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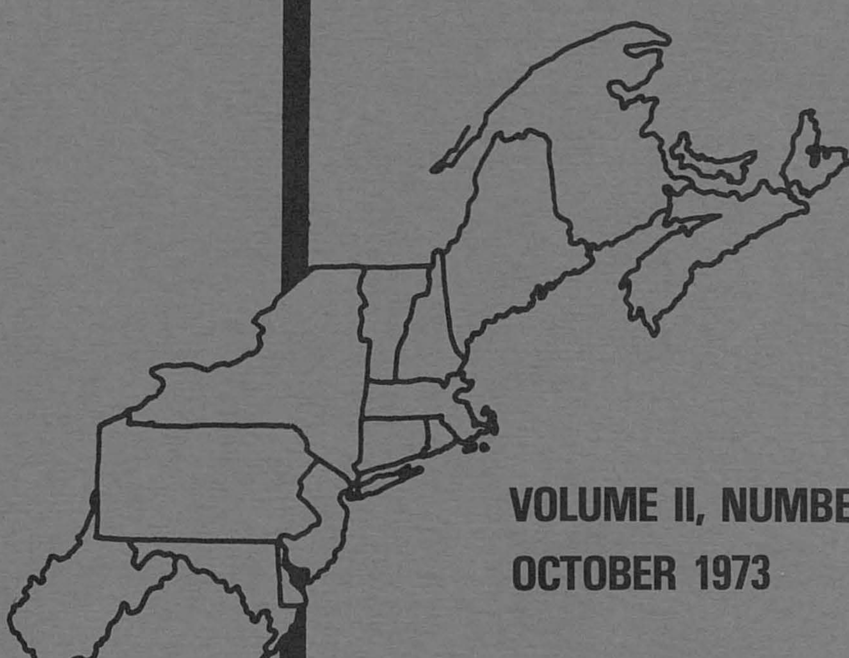

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FLOOD PROOFING DECISIONS UNDER UNCERTAINTY*

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Flood proofing first entered the flood damage reduction literature with the pioneering work of John Sheaffer [17]. Prior to this, flood control measures considered were predominantly structural -- consisting of dams, levees, dikes, channel improvements, etc. The addition of flood proofing to other flood damage reduction measures has broadened the choice among the existing alternatives for decision makers. Unlike the structural measures, flood proofing measures do not actually reduce flood stage or prevent the water from reaching the structures, but rather are as considered by Sheaffer [17], "adjustments to structures and contents which are designed and/or adopted primarily to reduce flood damages".

Flood proofing offers a number of special advantages. First the measure provides an additional safety measure for floodplain occupants. Secondly, flood proofing measures increase the availability of low premium flood insurance. A third spin-off is that flood proofing measures help to create an awareness of the potential flood hazard. Finally, potential advantages relate to the possibility that flood proofing may be more (economically) efficient than the structural or other alternatives in any particular situation and it may also be true that the distribution and incidence of benefits and costs are in some sense "better" than for the alternative measures.

Flood proofing measures are subject to a number of limitations, however. Potential drawbacks include: complexity of ownership of structures and tenure arrangements, structural limitations (effective flood proofing measures require a sound structure with relatively impervious basement and walls1/), the frequency of changes in ownership,2/ the need for an efficient flood warning system (at least for some forms of flood proofing), and the fact that flood proofing reduces damages but does not prevent floods as such.

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1/ See Gilbert White [18, p. 76].

2/ Churchill [4, p. 15] provides evidence of the frequency of turnover by types of firms.

Focusing on the final potential advantage of flood proofing described above, this paper develops a formulation for examining the economic efficiency of flood proofing in a partial equilibrium context for specified communities (in Massachusetts, Connecticut, and Vermont) in the Connecticut River Basin. We report the expected values and standard deviations of a measure of net benefits from flood proofing existing structures to various levels of intensity (the decision variable) for one of these communities. In these formulations, both benefits (damage reductions) and flood proofing costs are assumed linear in terms of depth of the flood,3/ where depth is stochastic with probabilities given by historical data. In addition to treating flood depth in a probabilistic fashion, the parameters in the linear benefit and cost functions are both assigned density functions permitting the uncertainty to be reflected in the magnitude of calculated standard deviation.

The paper is organized as follows. Some aspects of decision-making under uncertain conditions are briefly reviewed in Section II. Section III sets out the formulation utilized in estimating the first two moments of the net benefits formulation for flood proofing. The results of the analysis and some interpretation for a selected community are presented in Section IV. The final section provides some conclusions and implications and indicates the major limitations of the analysis.

II. Decisions Under Uncertainty

In water resources investment decisions, uncertainty4/ typically assumes great importance. Planning has usually been accomplished, however, by simply assuming away the aspects of uncertainty or by substituting an estimation technique with a "conservative" bias, such as requiring benefits to exceed costs by some arbitrary amount (or the benefit to cost ratio to exceed unity by some fraction) or by increasing the discount rate used in the evaluation. In such formulations the decision-maker generally operates only with "best values" (e.g. expected values or first moments) and ignores any other information he may have concerning degrees of uncertainty (higher moments).

Such ad hoc procedures for treating uncertainty may lead to suboptimal decisions on a number of counts. For example, the arbitrary manipulation of discount rates may result in a misallocation of resources between the public and the private sectors. The basic question is whether the discount rate for public investment decisions should include a "risk" component. Opponents of this approach argue that since the public sector

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3/ Support for this formulation is given by James [12] and others.

4/ The terms "uncertainty" and "risk" are used synonymously here since one can generally attach subjective probabilities to what Knight [14] would consider an uncertain event.

invests in such a wide range of projects concurrently, the unexpectedly favorable investments "average out" those which perform poorly, and, thus, it is reasonable to ignore uncertainty for the pooled set of investment plans. Others, notably Hirschleifer [9], argue that the use of a public discount rate which fails to reflect the riskiness inherent in the private discount rate will result in the displacement of private investment projects by public ones which yield lower returns. Arrow and Lind [2] modify Hirschleifer's arguments by demonstrating that if the subjective cost of risk bearing is the same for taxpayers as for private investments then the appropriate discount rate for public investment is the yield on private investment.

This formulation of the "proper" public discount rate is valid only if public funds are generated exclusively by displacing private investment or if there is no restriction on using the funds in the private sector.5/ That is, if public investment were to be financed by a reduction in current consumption rather than a displacement of private investment, then society would gain even with the returns to public investment less than the returns to private investment provided the yield on the public investment exceeds the societal rate of time preference. The second point is that if there are no restrictions constraining the funds to public investment, then public funds should not be employed in the public sector if they can more profitably be used in the private sector.

The procedure of using "best (expected) values" may also lead to suboptimal decisions. That is, by ignoring or not making explicit use of the knowledge available about the uncertainty we sacrifice what may prove to be important information. Obviously, planners should attempt to incorporate as much information as is economically feasible directly into the decision-making process.

Several examples illustrating an explicit incorporation of risk in water resources planning models are contained in Hufschmidt and Fiering [11, pp. 156-7] and in Conner [5]. These authors suggest introducing risk as an explicit argument in the preference function. Rather than to adopt a preference function such as, e.g. maximizing expected net benefits, in which case there is little basis for selecting from among projects or designs with similar expected values, the suggested procedure is to incorporate second6/ (or perhaps even higher) moments of the net benefit probability distribution. The authors recommend the following procedure using first and second moments exclusively. Denoting μ as the expectation of the relevant utility function argument,

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5/ See Mishan [16] for elaboration on these points.

6/ If the relevant probability distributions are known to be normal, the second moment suffices. Otherwise, it may be useful to include higher moments.

σ its standard deviation, and r as an index of the planners' aversion to risk, the preference function can be established as maximizing $\mu + r\sigma$, where r can be negative (indicating conservatism) or positive (the gambler). One can easily conceptualize the problem in greater complexity -- for example, the relationship may not be approximately linear, particularly if we consider a large enough range of σ.

This approach is similar to the well-known E-V (expectation-variance) framework in which points of indifference between various combinations of expected value and variance are determined to form an indifference surface, and the highest of these feasible frontiers is selected. Of course, for this approach to be operational a utility function must be specified. The E-V approach is subject to some criticism, however. For example, if the criterion (utility) function is non-quadratic or the probability distributions are non-normal, equating "risk" with variance (or, for that matter, any single measure of dispersion) is not totally satisfactory. "A more detailed analysis of the relation between skewness and risk is a desirable route to follow, if one is trying to restrict the information about distributions to a small number of parameters."7/

Other than simply disregarding risk in the objective function or choosing the safest project in the event of similar first moments, however, the method perhaps most frequently suggested is a lexicographic framework wherein, having achieved an acceptable level of uncertainty, the planner selects that project with maximal expected value. Alternatively, one can constrain oneself to achieve some minimally acceptable expected value after which the objective becomes risk minimization. The heavy emphasis which has been placed upon the safe yield concept by water planners and the perceived heavy costs of underdevelopment of water sources suggests that the lexicographic approach may be implicit in current and historical water planning.

To be sure, these examples are not exhaustive, and the theoretical literature pertaining to uncertainty is vast, but a complete treatment is not required for our purposes. The point is that water resource planning in general, and flood proofing literature in specific, do not appear to be utilizing these sorts of analyses to any significant extent.8/ While the explicit incorporation of risk into the decision model is likely to require more complicated (and expensive) estimation and optimization procedures, the typical degrees of variability and the magnitude of the sums involved are such that the payoff from such formal analyses should be sizable in many applications.

7/ Hanoch and Levy [8, p. 344].

8/ A notable exception at least in a conceptual framework is the formulation of Bhavnagri and Bugliarello [3].

Having treated some aspects of decisions under uncertainty, we turn next to the specification of the formulation for estimating net benefits from flood proofing.

III. Benefit-Cost Formulations

Flood proofing is an optional flood damage reduction measure to the individual floodplain occupant. Further, benefits and costs generated by flood proofing will vary among owners. For present purposes, however, we attempt to estimate the aggregate benefits in terms of damage reduction to both structures and contents and the aggregate cost of installing flood proofing measures to particular communities.

A. Benefits

The measure of direct benefits employed in this investigation is the amount of potential damage reduction to a structure and its contents if a particular flood depth occurs and flood proofing of intensity p were undertaken. Damages are assumed to be linearly related to market value of the structure and flood depth, i.e.

$$(1) \quad b_{pk} = a \cdot M_k \cdot d,$$

where b_{pk} measures dollar damages to the k^{th} type of structure, a denotes the damage coefficient,9/ M_k denotes the market value of the representative structure of type $\bar{k}$ and d stands for depth of flood in feet.10/ Homan and Waybur [10] have estimated a value for a equal to 0.052.

9/ Our implicit assumption is that $a_k = a_k'$ for all $k \neq k'$, and thus can be represented by a single coefficient a. Support for this assumption is given by James [12, p. 12], "Studies have found that unit damages vary among residential, industrial and commercial development, but the variation among these categories is quite small compared with variations within them."

10/ More precisely, d has been defined as follows:

$$d = \begin{cases} d^*, \text{ if } p > d^*, \text{ and} \\ 0.1p \text{ if } p < d^*. \end{cases}$$

That is, flood proofing is considered 100% effective if the intensity of flood proofing (p) exceeds the actual level of the flood (d*), while if the actual flood level exceeds the capacity of the flood proofing measure, the effectiveness is very low. Support for this sort of assumption is given by D. James [12, p. 15] who contends, "This type of flood proofing serves primarily to keep water out of buildings; once overtopped, its effectiveness is essentially lost."

Thus, b_{pk} is the benefit that can be derived if the structure is flood proofed to a depth p and a flood of depth d* occurs. Total benefits for all the structures of the k^{th} type for a particular year are, therefore, given by:

$$(2) \quad B^*_{pk} = b_{pk} \cdot Q_k,$$

where Q_k denotes the number of structures in category k.11/ The discounted stream of future benefits, B_{pk}, is given by:

$$(3) \quad B_{pk} = \beta \, B^*_{pk},$$

where β is defined by $\beta = (1 - (1+r)^{-t}) \div r$ and r is the discount rate assumed and t is the assumed life of the flood proofing measure.

B. Costs

Costs of flood proofing are also assumed proportional to the market value of the structure and depth of flood12/ -- hence

$$(4) \quad C_{pk} = e \cdot M_k \cdot Q_k \cdot p,$$

where C_{pk} is the total current cost (viewed as a lump sum payment) of flood proofing all structures of type k to withstand a depth of flood p, e is a cost coefficient, and M_k, Q_k and p are as defined above.

C. Decisions Under Uncertainty

Following the discussion of uncertainty and decision making in Section II, we contend again that to ignore some of the information which is available may lead to erroneous choices; that is, if information (subjective or objective) regarding degrees of uncertainty surrounding key parameters, and hence results, is ignored, then the decisions are less likely to be correct. Thus we shall treat the parameters, a, d and e as uncertain parameters, and will accordingly estimate the mean and variance (standard deviation) of the results. This, of course, enables the decision maker to compare not only expected net benefits of two alternative decisions, but also relative degrees of risk, where the standard deviation serves as a reasonable proxy for risk.

11/ This formulation is general. That is, if Q_k is small enough such that aggregation is unnecessary, we can set $Q_k = 1$ ~~U~~K categories, where K is the total number of structures involved, and sum over K.

12/ James [13] provides support for this assumption.

1. Benefits

For the benefits component we treat the parameters a and d of (1) as stochastic. The parameter a takes on three discrete levels or states (high, medium, and low) and the associated probabilities X_j are specified,13/ where of course $u_1'X = 1$ (u_1 is the 3X1 unit vector and X is a 3X1 vector of X_j).

Given the value of the decision variable p, the value of d depends of course on the depth of the flood, d* (refer back to footnote 10). For the representative year we selected six possible levels of flood (d*), ranging from zero feet to the maximum probable flood depths for each particular community and again attach associated probabilities Y_i, where $u_2'Y = 1$ (u_2 denotes the 6X1 unit vector).

Thus benefits are stochastic depending upon the relevant values of a_j and d_i. The expected value of the discounted stream of benefits from flood proofing structures of type k to level p is given by:

$$(5) \quad E(B_{pk}) = \beta\ X'a\ Y'd\ u_k'\ m_k$$

where u_k is the S_kX1 unit vector (S_k is the number of groups of observations in type k -- the larger is S_k the lower the level of aggregation) and m_k is the S_kX1 vector which denotes the product of $M_{gk}\ Q_{gk}$ for g = 1 ... S_k.

2. Costs

For the cost component, we treat the parameter e under uncertain conditions. Following the previous section, we assume high, medium and low coefficients and assign similar probabilities to each. The expected value of this formulation is similarly given by:

$$(6) \quad E(C_{pk}) = X'e\ u_k'\ m_k\ p,$$

where e is 3X1. In this formulation, obviously once the structure is flood proofed for a given flood depth (p) the actual depth (d*) has no effect on the cost function.

3. Net Benefits

As indicated earlier, the ultimate objective of the investigation is to quantify the first two moments of the net benefits formulation for

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13/ See Appendix A of Aklilu [1] for the assumed levels and weights for this and the other parameters to follow.

each level of flood proofing. (The decision variable is p.) These formulations are set out below.

First the expected value of this discounted stream of net benefits for a given level of p and a given structure type is found by combining (5) and (6), i.e.

$$(7) \quad E(N_{pk}) = \beta X'a\ Y'd\ u_k'\ m_k - p\ X'e\ u_k'\ m_k.$$

Expected net benefits from all of the K structure types in a given region is simply:

$$(8) \quad E(N_p) = u_3'\ E(N_p),$$

where u_3 is the kX1 unit vector and $E(N_p)$ is the kX1 vector of $E(N_{pk})$.

The variance of N_{pk} is given by:

$$(9) \quad V(N_{pk}) = E(N_{pk}^2) - (E(N_{pk}))^2,$$

and the variance over all structural types is given by:

$$(10) \quad V(N_p) = u_3'\ V(N_{pk}),$$ 14/

where,

$$(11) \quad E(N_{pk}^2) = \beta^2\ (u_k'\ m_k)^2\ (y'd)^2 \text{ 15/ } (X'a^2) + p^2\ (u_k'\ m_k)^2\ (X'e^2)$$

$$- 2\beta_p\ (u_k'\ m_k)^2\ (y'd)\ (X'a)\ (X'e).$$

14/ In general, the variance of a sum of random variables is the sum of the individual variances plus two times the sum of the covariance terms. However, the $V(N_{pk})$ are assumed independent for k = 1, ...,K, and hence the covariance term is null. (See Freund [6, pp. 174-175] for the proof.)

15/ For purposes of variance estimation, we employ $(y'd)^2$ rather than $y'd^2$. To use the latter formulation would yield a variance for a particular year. However, we are interested in the stream of benefits and costs over a reasonably long useful life such that over time the observed levels of d approximate our subjective distribution. The same is not true for a and e; if they are wrong in one period they are wrong for the whole analysis. Thus we employ the first formulation, treating that component as nonstochastic for purposes of variance estimation.

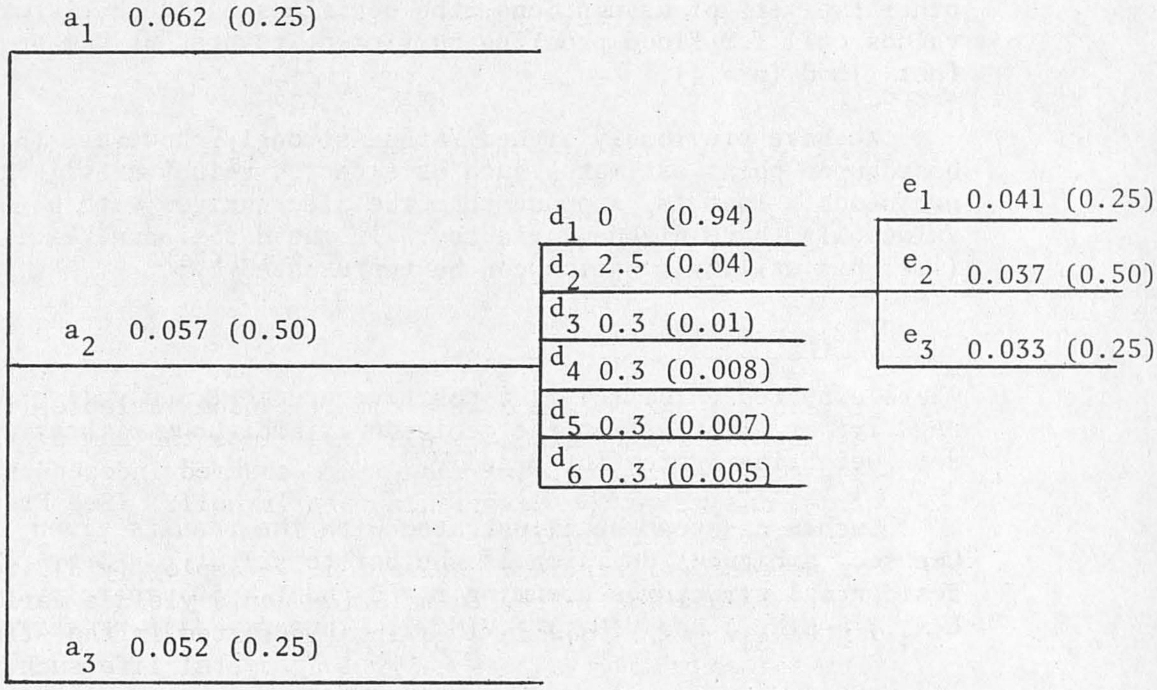
A sample of the results of the estimations using the formulations above is given in the following section. In the final part of this section, however, we hope to increase the clarity of the preceding formulations by illustrating the concepts and the approach in a decision tree context.

D. A Decision Tree Approach

The decision tree[16/] depicted in Figure 1 illustrates the concepts discussed in Section II and the approach outlined above. Viewed in this context, it is easily seen that there are 54 (i.e. (3)(6)(3)) combinations of values of the three parameters selected for treatment in an uncertain context. The values of a_j and e_j are not permitted to vary by community, but d_i depends upon the region as well as magnitude of the decision variable p.

Figure 1

A Decision Tree for Flood Proofing in Windsor, Connecticut
(p = 3)



16/ For examples of decision tree approaches refer to Magee [15, pp. 79-96], and Willis and Rausser [19].

To illustrate, suppose the decision involves whether to flood proof structures in Windsor, Connecticut to a depth of three feet. Then the most favorable combination of events for a "yes" decision is that a_1, d_2 and e_3 are the relevant parameters. But the probability of this is extremely low; .0025, or (.25) (.04) (.25). Likewise, the combination of a_3, d_1 and e_1 provides the most unfavorable situation for the "yes" decision, again with a low probability (.0588). Indeed, there are 52 other possible combinations of states of these uncertain parameters, and what we seek are some of the moments of this array-viz., the expectations and variances of equations (7) - (10). These results are set out in the following section.

IV. Empirical Results

Some results of formulations (7) and (9) for Windsor, Connecticut are set out in Table 1, where the levels of r and t examined are 5 and 10 percent and 20, 35 and 50 years, respectively, and the standard deviations are in parentheses. On the basis of expected values alone, the following decisions are indicated according to our partial framework.17/ First, flood proofing for this community is expected to be uneconomic under an assumed 10 percent discount rate as well as under a 5 percent discount rate if the 20 year life assumption is relevant. Under the other two sets of assumptions, the decisions on the basis of expected values call for flood proofing sufficient to prevent damage from a four foot flood (p = 4).

We have previously argued rather strongly, however, that decisions based upon point estimates such as expected values are likely to be erroneous. That is, suppose that the alternatives with higher expected values also have higher variances. If the decision maker is risk averse (i.e. his utility function can be represented by:

$$(12)\quad u = f(E, V),$$

where expected value (E) is a positive argument and variance (V) is a negative argument), then the decision is ambiguous without reference to some weighting system for E and V.

Such a case can be illustrated with the results given in Table 1. One such ambiguous decision is whether to select p = 3 or p = 4 for residential structures assuming r = 5 and t = 50 are relevant. That is $E(N_{41}) > E(N_{31})$ and $V(N_{41}) > V(N_{31})$. Thus p = 4 is preferred on the

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17/ In this initial stage of research we consider flood proofing as an all-or-none procedure, and exclude possibilities of combinations of structural or non-structural measures. A more robust model which incorporates all of these measures is currently being developed.

basis of the first argument of (12), while p = 3 is favored on the basis of the second. In this case, however, most reasonable weighting schemes would select p = 4, since realized net benefits under p = 3 stand a very good chance of being negative and only a roughly one in six chance of being greater than 6,000, while the results indicate only a one in six chance of realized net benefits resulting from the decision p = 4 being less than 6,900.

Table 1

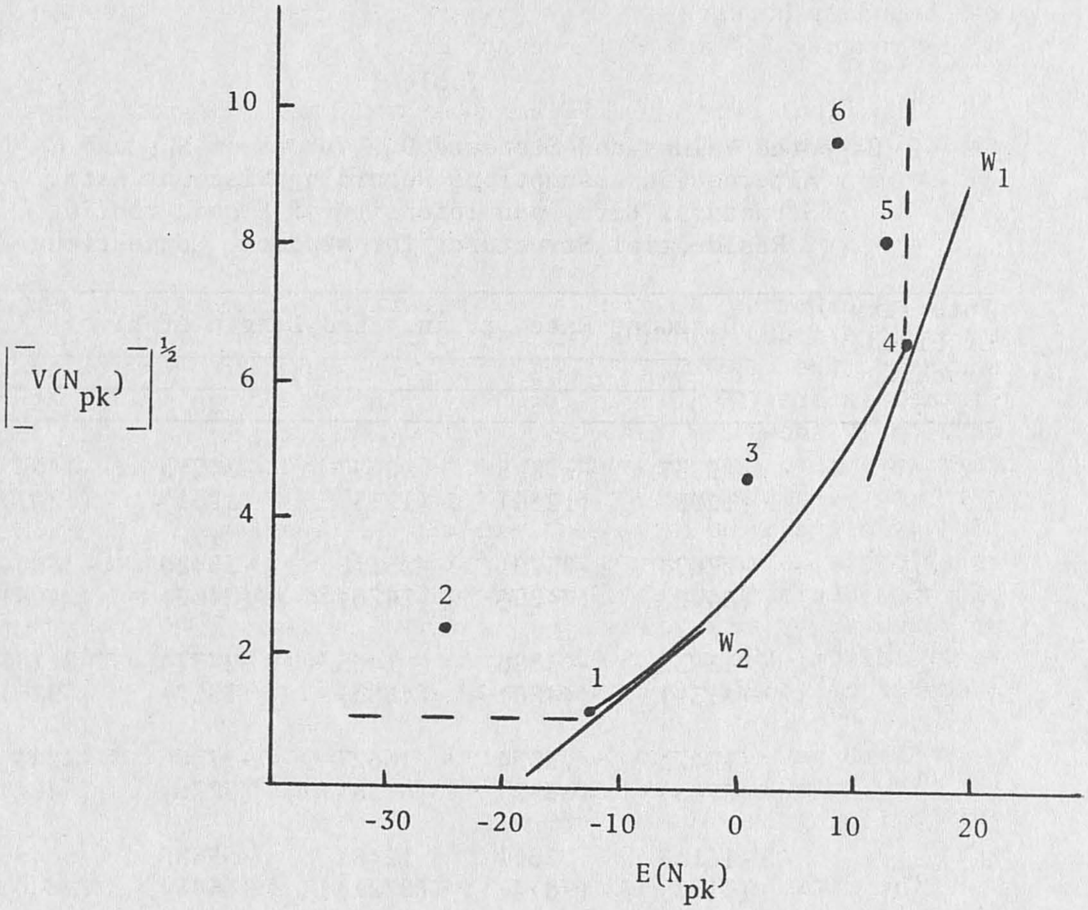
Expected Values and Standard Deviations of N_{pk} and N_p for Alternative Assumptions Regarding Discount Rate, Structural Life, and Intensity of Flood Proofing of Residential Structures for Windsor, Connecticut

Intensity of Flood Proofing (p)	Discount Rate (r) in % and Length of Life (t) in Years					
	5			10		
	20	35	50	20	35	50
1	-13537 (1205)	-12895 (1210)	-12557 (1213)	-14213 (1201)	-14027 (1202)	-13994 (1202)
2	-27074 (2410)	-25791 (2420)	-25115 (2426)	-28426 (2402)	-28054 (2404)	-27987 (2404)
3	-13852 (4139)	- 3856 (4480)	1405 (4682)	-24374 (3857)	-21481 (3926)	-20955 (3939)
4	-10421 (5783)	5334 (6382)	13627 (6733)	-27006 (5276)	-22445 (5401)	-21616 (5425)
5	-16143 (7123)	2611 (7814)	12482 (8221)	-35885 (6541)	-30456 (6684)	-29469 (6711)
6	-24207 (8388)	- 3160 (9131)	7917 (9570)	-46362 (7769)	-40269 (7921)	-39162 (7950)

The E-V framework of Figure 2 summarizes the potential decisions associated with these same assumptions (r = 5, t = 50). Assuming risk aversity, p = 2, 5, and 6 are clearly dominated by (inferior to) other decisions -- that is, p = 1 has a higher expected net benefits and lower risk than p = 2 and p = 4 similarly has a higher first and a lower second moment than do p = 5 or p = 6. Without specifying a weighting system for E and V, however, the decision among p = 1, 3, and 4 is ambiguous.

Figure 2

E-V Boundary for r = 5, t = 50



Suppose, however, that the results for a large number of alternative levels of p were obtained and the relevant efficient E-V boundary18/ were as indicated by the heavy line of Figure 2. Assume also that equation (12) can be expressed in linear form as:

(13) $W = b_1 E + b_2 V$,

where $b_1 > 0$, $b_2 < 0$, and, of course, $V = \frac{W}{b_2} - \frac{b_1}{b_2} E$. Then if $-\frac{b_1}{b_2} \geq W_1$ (the maximum slope of the relevant E-V boundary), p = 4 is the preferred

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18/ To be sure if p = 0 is admissible, this possibility dominates both p = 1 and p = 2.

decision, if $-\frac{b_1}{b_2} \leq W_2$ (the minimum slope of the E-V boundary), p = 1 should be selected, and if $W_2 < -\frac{b_1}{b_2} < W_1$, one of the decisions on the E-V boundary between p = 1 and p = 4 maximizes (13). In this example, W_1 is roughly 3.4 and W_2 is about 1.3.

The final section provides some concluding remarks and recognizes some of the major limitations of the approach.

V. Conclusions

The paper has presented a formulation for estimating means and variances of a flood proofing net benefits formulation in a partial equilibrium context. The empirical results for one community in the Connecticut River floodplain are provided in Table 1. The treatment of these results in Section IV shows the advantages of explicitly incorporating aspects of uncertainty into the analysis. The E-V framework depicted in Figure 2 indicates for example that if r = 5 and t = 50 are relevant, and if the decision maker regards increased expected net benefits as at least 3.4 times as valuable as reduced standard deviation of net benefits, then the recommended decision is to flood proof such that structures and contents are not damaged by an occurrence of a flood of four feet in depth. At the very minimum, the framework permits us to omit from further consideration a number of (dominated) decisions (p = 2, 5, 6).

As in any empirical investigation, however, the interpretation of the results must be conditioned by the assumptions made. Thus we provide the following caveats.

The first major limitation concerns the assumption of a linear relationship in both the benefits and costs relationships. The wider the range of market values and flood depths we employ, the less confident we may be that the linear relationship indeed holds.19/

Related to this, we of course recognize a possible aggregation bias20/ in those cases in which a number of structures are grouped. The potential bias is felt to be rather small in comparison with the additional (research) costs associated with disaggregation, however.

19/ Douglas James [12, p. 12] notes, for example, that care should be taken in employing such a formulation where flood depth exceeds five feet.

20/ Grunfeld and Griliches [7] demonstrate, however, the possibility that aggregation may under certain conditions produce net gains.

Another major limitation involves the partial nature of the approach. That is, the only alternatives are to flood proof to various levels or do nothing. In reality, of course, there are a number of potential measures, including structural and non-structural types, and a proper mix for any particular case may involve some combination of these. This overall approach is the subject of ongoing research, however, and the methodology presented above is easily incorporated into the fuller investigation.

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