Staff Papers Series

Staff Paper P87-37

November 1987

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ABSTRACT

Two analytical tools which aid decision making in flood control design, ex-post analysis and the value of information, are presented for the case study of Rushford, Minnesota. The ex-post analysis is conducted using a coincident frequency analysis of stream flow. A value of information model is formulated and estimated incorporating discounting for project destruction. The results suggest that the accuracy of the hydrological information is paramount in flood control decision making.

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INTRODUCTION

The United States suffers an average of about one billion dollars in flood damages every year. More than 10 billion dollars have been spent on structural measures alone to mitigate flood damages since passage of the Flood Control Act of 1936 [Cline,1968]. Flood control projects of the U.S. Army Corps of Engineers prevented flood damages estimated at 38 billion dollars during period 1936-1974 [Corps of Engineers,1974]. Decisions concerning the appropriate flood control measures, both structural and non-structural can have an important impact on the distribution and magnitude of these flood control benefits. Thus the importance of "accurate" quantification of flood damages (flood control benefits) for use in decision making cannot be over emphasized.

The major objective of this paper is to develop an ex-post evaluation of the urban flood damage reduction project at Rushford, Minnesota and provide estimates of the value of information for the project. The basic rationale for the ex-post evaluation, as Palanisami and Easter [1984] state, is to help improve ex-ante planning rather than merely criticize project implementation. Therefore, an important aspect of ex-post evaluation is to provide a feedback to help improve future ex-ante planning procedures. Both the ex-post analysis and the value of information estimates show how the project design and implementation might have been changed if more information had been available at the time of construction. The value of information and the ex-post analysis can both be useful tools for improving decisions concerning flood control.

This paper offers two new contributions to the analysis of flood control decisions. First, is the coincident frequency analysis used to analyze discharge levels from two watercourses which have their confluence at the protection site. Second, is the value of information model which explicitly accounts for the probability of project destruction by extreme discharges.

The paper is organized around six major sections. First the Rushford project and the project design flood is described in the last part of the introduction. Second, ex-ante costs and benefits are presented as they were calculated in 1956, 1965 and 1967. Third, the hydrological methods are described. The fourth major section of the paper outlines the ex-post analysis including the coincident frequency analysis technique. This is followed by the value of information model and estimation. The final section contains the summary and conclusions.

Project Description

The city of Rushford is located in southeastern Minnesota at the confluence of Rush Creek and Root River, the latter being a tributary of the Mississippi River. Prior to the flood control project, on the average of once each year the city experienced damages caused by separate or concurrent overbank flows on the Root River and Rush Creek.

Flood protection from the Root River and Rush Creek was authorized by the 1958 Flood Control Act. Construction was started in June 1967 and completed in 1969. The Root River was realigned and the Rush Creek was deepened. The project included construction of almost two miles of levee on the left bank of the Root River and right bank of Rush Creek to protect the principal commercial and residential areas; a levee about three-quarters of a mile long on the left bank of Rush Creek around the residential area to the east; and a levee about one-half mile long and a 470-foot wall along the left bank of Rush Creek. In addition, structures for drainage, traffic crossing over the levees, bridge alteration or removal, and utility and sewer system changes were built, as well as five pumping stations.

In response to a request from local authorities, the Rushford project was inspected on May 18th, 1972. Bank erosion was found to be prevalent, and remedial work was undertaken to halt erosion. Repair work consisted of shaping and riprapping banks and it was completed in late 1974. A construction contract for additional remedial work was awarded in September 1977 to correct severe erosion problems and to prevent further damage to the project upstream of the Minnesota Highway bridge No 43. Also included in the contract was the construction of a ditch outlet structure near Rush Creek and a roadway safety improvement. Construction was completed in 1979.

Project Design Flood

Because of the flashy nature and frequency of flooding at Rushford the Corps determined that the minimum protection to be considered would be for floods having a frequency of about once in 100 years. The plan of improvement which would provide the 100-year protection very nearly approximated the upper limit of protection which could be justified by anticipated benefits (given the information at that time). In the General Design Memorandum of 1965 [U.S. Army Corps of Engineers, 1956], modifications were made in the project design which changed the degree of protection. The final project design floods were 45,000 c.f.s. on the Root River above the confluence of Rush Creek and 16,200 c.f.s. on Rush Creek. These two values correspond to the 200-year flood for the Root River and the 100-year flood for the Rush Creek. The design flood on the Root River below the confluence of Rush Creek was 49,300 c.f.s..

EX-ANTE BENEFITS AND COSTS OF THE PROJECT

The first benefit-cost analysis done by the Corps of Engineers was presented in 1956 in the Project Document Plan (U.S. Senate, 1956). Estimated annual charges were based upon an assumed project life of 50 years and interest rates of 2.5%. The second benefit-cost analysis was presented in 1965 in the General Design Memorandum (U.S. Army Corps of Engineers, 1965). Estimated annual charges were based on discount rates of 3-1/8 percent for both Federal and Non-Federal works over a 100 year amortization period (Table 1).

After the project was constructed, the Corps of Engineers updated the benefit-cost analysis. This was done in 1967 and the updated benefit-cost rate was 1.3 (tables 2 and 3). This new estimate is closer to the one estimated for the 1956 Project Document Plan (1.16) than to the more recent one, given by the 1965 General Design Memorandum (2.1).

HYDROLOGY (EX-ANTE AND EX-POST)

Data transfer and probability interpolation (see Matalas and Jacobs) were performed among the three hydrologic stations in the Root River basin to estimate probability distributions of peak discharges at: a) Rush Creek at Rushford just before the confluence with Root River and b) Root River at Rushford just before the confluence. The past studies used probability distributions at these two points to estimate benefits.

The log-Pearson type III distribution [U.S. Water Resources Council, 1973 and U.S. Department of Interior, 1982] with regional skewness coefficients and adjusted to expected probability was fitted to the data to compare with the 1955 and 1965 ex-ante estimates. Even though there is more information and the methodology is improved, the probability distribution for the Root River at Rushford was almost the same. But this is not the case with Rush Creek at Rushford, where the new estimate is quite different from the "original" estimate shown in the feasibility study [U.S. Senate, 1956].

The new distribution for Rush Creek is steeper (in terms of a straight line in the log probability space) than the old distribution presented in the 1965 General Design Memorandum. The deviation between these two distributions makes the estimated 100 and 200-year floods higher than the initial estimates. This is equivalent to saying that the design flood for Rush Creek has a higher flood frequency than what was thought to be the case when the project was proposed.

The new methodology and the availability of additional data explains this difference. The methodology used in 1956 consisted of fitting the best line to the discharge-probability scatter diagram. The methodology used in this study fits recorded data to the log-Pearson type III distribution. Figure 1 shows the frequency-damage curves for Rush Creek floods using both distributions and the 1956 Rushford conditions. The area under these curves is the expected annual damages for Rush Creek. With the old distribution, the expected annual damages were $30,750, in contrast with the estimated value of $21,420 using the new distribution. This shows that the new information (18 years of data) and the new methodology are responsible for a

30% decrease in expected benefits. If one had used this new estimating procedure for the first benefit-cost analysis the benefit-cost ratio would have been less than one, 0.87. The new B/C ratio would have had negative implications for construction of the project. This indicates that there is a positive value of information associated with more information concerning peak discharge levels. However, the peak discharge levels are not the only factor associated with uncertainty. Other factors such as the town's growth and the damages sustained due to flood also contribute to the uncertainty of the project benefits and the decision to build.

EX-POST BENEFIT-COST ANALYSIS

There are two parts to the ex-post estimation of the flood control benefits. The first part consists of estimating the expected benefits for the future which will be called the stochastic (future) part. The second part involves estimating the past benefits which is the deterministic part of the analysis. In the particular case of Rushford, the flood frequency analysis is developed using coincident frequency analysis.

EX-POST PROJECT BENEFITS ESTIMATION

Coincident Frequency Analysis.

The methodology used in this analysis consists of using discrete values for the discharges of the Root River and Rush Creek, which determine discrete areas in the two dimensional space. A bivariate probability distribution is then fitted to this space. For instance, each area would correspond to the following set :

$$\{ (Q1,Q2)/ Q1a < Q1 < Q1b \; ; \; Q2a < Q2 < Q2b \}$$

where Q1,Q2 represent the peak discharges in the Root River and Rush Creek, and Q1a,Q1b,Q2a,Q2b are the bounds of the intervals of the discrete variables. Next, the mean values of each interval (W1,W2) were taken for each discrete area, (i.e., W1=(Q1a+Q1b)/2 and W2=(Q2a+Q2b)/2), and the estimated flood plain for these values would be the representative flood plain value for that specific discrete area.

Fitting a probability distribution to this space is the way of associating each flood plain with its occurrence probability and then estimating the expected annual benefits for the remaining life of the project. Fitting the lognormal function to empirical distributions of annual flood peak discharges may be more attractive than fitting other distribution functions, given the analytical derivation of distributions of conditional variables.

The bivariate lognormal function was fitted to random variables Q1 and Q2; peak discharges in the Root River and the Rush Creek respectively. For a bivariate (q1,q2) with simple correlation coefficient, r(q1,q2), of components q1 and q2, the bivariate lognormal probability density function is:

$$f(q1,q2) = \frac{1}{2\pi\mu(q1)\mu(q2)\sigma(q1)\sigma(q2)(1-r^2)^{.5}}\, e^{-Q_n/2(1-r^2)}$$

$$Q_n = \{q1-\mu(q1)\}^2/\sigma(q1)^2 + \{q2-\mu(q2)\}^2/\sigma(q2)^2 - 2r\,\frac{\{q1-\mu(q1)\}\{q2-\mu(q2)\}}{\sigma(q1)\ \sigma(q2)}$$

in which q1=log Q1 and q2=log Q2 and $\mu(q1)$,$\sigma(q1)$, $\mu(q1)q2$ and $\sigma(q2)$ are the means and standard deviations of q1 and q2 [see Yevjevich].

A polynomial approximation for bivariate normal probabilities methodology introduced by Moskowitz, et al [1986] is used to integrate this distribution on its discrete areas. The details of the computations can be found in Ramirez and Easter [1987].

Damage to Structures.

To estimate flood damages in Rushford one must identify residential, industrial, commercial and public units that might be flooded. In order to accomplish this, a structure inventory is needed. A base map which detailed the affected area was used to inventory residential structures. Information collected by driving down the city streets included the number of floors in each house, whether or not it had a basement, if it was split level and the elevation of the ground and first floor.

Ground elevation is obtained from the map, and first floor elevation is ground elevation plus (or minus if the house is a split level) the number of steps leading to the front door. In this study a height of 4 inches per step was used. Ground elevation is the point at which water comes into contact with the structure and first floor elevation is the elevation at which water causes damage.

For commercial, public and industrial structures, interviews with business owners or managers were necessary. The principle variables obtained were the area of the unit, value of merchandise susceptible to damage and the kind of equipment that might be in the building. For some businesses in which it was not possible to conduct interviews, the required data were obtained by sampling similar businesses elsewhere.

Market and Assessed Values.

To estimate the economic value of these units, assessed values were obtained from the county assessor, and market values were obtained from a local real estate agent. These latter values were used to build a correction factor for the assessed values which are almost always below the real economic value of the units. One conclusion drawn from this information is that the higher the market value of the house, the bigger the difference between market and assessed value of the unit. A correction factor based on the market values was used to adjust the original estimates. (1.38 for units with assessed value less than $25,000 and 1.54 for units assessed at more than this amount).

Damage Susceptibility.

An important step in measuring flood damages is to determine the damage susceptibility of units. Once the number of physical units and the value associated with each unit are known, a damage susceptibility relationship for these units is needed. This function (unit damage function) shows the fraction of its market value that would be lost if these units were inundated to a certain level. Figure 2 shows a simplified version of the relationships that the Corps of Engineers uses for residential units without a basement.

For some residential, commercial and public units, individual damage susceptibility relationships were developed using survey data. The remaining units had to be grouped on the basis of similar characteristics, and a standard damage susceptibility relationship was estimated.

Knowing these relationships, a computer program was developed to simulate the flood plain for a particular flood event and to compute damages for each individual unit and to aggregate these damages for the event.

The last step in estimating damages from the flood events (W1,W2) is to relate damages to discharges (table 4). The values in parentheses are the estimated representative damages for each two dimensional discharge interval. This table also shows the expected damages, probability times damages (values in brackets) for each interval. The expected annual damages is the sum of all values in brackets. The average annual future benefits other project due to flood prevention is $2,764,628 (1986 dollars) while the expected non-prevented damages is $363,000.

DETERMINISTIC AND TOTAL BENEFITS

These benefits are the damages prevented by the project during the time period since construction was completed in 1968 and 1985 (last year with available hydrologic data). The aggregate prevented flood damages for each year in the period 1968-85 are shown in Table 5. The total estimated value of benefits for this period is $36,161,798, in contrast to $49,763,304 (18 x 2,764,628), which is the expected value of benefits for this period using the bivariate log-normal distribution approach (Table 4).

Since the primary objective of this study is to compare the ex-post estimates with the original ex-ante estimates, both costs and benefits reported in actual prices were converted to 1967 prices with price indexes. The Engineering News Record's (ENR) construction index was used to deflate costs and the ENR building index was used to deflate project benefits. Table 7 shows the ex-post benefit-cost analysis for different discount rates starting with 8-7/8 which is the 1986 discount rate used by the Corps of Engineers and ending with 3-1/8 which is the discount rate used in the

General Design Memorandum [U.S. Army Corps of Engineers, 1965]. The average annual benefits calculated for the Rushford project, are $533,862, $570,262, $610,038, $648,736 respectively for 8-7/8, 7, 5, 3-1/8 percent discount rates. All four discount rates are real rates, since both benefits and costs were deflated.

Ex-post Costs and Benefit-Cost Analysis

Ex-post costs from 1967 to 1985 were collected from the Rushford flood control project records maintained at the U.S. Army Corps of Engineers office, St Paul District, Minnesota. The total Federal cost was $2,784,000 , and the non-Federal cost was $326,000 (1967 price level). The cost of repair work finished in 1974 was $160,354 and the cost of construction completed in 1979 was $421,000. The total annual costs of the project were $377,054, $300,274, $218,835, $141,504 respectively for 8-7/8, 7, 5, and 3-1/8 percent discount rates (see table 6).

The ex-post estimates show that flood control benefits are considerably more than costs, even with an 8-7/8% real discount rate. The actual benefit-cost ratios for this project could be higher than those shown in this table given that other types of benefits were not considered in the analysis.

Sensitivity Analysis

Multiple sources of uncertainty can be recognized in this analysis given the complexity of the hydraulics and hydrology of Rushford's flood plain. With the coincident frequency methodology used in this analysis, perhaps one of the major sources of uncertainty is the damage susceptibility relationships for industrial, commercial and public units due to the lack of homogeneity and the inability of people interviewed to estimate these relationships. On average, 45 percent of expected flood damages in Rushford are attributed to residential damages and 55 percent to industrial, commercial and public non-residential damages. A sensitivity analysis was developed for damages to these non-residential units. The non-residential damages were increased and decreased by 20%. Table 7 illustrates that the B/C ratio has a low sensitivity to this 20% change in non- residential damages.

Another source of uncertainty is the selection of a time horizon or planning period for the physical and economic life of the improvements to prevent or control flooding. Initially, in 1956, this period was considered to be 50 years, but later the Corps of Engineers changed it to 100 years. Table 7 also shows the sensitivity of the B/C ratio to the life of the project. The last row of this table presents the B/C ratio when the life of the project is only 50 years. The lower the discount rate the more sensitive the B/C ratio is to the time horizon. However, changing the life of the project does not affect the economic results of this analysis.

A third source of uncertainty is the contents growth for residential units. The Corps of Engineers suggests a value of typical contents approximately 40 percent of the structure value. They apply a growth rate for contents in residential units to estimate future damages. This growth factor is a function of Rushford's income per capita projections. The ex-post economic analysis presented in table 7 assumes a zero contents growth factor. For a sensitivity analysis, a 2% contents growth rate for the next 50 years was applied [U.S. Army Corps of Engineers, 1986]. The B/C ratio goes up only marginally with this change.

The last source of uncertainty considered is the discount rate. Selection of an appropriate discount rate is important because the rate has a substantial impact on B/C ratios. Selection should reflect at least the cost of borrowed capital for the entities involved, in this case the government. In this project the recommended value from the Corps of Engineers of 8-7/8% per year was used. However, for purposes of the sensitivity analysis, other rates were tried. Lowering the discount rate from 8-7/8% to 3-1/8% increased the B/C ratios almost three fold.

VALUE OF INFORMATION

The analysis above shows that the ex-post costs and benefit estimates for the Rushford flood control project are significantly different than some of the ex-ante estimates. The data collected in the analysis allows one to investigate the value of information on one specific source of uncertainty, the peak discharge levels. In the analysis an economic model of the value of information is developed, followed by an estimate of the ex-post value of information. This analysis differs from the ex-post benefit cost analysis in several ways. First, the value of information is estimated using optimum project sizes rather than 100 or 200 year flood control levels. This requires the formation of a benefit function and the optimization of this function. Second, the value of information presented below incorporates the potential loss of the project due to discharge levels greater than the project protection level. This irreversibility adds to the value of information estimates. Finally, the value of information is computed using only peak discharge levels as the source of uncertainty. It is, therefore, an estimate of the value of waiting for improved peak discharge information, an important component in the decision making process for flood control projects.

A Model

The benefits of the flood control project are measured as the damages averted by the project's construction. Here we make an assumption that is little used in actual benefit-cost analysis but we feel is required in such projects, that the project benefits are destroyed if a flood exceeds the constructed peak discharge capacity. That is, flood waters exceeding the project design size result in the destruction of the project. This is typically a physical reality and it has a strong effect on project benefit estimation. The benefits for a project of size (w^0) are defined as:

$$B(w^0(t),\ I_t,\ w_t,\ t) = \left[\begin{array}{l} D(w(t),\ t) \text{ if } w(s) \leq w^0(s) \text{ for all } s\geq 0,\ s\leq t \\ 0 \text{ otherwise,} \end{array}\right] \quad (1)$$

where I_t is the information at time t. In this expression D(w(t),t) is a total benefits function for a given point in time. The expected benefits at the beginning of the project's life include the benefits of the project over the entire life of the project multiplied by the probability that the given project size has not been exceeded in some previous period. This can be written as:

$$\Pr[w(s)\leq w^0(s) \text{ for all } s\in[0,\ldots t-1]\ |It]\cdot\int_a^{w^0(t)} D(w,t)dF(w|I_0) \qquad (2)$$

Assuming that {w(t)} is an i.i.d. random variable sequence, the first term of equation (2) can be written as:

$$\prod_{\substack{s\geq 0\\ s\leq t}} F(w^0(s),I_0) \qquad (3).$$

This product indicates the probability that the discharge level has not exceeded the project design level for all periods previous to s, s≥0. It is an implicit discount rate that accounts for the fact that there is some probability that the project has been destroyed by floods in the past.

Given these definitions of the annual benefits the net project benefits for a project of life T can be defined as:

$$V(w^0(t),I_0)= \sum_{t=0}^{t=T} (a^t) \prod F(w^0(t),I_0) \int_a^{w^0(t)} D(w,t)dF(w|I_0) \quad (4)$$

where a $= (1+i)^{-1}$ is the discount factor. The costs of the project are not subject to uncertainty and can be summarized by:

$$C(w^0(t)) = \sum_{t=0}^{t=T}(a^t)\ c(w^0(t),t) \qquad (5).$$

Thus the expected net present value of project (w^0) is:

$$J(w^0(t),I_0) = V(w^0(t),I_0) - C(w^0(t),t) \quad (6).$$

Allowing the information structure to change leads us to a more complicated form of analysis which involves the concept of option value and the value of information. In period 0 we have the decision to build or not based on the benefits versus the costs of flood control in this period and the expected benefits versus costs in period one. The dynamic nature of this model is captured in the way uncertainty enters in the decision to be made in the first period, that is, how does the uncertainty of the second period benefits affect the decision to build or not. Recall that these projects are irreversible. This implies that if the decision in period one is to build, this decision cannot be reversed in period two even if the benefit information changes. However, in the formulation presented below, the project can be increased in size, thus the decision is whether to build or not and how much to build in each of the two periods.

The two period model formulated below is similar to the models presented by Hanemann [1982] and Fisher and Hanemann [1986]. Define the first period net benefits as:

$$J_0(w(0), I_0) = V(w(0), I_0) - C(w(0)) \qquad (7)$$

and the second period net benefits as:

$$J_1(w(0)+w(1), I_0) = V(w(0)+w(1), I_0) - C(w(1)) \qquad (8)$$

where the information set indicates that no information about the second period benefits is available in the beginning of the second period. This is the manner in which the uncertainty enters the system, in the uninformed case there is no forthcoming information about the benefits in the second period.

Irreversibility in this model is structured as $w(0)+w(1) \leq w$ and $w(0) \geq 0$, $w(1) \geq 0$ where w is some maximum project size (i.e. one that protects against all possible floods). In this case the flood control project can be increased in size in the second period if the benefits and information structure justifies it.

The decision under imperfect information is to maximize $J_0(\cdot) + J_1(\cdot) \equiv Z(w(0)+w(1))$ subject to $0 \leq w(0) + w(1) \leq w$ and $0 \leq w(0)$, $0 \leq w(1)$.

If there is information forthcoming in the second period which the decision maker can use in determining the correct level of flood control, the problem is to maximize $J_0{*}(w(0), I_0) + J_1{*}(w(0)+w(1), I_1) \equiv Z{*}(w(0)+w(1))$ subject to $0 \leq w(0) + w(1) \leq w$ and $0 \leq w(0)$, $0 \leq w(1)$. Notice in this case that the information set has changed between the two periods. The only firm conclusion that can be made at this point is that the level of benefits with perfect information are greater than or equal to the benefits under imperfect information. This arises due to the costless nature of the information. This conclusion is proven formally by Hanemann [1982]. Under some conditions one can make statements about the level of development. If the benefit functions are concave then the amount of development in the first period can never be greater under perfect information than under imperfect information [Graham-Tomasi, 1985]. The ex-post value of information is defined as the difference between the net present value of the uninformed decision and the net present value of the informed decisions where both levels of development are determined as maxima under each information structure. In the following application of the model, we use the ex-post value of information to illustrate the sensitivity of project size to discharge information.

Applying the Model

For our flood control analysis, if information is forthcoming concerning the distribution of flood waters or the distribution of damages then a premium must be considered before development is started in the first period. Of course, should the benefits strongly outweigh the costs in the first period then it is unlikely that the premium for the value of information would reverse the decision.

The results of the value of information analysis are quite different from the ex-post benefit cost analysis in that the net present value is determined for the optimum project size (shown in brackets in table 8), including discounting for project destruction. The optimum size for the old information is provided in column 1. The net present values (NPV) based on the old distribution are positive for two of the three discount rates, indicating a favorable project plan at low discount rates. The optimum size project with the new information set shows that under all three discount rates the project is not economical and it should not have been built. The third column presents the NPV of the project sizes estimated as optimal for the old distribution of peak discharges but using the new distribution of discharges to calculate the benefits. All three NPVs are negative. The difference between columns 2 and 3 would be the value of information in the case that both information sets yielded positive benefits. However, since under the new information set the project would not have been built, the value of information is the value lost due to building the project under the old information. For the discount rate 2.5%, the project determined as optimal under the old information set (22,000 cfs) would have resulted in a net loss of $314,889 as calculated using the new information set. Note that the project under a discount rate of 5% would not have been built under either information set and thus the value of information is zero.

The estimates of the value of peak discharge information are quite sizable, relative to the net benefits of the project. In fact, in two of the three discount rate cases presented above, the new information would have reversed the decision to build the project. This indicates the importance of accurate information in the estimation of peak discharges, a major component in estimating flood control benefits.

The application of the discounting for potential project destruction lowers the benefits estimates and affects the estimates of the value of information. Table 9 contains the value of information estimates without discounting for project destruction. For the 2.5% discount rate the project would have been built under both information sets. However, the net present value of the optimum sized project, w*, constructed under the old information set is negative when evaluated under the new information set. The value of information when the discount rate is 2.5% is low. The difference between the net present value under each information set is $39.87. For higher discount rates the project would not have been built under the new information set. Thus, the value of information is highest for the 3.5% discount rate since the project would have been implemented under the old information state ($221,702) while for a 5.0% discount rate the project should not have been built under either information state. Note that the optimal project sizes are much smaller when project destruction is not included. This is due to the fact that the larger projects reduce the probability of damage from large discharges.

SUMMARY AND CONCLUSIONS

The flood control project in Rushford, Minnesota was recommended in U.S. Senate Document No 431 [1956] as a project to provide flood control for the two main streams that conform the flood plain in Rushford. The project was finally sanctioned for construction and built by the Corps of Engineers between 1967 and 1969. The benefit-cost ratio close to one and the 18 years of operation made this project attractive for an ex-post evaluation. The ex-post analysis indicates that the ex-post flood benefits were higher than ex-ante flood benefit estimates. This was due to the application of a new methodology to estimate expected annual flood benefits and the 18 years of additional information available to estimate peak discharge probability distributions and also the new damage susceptibility relationships. Costs also increased due to repair work done in 1974 and 1979. The ex-post benefit-cost analysis indicates that the project's performance was better than expected. The benefit-cost ratios with different real discount rates ranging from 3-1/8 to 8-7/8 are all 1.4 or greater with only flood control benefits included.

The value of information, estimated using the added peak discharge probabilities from 1956 to 1985 shows that the value of accurate discharge information can be very large and can imply reversal of project construction decisions. Ex-ante planning can be aided by recognizing the value of information gained from delaying decisions and by providing a sensitivity analysis on the flood distribution parameters. Also, the value of information estimates provided above incorporate a factor that accounts for potential project destruction and show that this factor will effect project size. The value of information estimation isolates only one source of uncertainty but it illustrates how sensitive project design is to this single factor. Ex-post benefit-cost analysis essentially groups all of the uncertainties and thus it fails to isolate individual issues since it analyzes the overall performance of the project.

The results of the ex-post benefit-cost analysis suggest that the project benefits are greater than originally thought while the value of information results show that the project may not have been an efficient investment. These seemingly contradictory results are due to the assumptions underlying each technique. The value of information analysis held all information concerning population and economic growth constant at the rate hypothesized in 1956 and only varied the flood discharge information. This simulates the environment of the decision maker in 1956 with two states of discharge information. The ex-post benefit-cost analysis contains more current economic growth information and uses the coincident frequency technique which increases the benefits realized from flood control. Therefore, the ex-post analysis provides large positive net benefit estimates as factors such as economic growth have more than offset the decrease in benefits due to inaccurate discharge information.

The ex-ante project planning could be improved by: (1) having a longer period on which to base predictions of the probability distribution for peak discharges, (2) improving the methodology for estimating expected flood damages, (3) making projections of residential, commercial and industrial growth, and (4) adopting appropriate discount rates for the analysis.

There were many obstacles in estimating ex-post benefits. Additional research on flood damage estimation procedures is needed. Research designed to estimate the relations between the value of contents and the value of the structures and the relationship of time variation of structure value and the value of the contents are needed. Also, more data concerning commercial and industrial damages is needed. In this project, 55% of the total flood damages was attributed to these non-residential damages but this percentage could be higher as in one reported case where commercial damage was 70% of total flood damage [Cornell, 1972]. Currently little information is available concerning flood levels and actual damages to different types of commercial and industrial property.

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Figure 1: Frequency Damage Curves.

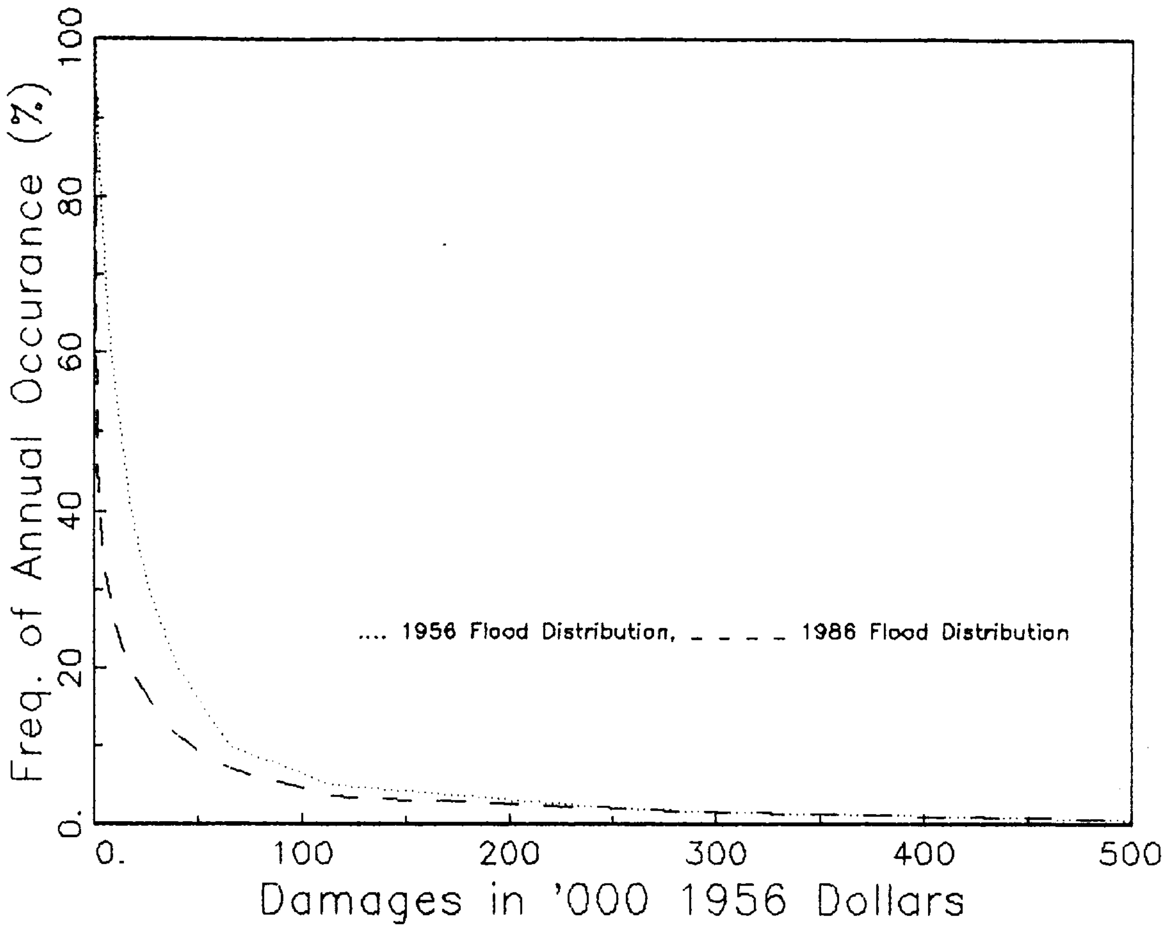

Figure 2: Damage Function for Homes

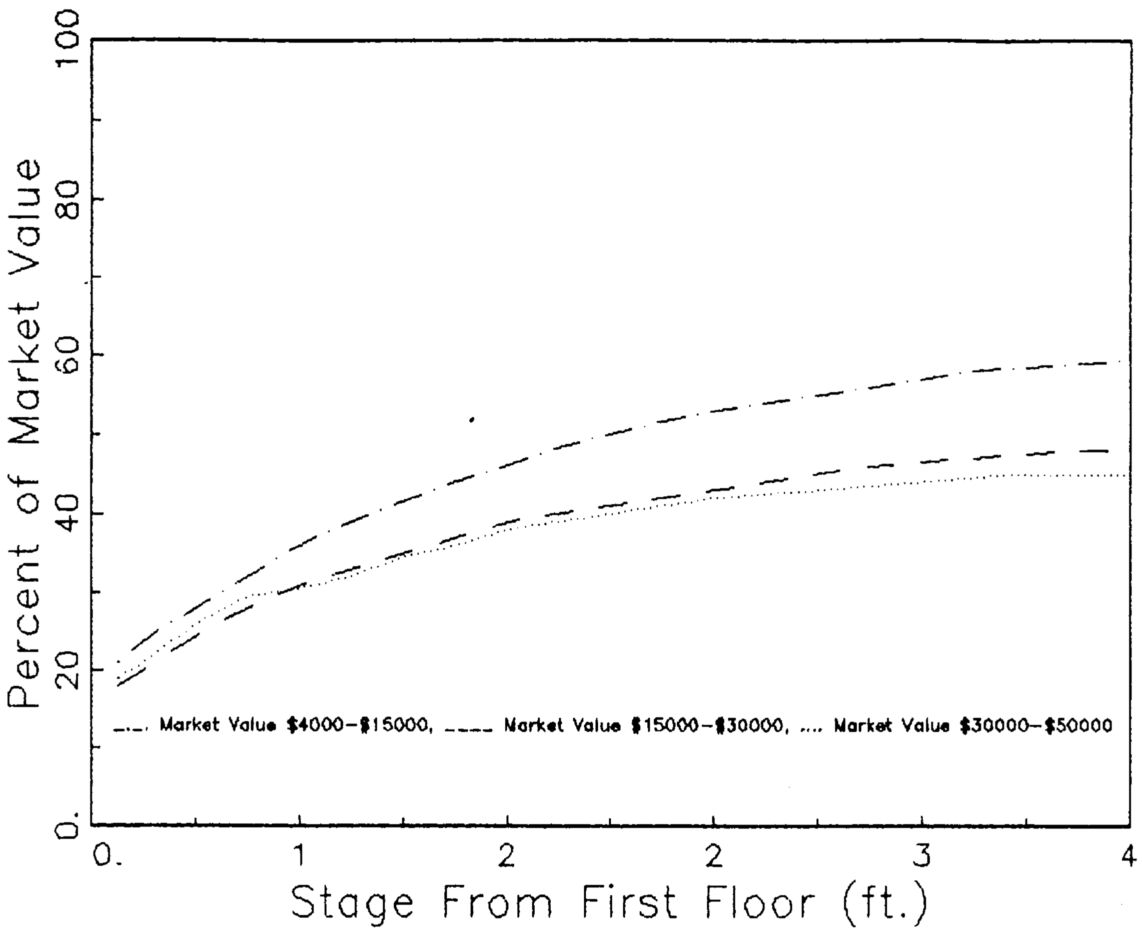

TABLE 1. EX-ANTE BENEFIT COST ANALYSIS (1956 AND 1965).

	1956	1965
Total Federal and Non-Federal annual charges	$ 32,810	$ 76,590
Average annual Benefits	$ 37,960	$163,000
Benefit-Cost ratio	1.16	2.1

TABLE 2. AVERAGE BENEFIT ESTIMATION FOR 1967 BENEFIT-COST ANALYSIS

Source	Avg Annual Benefits (July 1966) Prices
Rush Creek	$ 111,000
Root River	25,400
Duplication of damages	- (4,600)
Rural Benefits	400
TOTAL	$ 132,200
Correction for Future Growth	
(25% of total benefits, discounted over life of the project)	+ 16,500
Total after correction	$ 148,500
Additional benefits	19,900
Total annual benefits	
(July 1966 price level)	$ 168,400
(July 1967 price level)	$ 172,900

Source: U.S. Corps of Engineers, unpublished data, 1967.

TABLE 3. EX-ANTE BENEFIT COST RATIO ESTIMATION

Non-Federal Cost	
Interest	$ 10,200
Amortization	2,800
Operation & Maintenance	6,800
Major Replacement	2,300
Total Non-Federal Annual Cost	$ 22,100
Federal Cost	
Interest	$ 84,400
Amortization	23,200
Annual Inspection	300
Total Federal Annual Cost	$ 107,900
Total Annual Costs	$ 130,000
Average Annual Benefits	$ 172,900
Benefit-Cost ratio	1.3

Date: July 1967.
Discount rate: 3 1/8
Price Level: July 1967

Source: U.S. Army Corps of Engineers, unpublished data, 1967.

TABLE 4. AVERAGE DAMAGES FOR SPEICFIC DISCHARGE INTERVALS

RUSH CREEK DISCHARGE (Q2)	ROOT RIVER DISCHARGE (Q1)				
	0-9000	9000-18000	18000-27000	27000-36000	36000-45000
0-5000	(2,045,100)* [981,648]	(2,219,500) [541,558]	(2,705,000) [156,890]	(2,853,100) [51,356]	(3,915,700) [19,579]
5000-10000	(7,487,100) [74,871]	(7,659,000) [459,540]	(7,706,000) [215,768]	(7,840,000) [70,560]	(7,840,000) [39,200]
10000-15000	(10,013,900) [50,069]	(10,025,000) [180,450]	(10,350,000) [82,800]	(10,053,900) [60,323]	(10,053,900) [10,054]
15000-20000	(11,031,000) [22,062]	(11,090,000) [55,450]	(11,120,000) [55,450]	(11,120,000) [0]	(11,120,000) [0]

Expected annual damages prevented = $ 2,764,628

Expected annual damages not prevented = $ 363,000

(*) Values in parentheses are the estimated damages for every two dimensional discharge interval in 1986 U.S. dollars. Values in brackets represent the expected damages (Probability times damages) for every two dimensional discharge interval. They are also given in 1986 U.S. dollars.

Q1 = Peak discharge in the Root River in c.f.s
Q2 = Peak discharge in the Rush Creek in c.f.s

TABLE 5. ESTIMATED PROJECT BENEFITS FOR THE PERIOD 1968-1985

YEAR	BENEFITS (1986 price level)
1968	$ 0
1969	559,400
1970	0
1971	639,100
1972	1,688,320
1973	2,070,613
1974	1,762,886
1975	667,660
1976	6,550,000
1977	0
1978	8,463,900
1979	2,126,813
1980	7,735,380
1981	1,507,140
1982	41,440
1983	2,079,926
1984	60,900
1985	208,320
TOTAL	$36,161,798

TABLE 6. EX-POST BENEFIT-COST ANALYSIS WITHOUT CONTENTS GROWTH FACTOR (1967 PRICE LEVEL)

	Discount Rate			
	8-7/8	7	5	3-1/8
1967 present values				
Deterministic Benefits (past)	4,180,238	4,950,169	5,969,462	7,162,779
Net Stochastic Benefits (future)	1,834,857	3,187,136	6,139,281	12,706,616
TOTAL Benefits	6,015,095	8,137,305	12,108,743	19,869,395
Annualized Benefits	533,862	570,262	610,038	648,736
Annualized Cost	352,829	278,769	200,405	127,292
Additional repairs	24,225	21,505	18,430	14,212
TOTAL Annualized Cost	377,054	300,274	218,835	141,504
Benefit-Cost ratio	1.4	1.9	2.8	4.6

TABLE 7. SENSITIVITY ANALYSIS FOR THE EX-POST BENEFIT-COST RATIO

	Discount Rate			
Change	8-7/8	7	5	3-1/8
Without contents growth rate	1.4	1.9	2.8	4.6
With contents growth rate	1.5	2.1	3.1	5.6
20% increase in commercial, indust, and public damages	1.6	2.1	3.1	5.1
20% decrease in commercial, indust, and public damages	1.2	1.7	2.5	4.1
Project's life is change to 50 years	1.4	1.9	2.7	4.0

Note: All these sensitivity cases are with respect to the benefit cost analysis presented in table 7.

TABLE 8. NET PRESENT VALUE AND VALUE OF INFORMATION[a]. INCLUDING DISCOUNTING FOR PROJECT DESTRUCTION.

Discount Rate (%)	(1) NPV [Opt.Size[b]]W* Old Information	(2) NPV [Opt.Size] New Information	(3) NPV [Size W*] New Information	(2-3) [VOI*]
2.5	$ 377,326 [22,000cfs][b]	- $192,926 [21,000cfs]	- $314,889 [22,000cfs]	- $121,963 [$314,889]
3.5	$ 42,919 [20,000cfs]	- $356,496) [16,000cfs]	- $385,522 [20,000cfs]	$ 29,026 [$385,522]
5.0	- $215,367 [16,500cfs]	- $491,112 [16,000cfs]	- $506,892 [16,500cfs]	$ 15,780 [$ 0]

[a] 1956 price level.

[b] Optimum size protection for Rush Creek canal in cubic feet per second.

TABLE 9. NET PRESENT VALUE AND VALUE OF INFORMATION[a].
NOT INCLUDING DISCOUNTING FOR PROJECT DESTRUCTION.

Discount Rate (%)	(1) NPV [Opt.Size[b]]W* Old Information	(2) NPV [Opt.Size] New Information	(3) NPV [Size W*] New Information	(2-3) [VOI*]
2.5	$ 565,210 [16,500cfs]	$ 22,122 [16,000cfs]	- $17,749 [16,500cfs]	$ 39,871 [$39,871]
3.5	$ 204,512 [14,000cfs]	- $205,948 [16,000cfs]	- $221,702 [4,000cfs]	$ 15,754 [$221,702]
5.0	- $91,861 [14,000cfs]	- $397,356 [13,000cfs]	- $404,711 [14,000cfs]	$ 7,355 [$ 0]

[a] 1956 price level.

[b] Optimum size protection for Rush Creek canal in cubic feet per second.