frequency relationships required the use of a graphical probability distribution to achieve a good fit. The graphical probability distribution is based on the method of order statistics as described in EM 1110-2-1619. The uncertainty is developed by assuming a normal distribution about the discharge-frequency curve and adopting an equivalent number of years of record to develop the distribution. Using these values the HEC-FDA model calculates the discharges at other frequencies and develops confidence bands for the range of frequency events. For each of the 27 damage reaches, the equivalent number of years of record was determined with a consideration of the four mainstem Des Plaines River USGS gaging stations. For each of the four damage reaches that contained a mainstem gage, the equivalent number of years of record was chosen as the historic record length for the appropriate gage. A straight line interpolation was used to determine the equivalent number of years of record for the damage reaches between gages.

The method of order statistics was also used for the project condition, with detention components in place, as would be expected due to the regulating effects that reservoirs have on discharge-frequency curves. A standard deviation of errors about the regulated discharge-frequency curve was developed using the method of ordered statistics and an equivalent record length. The equivalent record length under project conditions was specified as 90% of the record length determined at each damage reach under baseline conditions. For this phase of study, it was assumed that the presence of levees did not impact the discharge-frequency curve. That is, for analyzing project conditions with levees only, the baseline condition discharge-frequency and associated uncertainties were used. The discharge-frequency relationships and deviation values for the baseline condition with storage components were also used for the baseline condition with storage components and levees.

STAGE-DISCHARGE AND UNCERTAINTY

The stage-discharge relationships along the river were developed using the HEC-2 computer backwater model under baseline and project conditions. EM 1110-2-1619 recommends a series of methods to determine a standard deviation value to develop a normal distribution about the stage-discharge curve. These methods include; using measured streamflow versus measured stage data and observing scatter within measurement periods as well as changes in the adopted rating curves over time, comparing high water data to hydraulic modeling results, and running a Manning's roughness coefficient ("n" value) sensitivity analysis to determine effects on predicted stages. Finally, the guidance gives minimum standard deviation values to adopt based on the accuracy of the survey(s) used to determine cross-sections for the hydraulic model. The above methods were utilized in determining standard deviations for the stage-discharge curves for each of the 27 damage reach index nodes.

Variations in USGS gage flow measurements over several decades were plotted at each of the 4 mainstem gages. These stage-discharge plots show the variation in the measured stage-discharge relationships over time and over a range of discharges. The maximum stage difference between the upper and lower limits of the curve was read at the 1% chance event discharge where available. If the curve did not extend to the 1% event discharge, the maximum stage difference between the projected upper and lower limits was read at the highest discharge. This determination was repeated at the four gages and maximum stage differences were: 2.8 feet at Russell, 2.6 feet at Gurnee, 3.0 feet at Des Plaines and 0.8 feet at Riverside.

A comparison of how the USGS adopted stage-discharge curves change over time was also considered. The maximum difference between the upper and lower limits was read at the highest discharge values if the curve did not extend to the 1% chance event. Maximum stage differences at the four gages were: 0.5 feet at Russell, 2.4 feet at Gurnee, 2 feet at Des Plaines and 0.4 feet at Riverside.

The 1986 flood event was used as a comparison of measured high water data to an HEC-2 computed water surface profile throughout the study limits. The HEC-2 water surface profile was generated and a plot was made with the high water marks placed at the locations where data was available. The simulated water surface profile along with the high water data was used to develop upper and lower limits of the water surfaces. Maximum stage differences between the upper and lower limits were determined for each of the 27 damage reaches. At the four mainstem gages these values ranged from 0.5 feet at the Gurnee gage to 1.3 feet at the Russell Road gage. Values were greater than and less than those reported at the gages for damage reaches located between gages.

The final method used to determine a maximum stage difference was a Manning's "n" sensitivity analysis performed for the 1% chance flood event using HEC-2. Maximum and minimum "n" values adopted were the calibrated "n" value multiplied by 1.25 and 0.75, respectively, for the lower portion of the river and 1.35 and 0.65 for the upper reaches of the river. The Manning's "n" sensitivity was split into two reaches due to the variability of stream and streambank conditions throughout the Des Plaines River. Typically the upper portion of the watershed from the Russell Road gage down past the Gurnee gage experiences log jams and overhanging vegetation. In this reach a higher "n" multiplier was used. At the gages, maximum stage differences between the upper and lower "n" water surface profiles ranged from 1.7 feet at the Riverside gage on up to 4.0 feet at the Gurnee gage.

Based on EM guidelines, the final standard deviation to apply to the stage-discharge relationship can be approximated by taking the maximum differences between the upper and lower limits, as determined by the 4 methods above, and dividing by a factor of 4. The divisor of 4 is based on the assumption that the maximum difference encompasses 95% of the possible values, thus equating to a total of 4 standard deviations or 2 standard deviations (+/-) on either side of the mean. Standard deviation values were developed for the 27 damage reaches along the entire Upper Des Plaines River study limit based on the results of the above described methodology. Of the 27 standard deviation values developed only three were adopted; 0.4 feet for the lower reaches of the river from river mile 44.5 to 49.6, 0.5 feet for the middle reach from river mile 49.6 to 89.3 and 0.6 feet in the upper reaches of the river from river mile 89.3 to 110.3. These values compared well to the minimum requirements stated in Table 5-2 of the EM based on the source of the study's cross-section data and a fair to good calibration associated with the hydraulic analysis.

The 1% event standard deviation values as determined above were linked to the HEC-2 derived stage-discharge relationships in the HEC-FDA program. At each of the 27 damage reaches, HEC-FDA computes the standard deviation values for events less than and greater than the 1% event. For purposes of this analysis, the 1% chance event was determined to be the event at which to apply the stage-discharge standard deviation. HEC-FDA takes the 1% event, stage deviation value and proportions the deviation value down the stage-discharge curve to 0 feet at 0 discharge. That is, discharges between 0 cfs and the 1% event have increasing stage deviation values from 0 feet on up to the given 1% event deviation value. The 1% event, stage deviation value is adopted for those events exceeding the 1% event.

STAGE-DAMAGE AND UNCERTAINTY

A significant economic database including a floodplain structure and traffic inventory had previously been created for earlier stages of the Upper Des Plaines River Feasibility Study. As part of this study six damage categories were identified, three of structural nature and three related to traffic:

1) Structural: Residential
2) Structural: Apartment
3) Structural: Commercial, Industrial, Public (CIP)
4) Traffic: Delays due to Floods
5) Traffic: Post-Flood Repairs
6) Traffic: Delays due to Repairs

An external program was developed to import the multiple economic databases associated with the three structural inventories into the HEC-FDA program. These databases included;

structure value, content value, first floor elevation, river mile and river bank designation. HEC assisted the District in importing the structural databases and IWR assisted in the import of the traffic databases into the HEC-FDA format. The stage-damage relationships, as typically compiled for any flood study, were augmented with information to ascertain the uncertainty about the relationships. The six economic parameters were individually analyzed with regard to uncertainty in their stage-damage function and composite stage-damage relationships were developed for each of the 27 damage reaches.

Structure Damage Evaluation

The Des Plaines River flooding of 1986 and 1987 and the synthetic water surface profiles served as a good indicator of the areas vulnerable to flood damage. Several highly damaged areas were inventoried by the State of Illinois after the 1986 and 1987 flood events. The State conducted structure inventories that were adopted in the current evaluations. In other specially designated areas, field surveys were contracted for determination of first floor elevations and structure type information - specifically for those structures within the 0.2% chance exceedance floodplain. The contract surveys covered an additional 568 structures: 418 single family residences, 150 commercial-industrial-public structures as well as apartment and townhouse units.

These field surveyed investigations were supplemented with a combination photo and field survey that utilized 1 foot contour-ortho maps to estimate first floor elevations. In addition, windshield surveys were used to establish the type of structure and to capture observable CIP structure features via a photograph. This information was used in the selection of the appropriate depth-damage functions to be used in the economic analyses.

Upon completion of the above surveys, three basic structure inventories were compiled: a single family housing inventory totaling 4,204 structures in 76 clusters; an apartment and townhouse unit inventory totaling 2,286 units in 126 clusters; and a CIP structure inventory totaling 687 structures in 687 clusters. If a number of structures and units were affected by overbank flooding from a common location, then they were clustered and analyzed as a group at that location. Due to their less common features, CIP structures were kept to individual clusters.

The inventories contain the vital parameter values necessary to evaluate flood damage potential. These parameters are: the structure location referenced to an overbank (left or right) and a river mile designation, the structure type code used to assign an appropriate depth-damage function for structure and content, the first floor elevation of the structure to which the depth-percent damage functions are referenced, the structure value estimate, and the content value estimate within the structure.

The depth-percent damage functions for residential and apartment structures were based on the Federal Flood Insurance Administration curves. Actual damage claims from the 1986 and 1987 flood events along the Des Plaines River were extracted from a FEMA database and were used to adapt these curves to the Des Plaines River area. For CIP structures, a catalogue of depth-percent damage functions developed and used at the Baltimore/Galveston Corps District offices was referenced (IWR, 1985), modified, and ultimately applied to the CIP structures within the current study. Flood damage computer programs developed by the Chicago District and used in previous District flood damage evaluations were used to perform the multiple depth-damage computations.

Uncertainty in the Residential - Structure Category

Uncertainty characterizations for the residential damage estimates included: 1) first floor elevations, 2) structure value, 3) content to structure value, and 4) the depth - percent damage functions for both structure and contents as computed per structure type. The uncertainty in the first floor elevation is dependent on the source of the inventory (field survey or topographic map) from which elevations were assigned. A normal distribution with a 0.3 foot standard deviation was used for the uncertainty in the elevation component. Uncertainties in the structural value were computed assuming a normal distribution with a +/- 10% deviation. Specific content values were determined by multiplying the structure value by a ratio of 0.52. This ratio was assumed to have an uncertainty about it, defined by a normal distribution and standard deviation of 0.51. Uncertainties associated with the depth - percent damage functions were assigned a normal distribution and were determined from an analysis of original FEMA damage claims, both at a national level and specific post flood claims from the study area.

Uncertainty in the Apartment and CIP - Structure Categories

The uncertainty characterization of the apartment and CIP structures categories included several considerations. Uncertainty in the first floor elevation was assigned a normal distribution and a 0.3 foot standard deviation. Uncertainties in the structural value were computed assuming a normal distribution with a +/- 8% and +/- 25% deviation for the apartment and CIP categories, respectively. Statistical analyses were undertaken to determine uncertainties about the content values for the apartment and CIP categories. Uncertainties were distributed normally with deviations of +/- 8% and +/- 25% for the apartment and CIP structure categories, respectively.

Traffic Damage Evaluation

During the 1986 and 1987 flood events, many communities experienced flooding on major roads that impeded, and in some cases prevented, normal and emergency travel thereby resulting in significant damages. To quantify the damages associated with roadway flooding, the transportation analysis identified 50 major roads likely to flood, mapped the detour routes around the flooding, determined the costs associated with using the detour routes and determined the costs associated with residual flooding such as road repair and replacement. The transportation damages were classified in three categories:

1) Flood detour costs (i.e., costs resulting from taking detour routes during flooding),
2) Road repair costs (i.e., costs of damage to the physical structure of the roadway),
3) Construction repair detour costs (i.e., costs arising from the use of detour routes during post-flood reconstruction and repair).

The traffic delay, detour analysis calculated the cost of the extra time and additional mileage incurred by using detour routes over the period of time a road is flooded. The amount of time a roadway is flooded (flood duration) is a primary determinant of traffic damages. With increasing severity of flood events (i.e., from the 2% chance exceedance event to the 1% event), both the flood duration and number of flooded streets increase, leading to more traffic detours with a longer duration. Delay costs were based on the number of vehicles detoured, the additional time and distance involved, and the duration of time flood detours are in effect.

Road repair costs were based on the U.S. Department of Transportation, Federal Highway Administration (USDOT, 1981) report of roadway and embankment flood impacts. This report relates depth and duration of flood events with percentages of roadway loss. Repair costs were computed based on the amount of embankment and pavement needed for repair. Costs associated with delays due to repair were computed by using the flood traffic delay model with durations and detours resulting from construction operations rather than road flooding and closures.

Uncertainty in the Flood Detour - Traffic Category

Uncertainties in flood detour damages arise from a number of contributing quantities, each of which has some associated degree of uncertainty. Four categories of uncertainty were identified as the main ones to consider in assessing a general uncertainty about the flood detour, damage category. The four categories and their assumed uncertainty distributions are:

1) Vehicle cost per mile - triangular distribution,
2) Daily number of vehicles - triangular distribution,
3) Duration of road closure - triangular distribution, and
4) Elevation of the roadway - normal distribution.

The categories for vehicular cost per mile and daily number of vehicles were assumed to have a range of +/- 10 percent under a triangular distribution. Uncertainty about the actual duration of road closure was assumed to have a triangular distribution with an expected range of +/- 12 hours with the durations restricted to non-negative values. Variability in the roadway elevation, as with first floor elevations, was assumed to have a normal distribution with a mean of zero and a standard deviation of 0.3 feet, based on the topographic maps and the Corp's EM 1110-2-1619 criteria.

Uncertainty in the Road Repair - Traffic Category

Several quantities were assumed to be variable in the determination of road repair costs, such as:

1) Volume of embankment - triangular distribution,
2) Area of pavement - triangular distribution,
3) Unit cost of embankment repair - triangular distribution, and
4) Unit cost of pavement repair - triangular distribution.

All four categories above were assumed to have a range of +/- 10 percent using the assumed triangular distribution.

Uncertainty in the Repair Detour - Traffic Category

Uncertainties in detours during repair operations were developed in a similar fashion to those developed for detours due to flooding. Where flood depths and durations defined the extent and duration of detours due to flooding, the number of days until repairs are completed defines the duration of detours due to repair operations. A triangular distribution was used with the maximum repair time being defined as that estimated with one, ten hour work shift per day. The most likely repair time was assumed as one using a 24 hour work shift per day. The minimum repair time was assumed to be 10 percent less than that determined for the most likely time.

ANALYSIS OF RISK AND RELIABILITY

The hydrologic and hydraulic relationships were combined with the stage-damage relationships to develop a risk and reliability analysis using the HEC-FDA program. The HEC-FDA program incorporates a Monte-Carlo simulation to sample the interaction among the various hydrologic, hydraulic and economic relationships and their individual uncertainties. The Monte-Carlo simulation routine randomly samples a discharge over a range of frequencies and within the confidence bands of the discharge-frequency curve. At that discharge, the routine then samples between the upper and lower confidence band of the stage discharge curve and randomly chooses a stage. At that stage, the routine samples between the upper and lower confidence bands of the stage-damage relationship and chooses a corresponding damage. This is an iterative process which is repeated until a statistically representative sample is developed.

Reliability statistics are based on the results of the Monte-Carlo random sampling. The number of Monte-Carlo simulations is chosen internally to the HEC-FDA program and represents the number of random samples for each reliability analysis. As described above, the incorporation of uncertainty about both the stage-discharge, discharge-frequency, and stage-damage relationships is inherent in the random sampling. For each damage reach and each plan the Monte-Carlo simulation proceeds until a minimum criteria, representing the acceptable change in sample mean and standard deviation, is reached. Once the criteria is satisfied at one reach the model proceeds with a Monte-Carlo simulation on the next reach and continues for all 27 damage reaches. The resulting damage-frequency relationships and expected average annual damages are reported for each of the 27 damage reaches and for the study area as a whole.

The HEC-FDA program was used to study the Upper Des Plaines River under four different scenarios:

1) Baseline Condition - no projects in place,
2) With Detention - with 11 flood control detention components only,
3) With Levees - with 5 levee components only, and
4) With Detention and Levees - with 11 detention and 5 levee components.

The baseline condition HEC-FDA model was developed using the previously described hydrologic, hydraulic and economic factors and their associated uncertainties. The three flood damage reduction measures and the baseline condition inputs to HEC-FDA are presented below.

<u>BASELINE - NO PROJECT</u>

Baseline condition, water surface profiles were imported from the corresponding HEC-2 output for determination of the graphical discharge-frequency relationships and the stage-discharge relationships at the 27 index nodes. Uncertainty in these relationships was determined using the methods previously described. The baseline conditions stage-damage relationships, described above, were used in all four scenarios.

For this study, discharges and stages associated with eight synthetic events (99%, 50%, 20%, 10%, 4%, 2%, 1%, and 0.2% chance exceedance events) were used to define the baseline condition. The baseline condition damages excluded areas that are being protected by existing and currently planned flood protection.

WITH DETENTION ONLY

Eleven detention components, totaling 9,540 acre-feet, are proposed as part of the Upper Des Plaines River flood damage reduction plan. The detention only condition was tested in HEC-FDA and used the imported HEC-2 water surface profiles computed with the detention facilities. Discharge-frequency and stage-discharge relationships for the with detention plan were developed using this HEC-2 water surface profile. Relationships were read in for each of the index nodes representing the 27 damage reaches. The baseline conditions stage-damage relationships, as previously described, were used in all four scenarios.

WITH LEVEES ONLY

Residual damages were evaluated and 5 levees were proposed to protect the localized areas that still experienced high residual damages even with the detention plan in place. The proposed levees were analyzed individually in HEC-FDA. Optimal levee heights were determined by comparing the HEC-FDA derived benefits to estimated costs at the various levee heights tested. The 5 levee heights tested corresponded to protection from the 4, 2, 1, 0.4 and 0.2 percent chance exceedance events at the five levee locations. For the levees only analysis, it was assumed that discharge-frequency and stage-discharge relationships were equivalent to those defined in the baseline - no project condition described above.

Results from the levee analysis included expected annual damage reduced for each levee at each height tested. The tested levee heights were checked for feasibility by determining the costs for each height. A review of these items allowed for the determination of the final levee heights which maximized net benefits. The optimized levee heights at the 5 levee locations were then incorporated into HEC-FDA for the final analyses; levees only and detention plus levees.

WITH DETENTION AND LEVEES

The 5 optimized levees were added to the 11 detention components for the final plan analyzed. This final plan was developed by importing the HEC-2 water surface profiles as developed for the detention component plan and using that profile to determine discharge-frequency and stage-discharge relationships. The five optimized levees were accounted for within the HEC-FDA platform. The baseline conditions economic relationships, as previously described, were used except in the five reaches containing the proposed levees. In those reaches the stage-damage relationships were modified according to the degree of protection provided by the levee.

RESULTS AND DISCUSSION

Results from the HEC-FDA analysis showed that expected annual damages would be approximately $21,407,00 for baseline conditions with no project in place. This result is 15 percent higher than the baseline value predicted by traditional economic methods ($18,648,000). This difference is primarily due to the inherent statistical effect of uncertainty in the higher estimates as related to the discharge-frequency, stage-discharge and stage-damage relationships. EM 1110-2-1619 states that the error in damage at any stage is not symmetrically distributed around the mean damage. This is particularly true at the lower stages, because damage values cannot be negative. Thus the probability of overestimating damage is greater with a risk and reliability analysis than with traditional economic methods. The difference between the two methods of analysis is typical of risk based analyses and was not considered unreasonable. The $21,407,000 expected annual damage value was accepted by the Chicago District for baseline conditions damages.

Results from the risk and reliability analysis of the detention only plan indicated an expected annual residual damage of $16,774,000, a reduction of $4,633,000 (22 percent) when compared to baseline conditions. The five levees at their optimized heights were incorporated into an HEC-FDA analysis of levee components only. The combination of the five optimized levees resulted in an expected annual residual damage of $17,128,000 or a $4,279,000 expected annual damage reduction when compared to baseline results. The final scenario tested was the optimized levees in combination with the detention components. The HEC-FDA analysis of the levee plus detention plan resulted in $13,200,000 for expected annual residual damages. This equates to a $8,207,000 reduction of damages over the baseline condition expected annual damage. A summary table of expected annual damages and the reliability of those estimates is shown in Table 1 for the four plans analyzed.

Table 1. HEC-FDA Computed Reliability of Expected Annual Damage Estimates

Alternative	HEC-FDA Computed Expected Annual Damage (x $1,000)			Probability that Damage Reduced Exceeds Stated Value		
	Without Project	With Project	Damage Reduced	0.75	0.50	0.25
No Project	21,407	21,407	0	0	0	0
Detention Only	21,407	16,774	4,633	2,019	4,345	6,248
Levees Only	21,407	17,128	4,279	2,380	3,781	5,567
Detention + Levees	21,407	13,200	8,207	3,798	7,351	10,870

As an example, the above table shows that there is a 75 percent chance that the annual damage reduced by the detention and levee alternative would exceed $3,798,000 and there is a 25 percent chance that annual damages reduced would exceed $10,870,000. Therefore, it can be said that there is a 50 percent chance (75 - 25) that annual damages reduced would lie somewhere between $3,798,000 and $10,870,000. These results quantify the uncertainty of the project and the expected range of damage reduction (benefits). A breakdown of residual damages by damage category for each of the alternatives tested is shown in Table 2 below. Preliminary costs of the project alternatives are undergoing final reviews and are included for comparison purposes only.

Table 2. HEC-FDA Computed Residual Damages by Category for Four Alternatives

Alternative	Expected Annual Damage (x $1,000) by Category						Total Residual Damage	Avg.Ann. Project Cost (x $1,000)
	Structural Damages			Traffic Damages				
	Res.	Apt.	CIP	Flood Detour	Road Repair	Repair Detour		
Baseline	2,547	1,683	1,558	5,064	1,701	8,854	21,407	0
Detention Only	2,099	1,367	1,135	3,977	1,507	6,689	16,774	4,797
Levees Only	1,181	777	985	4,881	1,394	7,910	17,128	1,204
Detention + Levees	1,062	707	767	3,946	1,362	6,002	13,846	6,001

Finally, the HEC-FDA program allows the user to determine the reliability of the performance of the proposed projects. That is, given a target stage within a particular damage reach, HEC-FDA will determine the probability that that stage will not be exceeded under baseline conditions and as a result of any project tested.

Large watershed analyses that require a large number of damage reaches for adequate evaluation present a challenge regarding how best to summarize a project's performance over each of the damage reaches. Damage reduction and a design level of protection are generally the two key factors of interest in defining and describing project performance. For the HEC-FDA analysis, HEC recommends that a unique target elevation in each reach be established by 1) defining the event frequency target and 2) defining an acceptable level of residual damage as a percentage of the chosen event frequency. With this general criteria, a unique target level (elevation) is established, based on baseline conditions, for each damage reach within the system. For damage reaches containing proposed levees, the target stage defaults to the top of levee elevation. For reaches containing existing levees, the target stage falls somewhere below the top elevation at a user specified probable failure point based on geotechnical and other considerations.

The goal of any flood control measure in any plan being evaluated, other than levees, is a reduction of damages through a reduction in stage. A measure of project performance, then, can easily be documented for multiple reaches over multiple events for any given plan using the standard risk based techniques. If reliability statistics are tabulated against consistent target stages for each plan analyzed then performance levels can be assessed and compared between plans in a systematic fashion. These results are detailed for each damage reach and each plan in the HEC-FDA output. An overview of general project performance across the watershed and between plans can be documented in a manageable and understandable format using these tools.

The target stages for the Upper Des Plaines River study were determined by defining the following variables in HEC-FDA: 1) the event exceedance probability set at the 1 percent chance exceedance event and 2) the percent residual damages set at 5 percent. These values are used to set a target stage at that elevation which corresponds to a damage equivalent to 5 percent of the 1 percent chance event's damages. Where, for each damage reach 5 percent of the baseline condition's 1 percent storm event's resultant damages is considered an "acceptable" level of residual damage. This is a concept consistently applied in determining the target stage for all damage reaches evaluated and allows for a reasonable comparison between alternatives tested. Results are shown in Table 3 for four damage reaches, three having the highest baseline damage.

SUMMARY

A risk and reliability analysis has been successfully applied to a flood damage reduction study for the Upper Des Plaines River in northeastern Illinois. The Corp's HEC-FDA model provided a systematic analysis of risk and reliability for the 27 damage reaches within the study limits of the Upper Des Plaines River and allowed the risk analysis to be completed in an expeditious and economical fashion. Results from the analysis have provided a comprehensive comparison of the flood damage reduction alternatives and the expected benefits accrued by location and damage category. In addition, the reliability of the flood damage reduction alternatives has been ascertained at 27 locations along the river.

Table 3. Project Performance at Four Damage Reaches

Damage Reach (river mile)	Target Stage (feet NGVD)	Expected Annual Probability of Exceeding Target Stage	- Long Term Risk - Probability of Exceedance in 'x' years			Conditional Non-Exceedance Probability by Event (%)		
			10	25	50	10%	2%	1%
Baseline								
49.6 - 60.0	622.0	0.06	0.45	0.78	0.95	0.89	0.08	0.02
71.7 - 76.5	639.4	0.05	0.42	0.74	0.93	0.89	0.18	0.08
80.0 - 89.3	645.8	0.06	0.47	0.79	0.96	0.85	0.12	0.04
93.4 - 95.9	664.5	0.11	0.69	0.94	1.00	0.47	0.02	0.01
Detention Only								
49.6 - 60.0	622.0	0.05	0.38	0.70	0.91	0.94	0.15	0.04
71.7 - 76.5	639.4	0.04	0.32	0.62	0.86	0.96	0.31	0.15
80.0 - 89.3	645.8	0.06	0.44	0.77	0.95	0.85	0.21	0.11
93.4 - 95.9	664.5	0.11	0.67	0.94	1.00	0.50	0.05	0.02
Levees Only								
49.6 - 60.0	622.0	0.06	0.45	0.78	0.95	0.89	0.08	0.02
71.7 - 76.5	639.4	0.05	0.42	0.74	0.93	0.89	0.18	0.08
80.0 - 89.3	645.8	0.06	0.47	0.79	0.96	0.85	0.12	0.04
93.4 - 95.9 Gurnee Levee	667.3 Top of Levee	0.02	0.18	0.39	0.62	1.00	0.62	0.38
Detention + Levees								
49.6 - 60.0	622.0	0.05	0.38	0.70	0.91	0.94	0.15	0.04
71.7 - 76.5	639.4	0.04	0.32	0.62	0.86	0.96	0.31	0.15
80.0 - 89.3	645.8	0.06	0.44	0.77	0.95	0.85	0.21	0.11
93.4 - 95.9 Gurnee Levee	667.3 Top of Levee	0.02	0.15	0.34	0.56	1.00	0.72	0.52

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