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A FRAMEWORK FOR UNCERTAINTY MANAGEMENT IN WATER RESOURCES PLANNING

A Report Submitted to the:

U. A. Army Engineer Institute for Water Resources
Kingman Building
Fort Belvoir, Virginia 22060

by

Decision Sciences Corporation
Jenkintown, Pennsylvania

Under

Contract No. DACW73-72-C-0078

OCTOBER 1974

IWR CONTRACT REPORT 74-9

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ABSTRACT

This document is the product of a study to develop a methodology which Army Corps of Engineers' planners could utilize to explicitly consider uncertainties, i.e., uncontrollable and unanticipated eventualities that can adversely affect water resource planning.

The study attempts to broaden the planning process by considering the changing nature of the environment for water resource planning, and to provide a better way to recognize "uncertainties" and anticipate their impacts prior to a decision to implement any specific actions. The ultimate purpose is to provide an anticipatory procedure that will assist the planner to avoid, where possible, the adverse consequences of unanticipated events.

In summary, the management of uncertainty in Water-Resource Planning introduces a major choice involving risk taking:

- Delay action and pay more (in time and resources) to further reduce uncertainty/risk, or
- Take action now, and accept the presence of uncertainty/risk

This report describes the methodology for:

a) Making this choice, recognizing the vital importance of the manager's perception of, and willingness to take risk

b) Procedures for structuring uncertainty, having made the choice.

In essence, the methodology provides a quantitive basis for trading off resources (time and cost) to gain information versus the acceptance of uncertainty/risk

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I. INTRODUCTION

A. UNCERTAINTY IN THE WATER RESOURCE PLANNING PROCESS

Water resources planners typically define problems, formulate,assess and evaluate alternative solutions that will prevail over a time horizon of up to fifty years or more. Moreover, the planning process itself is often conducted over a time span of five to ten years. This situation, coupled with the phenomenon of rapid technological and environmental change that exists in today's world, automatically inbed some problem of uncertainty in every water resource planning process. Thus, in fact, the need for isolating and dealing with the problems of uncertainty are inherent in any long term planning process and must be evaluated in any program involving a change in the environment. Uncertainty, then, can be thought of as a measure of our lack of knowledge about change that can affect the outcome of planning.

The impact of uncertainties is reflected in the planning process in terms of unanticipated events or new conditions which will impact on the implementation of any water planning decision, or affect the consequences of the decision once implemented.

B. PAST EXPERIENCE AND JUDGMENT IN DEALING WITH UNCERTAINTY

Past experience plays an important role in the planning process. The personal experience, creativity, and flexibility of Corps professionals are important tools currently used for dealing with uncertainty. The methodology explored in this document seeks to augment such experience and creativity, and should not be construed in any way as a pat or binding formula. Similarly, past experience makes plain the ubiquitous nature of uncertainties; indeed, as a spur to both contemplation and action-taking, uncertainties have a certain identifiable utility. The study assumes the natural, inevitable, and even potentially beneficial dimension of uncertainty. At the same time, however, it also assumes that a logical procedure to deal with uncertainty as a quantifiable dimension will serve to strengthen the capabilities of the creative Corps planner who can gain new flexibility and leverage by reducing the potential impact of uncertainties to manageable factors.

This report presents the results of a study which was conducted under contract for the Institute for Water Resources.

The study was designed to define a methodology by which such concern regarding uncertainty is explicitly considered, reduced where appropriate, and then documented, so that the decision-maker is made aware of the uncertainties in a plan and their possible consequences.

The methodology, was derived in part from data and examples as reported by Corps planners. The study was not intended to be a rigorous, theoretical analysis of uncertainty and risk, but is rather an attempt to develop a practical, usable, constructive approach for dealing with uncertainty at all levels of planning.

C. OUTLINE OF REPORT

Chapter II presents a discussion of the causes of uncertainty in planning, and provides a framework for analyzing uncertainty. Chapter III describes the suggested process for dealing with uncertainty, while Chapter IV provides illustrations of how it is applied. Finally, Chapter V summarizes the results of the study.

II. UNCERTAINTIES IN WATER RESOURCE PLANNING

A. UNCERTAINTY, CAUSES AND CLASSIFICATION

Regardless of when they occur, either in the planning process, during implementation or post-construction, all uncertainties can be divided into two broad classes: operational uncertainty* (dealing with potential technological or environmental changes), the more familiar concern, "... is a fancy way of saying the system you have analyzed ... the hardware characteristics of the system may have changes...". On the other hand, strategic uncertainty potential caused by broader institutional and social change beyond the technical control of the planner is a broad term designed to encompass the fact that one is uncertain as to the actual state of the world, its components and realities. By definition, operational uncertainties arise and must be treated in a framework of strategic uncertainties.

Perhaps the best way to define the nature of uncertainties and their impact on the planning process is to give a few examples of the occurrence of events which were not clearly foreseeable. These situations are drawn from the experience of Corps of Engineers' planners, as described in interviews which examined the nature of uncertainty, its impact, and processes to deal with it. Interviews were conducted with planners at all levels in the Corps from the District up through the Office of the Chief of Engineers.

Based on interviews conducted with Corps planners, the major sources of uncertainty in the water resources planning process are caused by four major types of potential change:

1) Social Change - wherein the values and knowledge, along with the role of human actors changes dramatically - and often erratically - over time (e.g., the Energy Crisis and environmental litigation).

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* Operational uncertainty is commonly referred to as technological uncertainty. See Mandansky, A., "Uncertainty," and Quade, E. S., and Boucher, W. I., Systems Analysis & Policy Planning: Application in Defense, Rand Report R-439-PG (abridged). American Elsevier Publishing Co., New York, N. Y. 1968.

2) Institutional Change - wherein the role of government, higher education, organized research, the military, and other major organizational arrangements change dramatically - and often radically - over time (e.g., the Revenue-sharing or Public Participation strategies; agency policy revisions, etc.).

3) Environmental Change - wherein knowledge of the various interrelationships of parts of the environment changes, especially as concerns geo-technical and economic considerations (e.g., Mechanics of Beach Erosion and the cause/effect relationships influencing the water levels of the Great Lakes)

4) Technological Change - wherein our rapidly changing hardware, and its related software approaches, experience obsolescence and replacement in a dizzying way (e.g., the introduction of SIRAP; advanced waste treatment systems; hydropower issue, etc.).

Corps experience to date has been especially successful in dealing with operational uncertainty where the last two of these four change sources are concerned. Interviewers, however, share the persuasion that the months and years immediately ahead will include a greater than ever emphasis on strategic uncertainty, caused by social and institutional factors.

B CASE EXAMPLES

As part of the interview process conducted by Decision Sciences Corporation, eight case examples involving uncertainty were described. These include events drawing upon all four types of uncertainty. These eight events are categorized below and outlined in Figure II-1:

EVENT	RELATED SOURCES OF UNCERTAINTY
1) Channel Dredging	Environmental
2) Extreme Event	Environmental
3) Advanced Waste Treatment Systems	Technological
4) Hydropower Issue	Technological
5) Flood Control Issue	Social

FIGURE II-1

TYPICAL UNANTICIPATED EVENTS *

	EVENT	DESCRIPTION
1	Channel Dredging	A $20 million project to improve a navigation channel is under construction. After three months of construction work under the prime contract, it is discovered that rock is present in the proposed channel, and removal will require change orders for an additional $20 million.
2	Extreme Event	A severe hurricane has occurred which caused extensive flooding of areas behind existing protective works. The Weather Bureau, after an analysis of the characteristics of the storm, has revised the parameters of the Standard Project Hurricane (SPH). A study of the impact of this revision indicates that existing projects are inadequate to provide SPH protection, and furthermore, that projects under design will have to be modified to provide this level of protection.
3	Advanced Waste Treatment Systems	Planning has been completed in a regional waste treatment system that utilizes secondary treatment facilities, and will just meet existing standards. At a professional meeting, the technical representatives of the regional COG learn of new advanced waste treatment system that is competitive in cost, and will also provide an effluent that exceeds current standards.
4	Hydropower Issue	As a result of diminishing domestic energy sources, the Corps of Engineers has been requested to reappraise all its existing and planned structures for power production. This will divert significant effort from existing planning activities.
5	Flood Control Issue	At a public hearing regarding alternatives for reducing the flood hazard in a small community, four (4) alternatives are presented, three (3) of which are economically justified and one that is not. Strong support is given to the flood control system that is not economically feasible, i.e. B/C is 0.8.
6	Environmental Litigation	A flood control project has been approved and is ready for preconstruction planning. During public hearings, a well organized group of citizens raises strong objections to the construction of the project. This group bases its objections on the argument that non-structural flood plain zoning should be utilized in order to protect the natural environment. As a result of the objections, considerable controversy has resulted and a suit has been filed to stop the project.
7	Agency Policy Revisions	A project has been planned and is in the division review process with an affirmative recommendation from the District Engineer. The project has received preliminary comments that are favorable from all non-agency organizations and interests. During its Division review, the policy on local cost sharing criteria has been reinterpreted and now requires additional local funding that cannot be produced because it will exceed the bonding limit of the local governmental unit.
8	Multiple-Objectives ✔	A Planning Chief is part way through a study and is faced with new legislation that indicates that in addition to the objectives of national economic efficiency, environmental quality, social wellbeing, and regional development shall be considered in developing the plan. The planning staff can analyze national and regional economic development, has some competence in environmental analysis, but is aware that neither it nor other available sources have the ability to perform social wellbeing analysis. In addition, even if each objective could be equally well analyzed, there is no set of criteria to indicate how trade-offs are to be made among the objectives to arrive at a preferred plan.

*** Based on interviews with Water Resource Planning personnel in field agencies, review agencies, and policy agencies. Although situations described are based on actual interviews, the details have been modified for purposes of discussion points of this report, and thereby do not accurately represent an actual situation.**

EVENT	RELATED SOURCES OF UNCERTAINTY
6) Environmental Litigation	Social
7) Agency Policy Revisions	Institutional
8) Multiple Objectives	Institutional

It should be emphasized that the situations described in Figure II-1 are the outcomes of unanticipated events that were not necessarily considered in planning. They are described here to illustrate the range of uncertainties arising in both operational and strategic contexts.

Although the examples were constructed to emphasize one source of uncertainty in each, typically, all four sources are present in any situation. Nevertheless, it is possible, practical, and potentially quite productive to ascertain the key, or major source of uncertainty, whether social, institutional, environmental, or technical, in every case confronted.

The Channel Dredging Event (#1) is an example of an operational environmental unanticipated occurrence in that it is limited in scope, applying only to the particular project. In contrast, the Extreme Event (#2) situation is broader in scope, concerning planning implications over a range of projects throughout the region.

Another useful contrast can be drawn between the Channel Dredging which is a geological uncertainty and is, therefore, described as environmental in source, and Environmental Litigation which is social in source, but considers environmental issues. In this report, environmental uncertainty is used in the sense of uncertainty as to the geotechnical economic and ecological conditions and relationships.

C. UNCERTAINTY: DECISION PROCESSES INVOLVED

Another scheme for the categorization of the above examples may be considered. The factors that define this scheme are shown in Figure II-2 and are used to characterize the nature of the situation in which the planner encounters uncertainties. The parameters of interest are belief or understanding of the <u>nature of the situation</u>, and the belief

FIGURE II-2

A CATEGORIZATION OF THE NATURE OF UNCERTAIN SITUATIONS

		UNDERSTANDING OF OR AGREEMENT OVER THE DESIRABILITY OF THE POSSIBLE OUTCOMES	
		AGREEMENT	DISAGREEMENT
UNDERSTANDING OF THE NATURE OF THE PROBLEM OR KNOWLEDGE OF AVAILABLE COURSES OF ACTION	AGREEMENT	I. CALCULATION	III. NEGOTIATION
	DISAGREEMENT	II. PROBLEM-SOLVING	IV. INSPIRATION

in the desirability of the various possible outcomes.* The decision situation is categorized according to whether or not there is agreement or understanding on these two parameters. Each quadrant of the matrix of Figure I-2 represents a different type of decision and, therefore, requires a different decision making process. The general nature of the appropriate process for each situation is shown in the quadrant. For example, if there is agreement on the nature of the problem and the desirability of the outcomes, then the appropriate process is one of calculation (quadrant I).

It is important to note that the parameters used in this framework are defined by the planner's perception of the situation, and the desirability of the outcomes, and not the nature of the situation and the possible outcomes themselves. The planner will act with the process which is appropriate to that situation in which he perceives himself.

In order to illustrate this scheme, consider an example which consists of a lone traveler. In Case 1, the traveler knows his destination and his present position, and all that is required is to determine an appropriate route to that destination. This case is clearly an example of calculation. In Case 2, the traveler again knows his destination, but does not know his present location. He is lost, and must first determine his present position, an exercise in problem solving, before he can calculate a route to his destination. Case 3 is the situation where the traveler knows his present position, but is unsure as to which destination to choose. Here, he must first select a single destination, a process of negotiation or trade-off, before he can determine an appropriate route. Finally, in Case 4, the traveler is both lost and undecided as to where he should go. Here, he must determine his present position and select a single destination before he can determine a route. Alternatively, he can make an "inspired" choice based on adopting an attitude of optimism or pessimism towards his situation -- set off in one direction, and hope for the best.

Figure II-3 categorizes the eight examples previously described in terms of the key source of uncertainty that led to the unanticipated situation, the nature of the uncertainty situation, its context, and the general technique that could have been utilized in anticipation of the situation. In the Channel Dredging case the unanticipated condition stemmed

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* James D. Thompson, Organizations in Action, New York: McGraw-Hill Book Co., 1967. pp. 132-138

FIGURE II-3

NATURE OF UNCERTAIN SITUATION

CASE	SOURCE OF UNCERTAINTY	NATURE OF UNCERTAINTY	CONTEXT FOR UNCERTAINTY	TECHNIQUE
Channel Dredging	Environmental	Geological Uncertainties	Operational	Problem-Solving
Extreme Event	Environmental	Climatologic Uncertainty	Strategic	Problem-Solving
Advanced Waste Water Treatment	Technological	Best Available Technology	Operational	Negotiation
Hydropower Issue	Technological	National Energy Priorities	Strategic	Negotiation
Flood Control Issue	Social	Community Preference	Operational	Negotiation
Environ-mental Litigation	Social	Social Priorities	Strategic	Inspiration
Agency Policy Revisions	Institutional	Change in Cost Sharing Rules	Operational	Problem-Solving
Multiple-Objectives	Institutional	Institutional Changes in Project Evaluation Procedures	Strategic	Inspiration

from lack of information regarding project geology. Clearly the source is environmental. The technique indicated for the case in problem solving, i.e., getting more information during planning on the nature of the geological problems that might be encountered. In contrast, the Flood Control Issue case describes an unexpected situation that stems from different preferences for economic efficiency. The source is Social and indicates a lack of agreement regarding social priorities--the community prefers flood control at any federal cost, while, the broader federal interest requires that each dollar of federal money at least return a dollar of benefit. The technique indicated is Negotiation, i.e., coming to agreement on a mutual policy between federal and local interests that meets some minimum standard for both.

D. ELEMENTS OF A METHODOLOGY

By working backwards through the above discussion, it is possible to define the rudiments of a methodology for dealing with uncertainty. As previously discussed, uncertainty can be characterized as to the perceived nature of the situation. Such an analysis provides insight into the nature of the techniques required to deal with the uncertainty.

An examination of this framework provides some insights into causes of ineffective planning. The first of these is the result of perceptual error. The planner perceives himself to be in one situation when in reality, he is in a completely different type of situation. This error is often cited in the operations research literature. One symptom of this type of error is the existence of apparent contradictions or internal inconsistencies within the proposed solution.

Another problem which arises in group situations is that different members of the group operate within differing views and values simultaneously. Often this discrepancy is not overt, but takes the form of various members of the group working at cross-purposes to one another. What is required in this situation is some form of meta-decision-making. The group must examine its own decision-making processes and decide which process is appropriate.

Thirdly, it is necessary to examine the situation to identify the nature of the changes which are the underlying causes of uncertainties. If uncertainty is a result of technological changes, then the planner must fall back on research to obtain the necessary information. Similarly, if the uncertainty results from institutional, social or environmental changes, the planner must search for information within the appropriate institutions or agencies, through public participation and an analysis of social preference trends, or through additional geotechnical data gathering. Clearly, it would not be appropriate to have a public referendum to determine geologic conditions in the Channel Dredging example.

Finally, it is possible to characterize uncertainties by context as to either operational or strategic. Operational situations are more limited in scope and do not require the breadth of data that would be included in dealing with strategic uncertainties. In the Channel Dredging example, only a limited amount of information was needed, that information applicable to the specific channel. In the Extreme Event situation, however, a broader set of data must be considered including such data as are available on weather modifications on the global scale. Operational situations tend to require specific data drawn from a more limited set of sources, while strategic situations tend to require broader data drawn from a more universal set of sources.

The distinction between operational and strategic uncertainties is by no means a clear-cut one. As a better understanding of a problem is acquired, the latter tend to shade into the former. Calculation replaces inspiration. For reasons discussed below, however, it is unnecessary and undesirable (and impossible) to rid a problem of all uncertainty. It is necessary to manage or cope with uncertainty. In any case, the planner must exercise considerable judgment in covering enough general sources so as to assure that he has obtained the appropriate specific sources of information.

IMPACT OF UNCERTAINTY

The basic vehicle whereby uncertainty is evidenced in our planning process is in the form of information or lack of it. As we have pointed out, lack of complete information, whether it be an unclear statement or objectives and Corps policies, an error in the data required for planning, or the lack of an understanding or knowledge of the wants and desires of the affected local population, can significantly impact on the process of developing water resource plans.

This impact is measured by the significance of error resulting from an outcome different from that which was anticipated. In the Channel Dredging example, this error was measured by an additional $20 million expenditure for rock excavation, and its significance is indicated by how drastically this additional cost would change the priority of the project, relative to other urgent work, if it had been known in advance. In the other examples, the potential impact of error cannot be quantified so readily, but nevertheless, is conceptually similar to this geological example. In order to generalize this concept, the overall impact of uncertainty will be defined in terms of two types of cost:

a) The Cost of Determining Additional Information, and

b) The Potential Cost of Error, resulting from not obtaining the additional information

In the Channel Dredging example, the key source of uncertainty derived from lack of knowledge regarding geology. Additional information could have been achieved by obtaining additional soil borings. However, there is an obvious limit to the number of borings that can be obtained within the practical limitation of the time and funds available for planning. The sum of these two costs is indicative of the total impact of uncertainty in a given situation (Figure II-4).

A planner must first determine the nature of the curve of cost versus uncertainty, and then identify his present location on this curve. Two possible cases are shown in Figure II-5. For example, at Point "a" the marginal incremental cost savings resulting from obtaining additional information is greater than the incremental cost of the additional information and, therefore, more information should be obtained. Point "b" illustrates the case in which the cost of gathering information exceeds the potential decrease in the cost of not having the information.

The above discussion highlights the impact of uncertainty as measured in terms of economic costs. Other impacts, discussed below, must be considered, some of which are readily converted to economic costs, and others involve social costs, for which no convenient conversion is possible.

For example, when there is high uncertainty, a major impact is the increased time required to complete planning. This time is required to develop objectives and goals, to develop better, "more certain" engineering and geotechnical data, or to develop a better understanding of local desires. Increases in time usually result in a direct increase in the costs of information gathering, total national costs due to the impact of changing goals and objectives over a prolonged planning period. This lengthening of the planning process, coupled with rapidly changing societal preferences can, in the extreme, result in the development of plans which are out of date vis-a-vis evaluation criteria, when they are submitted to Congress for authorization.

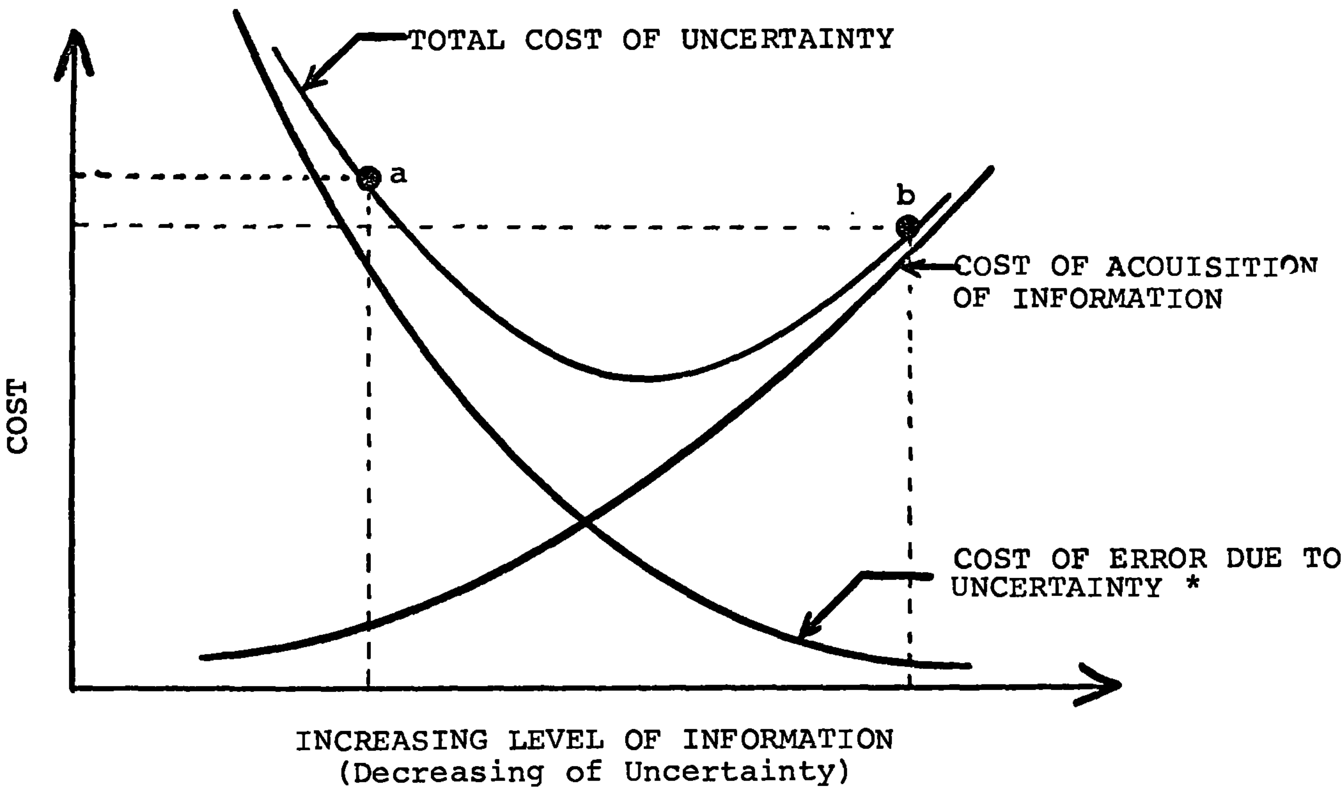
An indirect, but significant, impact associated with the uncertain nature of water resource planning objectives and policies is a decrease in morale and efficiency of those field level planners who must implement this planning process. This phenomenon is also accompanied by increased stress among the various levels of planning, both review and policy setting, in the Corps.

In this chapter, we have attempted to define the nature of the problem and to lay the groundwork for a methodology for dealing with uncertainty. In the next chapter, we will discuss this methodology in more detail.

FIGURE II-4

LEVEL OF INFORMATION

VERSUS COST



* Under assumption of more information acquired.

III A METHODOLOGY FOR MANAGING UNCERTAINTY

The management of uncertainty is a process consisting of four steps:

1. Identification and analysis of elements of uncertainty,

2. Determination of the significance of each element of uncertainty,

3. Estimation of the consequences that may ensue, and

4. Action to reduce the impact of the uncertainty to the extent desirable and feasible.

In turn, the reduction of the impact of uncertainty may involve data collection to improve the certainty of the necessary assumptions, a re-examination of planning objectives, an examination of the alternative consequences of the various assumptions possible, or a combination of these actions.

It should be emphasized that the "dealing" with uncertainty as it affects water resource planning is done in two major phases:

- The identification and analysis of uncertainties occurs during the preliminary planning phases ranging from the definition of goals and objectives through to the formulation of alternatives for meeting objectives.

- The analysis of the impact of uncertainties on a plan as the many alternative courses of action are assessed and evaluated to determine a recommended plan.

A general process for dealing with uncertainty is presented below.

A. IDENTIFICATION AND ANALYSIS OF UNCERTAINTIES

As pointed out above, the first step in the process of dealing with uncertainties is to identify and analyze the uncertainties. This is particularly important during the initial data gathering where data requirements include, but are by no means limited to the following:

- climatic
- hydrologic
- meteorologic
- topographic
- economic
- geologic
- demographic
- land use
- ecological
- sociological
- safety
- environmental
- aesthetic

Clearly, there are uncertainties inherent in the collection and use of any of the above data.

Uncertainties can also be categorized as to whether they are absolute or reducible. Climatological uncertainties, such as the exact year of the occurrence of different amounts of precipitation, are absolute or unreducible. In this situation, resolution is limited to taking an explicit risk-taking stance, i.e., optimistic--- taking action with the belief that a favarable outcome will result; pessimistic -- actions taken accepting the contingency of an unfavorable outcome.

The situation of unreducibly uncertainty can be contrasted with geologic uncertainties which can be reduced by obtain-additional core samples. The question of the worth of these samples vesus their cost must still be resolved.

Thus, in general, when facing reducible uncertainties, the situation is one of determining the value of additional information. Alternatively, when faced with unreducible uncertainty, the situation requires a reassessment of the propensity to take a chance.

B. PROCEDURES

Uncertainties must be evaluated with respect to a possible course of action, with the strategy for action to minimize the impact of uncertainty dependent on the four parameters identified below:

- Existent or initial level of uncertainty
- Reducible uncertainty
- Cost of reducing uncertainty
- Sensitivity of the alternatives or plan outputs to the initial or existent and reducible uncertainty

Each of these parameters is discussed below, with an illustrative case used to demonstrate the procedure for applying parameters.

1. Analysis of Initial or Existent Uncertainty

The first uncertainty management task is an analysis of the uncertainty present in the initial or existing situation. This analysis is a multi-step process with uncertainty a function of knowledge of the existence, outcome, and utility of all alternatives. These parameters are illustrated in the following example of the Flood Control Event.

The full range of alternatives includes structural and non-structural alternatives could be considered. The various outcomes include floods of different magnitudes; however, in this illustration, only two outcomes are shown -- flood and no flood.

Figure III-1 indicates four possible alternatives. The choice among these four is a man-made one resulting in various costs. If a structural solution is implemented, there are a number of costs incurred including the actual construction costs. Non-structural alternatives result in costs of a somewhat different nature, including the cost of clearing the flood plain of existing development and the opportunity cost associated with the non-development of the area.

There are two possible outcomes in this example. Either a flood does or does not occur, and this decision is an act of nature. If there is flooding, there is a potential for flood damage, and if no protective mechanisms have been implemented, then there will be a cost associated with actual flood damage. If there is no flooding, then there are no flood damage savings.

The utilities of the various combinations of decisions and acts of nature are also shown. The utility is the sum of the cost of the man-made decision and the cost of the natural event. For example, if a control structure is built and there is no flooding, then there is the continuing cost of paying for the structure ($100,000). If there is flooding, the utility is the difference between the flood damage prevented ($300,000) and the cost of paying for the structure ($100,000) which is shown ($200,000).

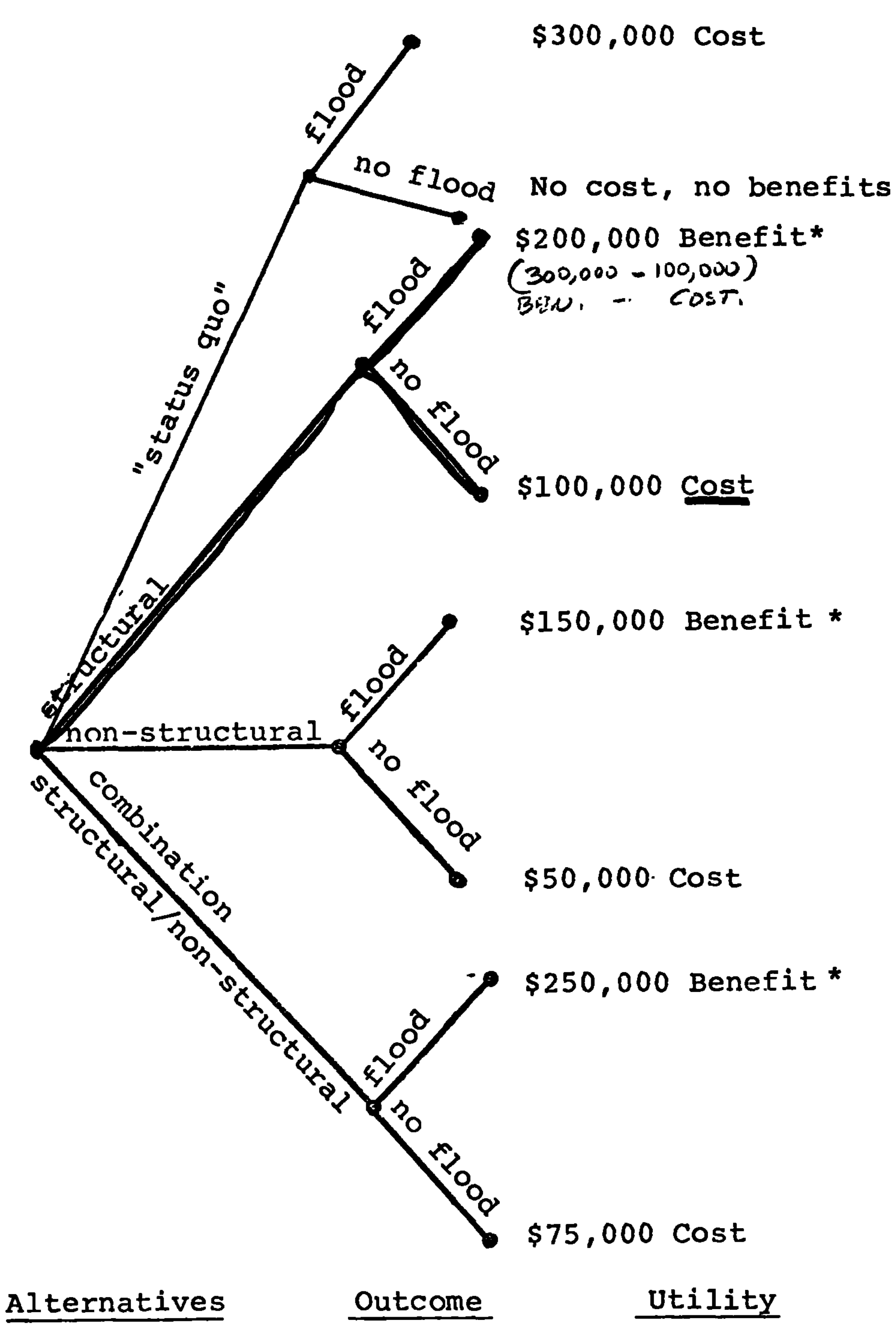


FIGURE III-1
FLOOD CONTROL ALTERNATIVES

* Benefits are defined in damages avoided.

This example will be used to illustrate a process for identifying initial or existent uncertainties.

The basic approach suggested is to:

1) Develop a set of all possible alternatives

2) Evaluate the feasibility of these alternatives and eliminate those that are infeasible*

3) Identify outcomes of those alternatives that are feasible

4) Determine utility of each feasible outcome (since this requires application of a value system, good planning requires that several sets of utilities be generated. This would assist in explicitly identifying competing value systems during this stage of analysis. Although this is an extremely important aspect it is a separate planning topic and is beyond the scope of the present effort).

PUBLIC PARTICIPATION PROGRAM.

In order to determine the utility of each alternative, it is first necessary to identify all the parties who are affected by the alternative, and to then determine the utility of the particular alternatives for each interest group.

The first concern of the planner is to examine the extent of knowledge of possible flood control alternatives.

Our first step is to generate, (using a morphological approach), all feasible combinations of devices to establish all feasible alternatives. This process, in fact, reduces uncertainty in that it is likely to generate alternatives which the planner had not previously considered, or show explicitly the reasons why other alternatives are disregarded. Note that our technique does not address or identify those uncertainties which may arise from new technological developments or a change in national policy. This approach is limited in that it does not consider devices which are not existing during

* A general approach for these two tasks can be found in the so-called morphological analysis technique in which general elements of a problem are arranged in all possible combinations, and infeasible combinations eliminated.

the process of plan development, the creation of such devices being a major source of uncertainty.

Our example considered two flood control devices, one structural and one non-structural. There are only four possible combinations of these devices, as shown in Figure III-2. As it happens, all combinations are feasible. If a combination is not feasible, the planner should document the reasons why. Of course, in a more complex situation, our planner would be faced with structural devices of different sizes, and varying strategies for non-structural protection, all of which must be considered.

FIGURE III-2

GENERATION OF FEASIBLE ALTERNATIVES

	STRUCTURAL	NON-STRUCTURAL	IS THIS COMBINATION OF DEVICES FEASIBLE?	IF NOT FEASIBLE, WHY?
1.	NO	NO	YES	-
2.	YES	NO	YES	-
3.	NO	YES	YES	-
4.	YES	YES	YES	-

The planner must then determine the outcome of the alternatives identified above. As shown in Figure III-1, for the four alternatives possible and the two states of nature considered, flooding and no flooding, there are only eight outcomes possible. Of course, in a more realistic setting, the planner must consider a continuum of flood magnitudes, and there would be many more outcomes. The uncertainty associated with estimating the magnitude of the largest flood possible is always present, and must be considered.

Next, the planner must consider the utility of the many outcomes. Uncertainties considered in this example are the result of local geological, demographic, economic, social, political, etc. considerations. Specifically, our planner must examine data to ascertain the assumptions and techniques used to develop the data. For example, there may be considerable uncertainty regarding the use of national economic projections for local planning.

In summary then, the planner must ascertain the uncertainties (the degree to which he lacks knowledge) regarding the existence, outcome, and utility of all alternatives.

2. Determination of Reducible Uncertainties

The second parameter places emphasis on determining what uncertainty is reducible. It is then necessary to determine what information needs to be acquired, how much it will reduce the impact of the uncertainty, and therefore, whether or not the information is worth getting. One final question is whether the information is worth getting now.

Among the means available are:

1) Additional data gathering

2) Use of different assumptions

3) The use of different analysis techniques

Additionally, the planner must identify methods to reduce the impact of the existant uncertainties on the planning process. Specific techniques include staging of investment and construction, and preservation of multiple options or alternatives until a specific decision must be made.

Naturally, the process of determining reducible uncertainties cannot be strictly defined and routinized. Rather, the process is a function of the experience and creativity of the planner himself. There are statistical sampling techniques which can be used to define a data gathering strategy, and to determine the degree to which this strategy of data gathering affects the existent uncertainty. In still other and very different cases, the particular uncertainty is caused by factors for which additional data gathering is not possible, and the impact of such assumptions cannot be estimated anywhere near as easily. Instead, the planner must use professional judgments to hypothesize various scenarios as a consequence of the different assumptions, and then examine these scenarios to determine to what degree the initial uncertainties have been reduced.

Friend and Jessop* have categorized uncertainties according to the basic source of the uncertainty, and they have identified the general nature of the technique required to reduce each uncertainty. The first source of uncertainty involves insufficient knowledge of the environment, or demographic and economic data as well as the geotechnical and ecological data which is commonly included as environmental data. Our normal mechanism for reducing this uncertainty is to do more research and data gathering. A second source of uncertainty identified originates from a lack of knowledge of the intentions of others in related fields of action. A typical response to this uncertainty is a call for additional coordination. A third and final source of uncertainty is based on a lack of knowledge as to appropriate value judgments as is frequently encountered in computing economic, social, and environmental costs and benefits. The planner's usual response here is to call for clarification of existing policy, or to call for new policy.

3 Cost of Reducing Uncertainty

The third parameter considered in our proposed process is an estimate of the cost of removing uncertainty. In an introductory section of this report, the cost of the uncertainty as it exists, and the cost of "buying" information to reduce the existent uncertainty, were discussed. The latter component is the parameter of interest here. That is, the planner must determine the cost in manpower, time, and money of acquiring additional information and reducing uncertainty.

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* J. K. Friend & W. N. Jessop, "Local Government & Strategic Choice. London: Tavistock Publications, 1969.

In general, the cost of reducing uncertainty increases as the total amount of uncertainty remaining decreases. Two such patterns of cost as valued are shown in Figure III-3. It is necessary to consider the incremental benefits to be derived for each incremental expenditure. This point has also been discussed earlier.

It is also important to recognize the economic leverage associated with planning cost. For the costs here, while significant, are but a fraction of the total costs associated with water resource development. Expenditures of tens or hundreds of thousands of planning dollars, while large, may be insignificant in comparision to the economic uncertainties associated with a project of tens or hundreds of millions of dollars! In short, the planner must consider the cost of planning information, in relation to the value of that information in reducing project costs ✓ whether they be for structural or non-structural alternatives. However, the planner must recognize that planning budget limitations ultimately govern his ability to balance his information needs with the execution of his function.

(4) Sensitivity to Uncertainty

The next parameter to be developed is an estimate of the sensitivity of the possible plans to the initial and reducible uncertainty. This step is an extremely critical one and its importance is illustrated in two flood control cases discussed below.

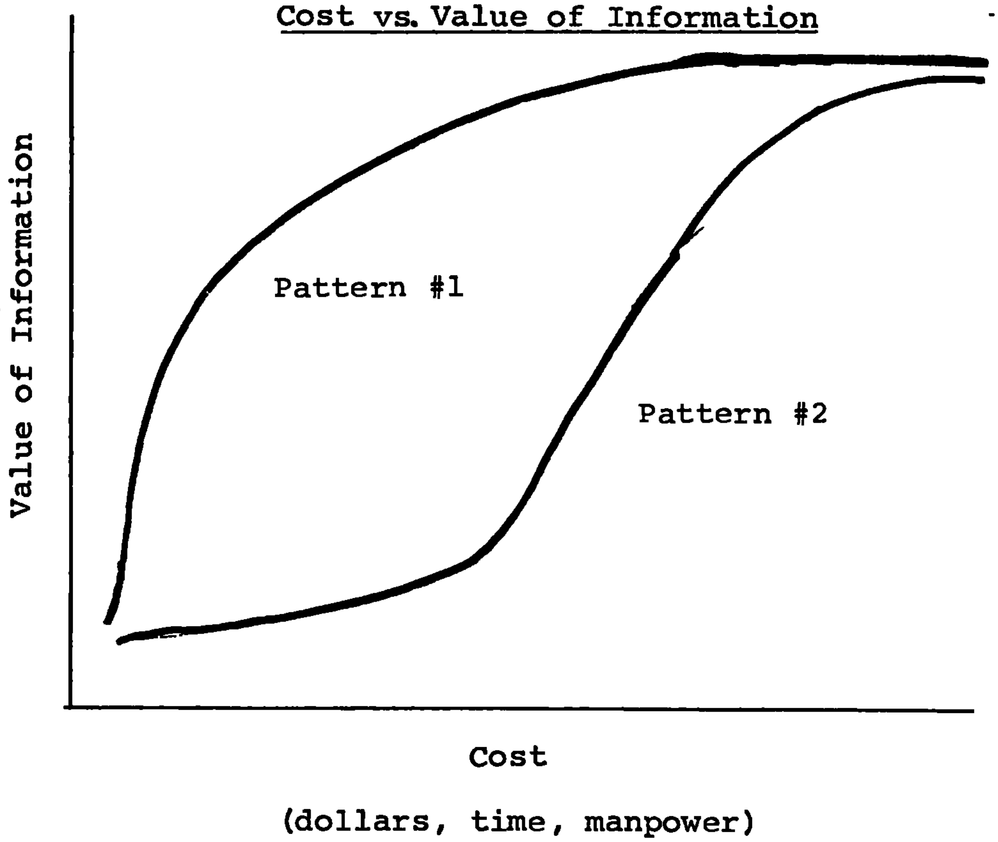
The first case illustrates a situation where the possible plan alternatives are variations of a single mechanism and are therefore all equally impacted on by the initial uncertainty. The second case illustrates a situation where different mechanisms, structural and non-structural, are viable plan recommendations, each having a different uncertainty.

In the first case, a flood control requirement is caused where the downstream river stretches have been fully developed. Food plain zoning is not possible and channel improvements have already been implemented to the extent possible. We also assume that an upstream dam is the only suitable relief mechanism. Now while our planner must consider many factors in such a study, this particular example will consider only one factor, the geology of the possible dam site. The various dam configurations are all impacted by geologic uncertainty, and therefore any resources allocated to reducing geologic uncertainty would reduce the uncertainty of any recommended course of action.

FIGURE III-3

Alternative Patterns

Cost vs. Value of Information



A second case, similar to the first, assumes that flood relief is possible with either an upstream dam or through flood plain zoning, or both. In this case, the one alternative, the dam, has a high amount of geologic uncertainty, and the other alternative, flood plain zoning, is only slightly impacted on by geologic uncertainty. An allocation of resources to reduce geologic uncertainty will reduce the uncertainty of the recommended plan if a dam is recommended, but will have no effect on the uncertainty of the recommended plan if flood plain zoning is recommended. In short, any decision to deal with uncertainty must consider that there is a possibility that reducing the geological uncertainty may have no impact on the uncertainty of that alternative action which is finally recommended.

The uncertainty that remains in a recommended course of action may be a function of that course of action which is recommended. If there is a significant uncertainty which impacts all alternatives equally, then the uncertainty in the recommended plan is a function of the situation, and not the particular plan and, therefore, any information obtained must reduce the uncertainty of the total situation. Conversely, it is possible that only particular alternatives include uncertainties, and therefore, only if the final plan includes these alternatives is the plan itself sensitive to uncertainty. Any information gathered to reduce these uncertainties does not necessarily reduce the uncertainty in the recommended plan unless these "uncertainty sensitive alternatives" are part of that plan.

C. STRATEGY FOR DEALING WITH UNCERTAINTY

The discussion to this point has sought to identify and describe four parameters which the planner must consider as he deals with uncertainty in planning. The strategy which the planner utilizes is, in part, a function of the risk which will be assumed in developing planning alternatives.

The particular action for dealing with uncertainty is dictated by the overall position that is adopted regarding risk-taking. This position is set by the degree of optimism or pessimism that is adopted regarding the uncertain situation. The general procedure is to make explicit, the risk-taking position and decide whether to:

a) continue with existing information

b) bring more information

c) examine and, if appropriate, change the risk-taking position

The choice is determined as a function of the four parameters previously discussed.

- Existent or initial uncertainty
- Reducible uncertainty
- Cost of eliminating uncertainty, and
- Sensitivity of the plan to uncertainty

We recognize, of course, that while our four parameters are advanced as necessary components to decisions dealing with uncertainty, we have not offered a complete set of specific techniques for measuring and quantifying these parameters. This last task was plainly beyond the scope of this limited introductory study.

THE TIME HAS COME. NEXT EFFORT

The process described above should be considered a framework for dealing with uncertainty, with further development of detailed techniques still required. Figure III-4 illustrates how such a process could be utilized based on an intitial risk-taking position that is pessimistic regarding the ultimate outcome of an uncertain situation.

Examples of conbinations of the four parameters discussed are shown. Only values of "High" or "Low" are used for each parameter and, therefore, sixteen possible combinations of values are listed. For each such combination, an "indicated action" is stated.

As the Figure suggests, an important step in dealing with uncertainty is to analyze the multiple effects of any one specific course of action. For example, in the case of involvement of the public in planning to better develop an understanding of local preferences, the planner must realize that such action usually requires additional time and staff resources of the planning agency. However, the move will result in a better informed and more expert public which can more effectively participate in planning and which will continue to be a part of the planning process. Indeed, once explicitly brought into the process the public will probably long remain a critical part of the process. The planner should anticipate this reaction, as he should the multiple reactions to any decision he helps shape. *

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* Obviously, an optimistic approach could be taken and the resulting Figure would be somewhat different. Several categories of risk-taking strategies have been identified in the literature, for example; Riggs, J. L. Economic Decision Models, Chapter 10, McGraw-Hill, 1968.

FIGURE III-4

DECISION MATRIX

Combin-ation	Sensitivity to Uncertainty	Cost to Reduce Uncertainty	Initial or Existent Uncertainty	Reducible Uncertainty	If initial position is pessimistic toward outcome of an uncertain situation, then: Indicated Action is
1	High	High	High	High	Proceed or buy information based on analysis value of incremental information costs.
2	High	High	High	Low	Reexamine risk-taking position.
3	High	High	Low	High	Buy information.
4	High	High	Low	Low	Buy information.
5	High	Low	High	High	Buy information.
6	High	Low	High	Low	Buy information.
7	High	Low	Low	High	Buy information.
8	High	Low	Low	Low	Re-examine risk-taking position
9	Low	High	High	High	Proceed or buy information based on analysis value of incremental information costs.
10	Low	High	High	Low	Re-examine risk-taking position
11	Low	High	Low	High	Proceed or buy information based on analysis value of incremental information costs.
12	Low	High	Low	Low	Re-examine risk-taking position
13	Low	Low	High	High	Buy information.
14	Low	Low	High	Low	Re-examine risk-taking position
15	Low	Low	Low	High	Proceed or buy information based on analysis value of incremental information costs.
16	Low	Low	Low	Low	Re-examine risk-taking position

Secondly, the planner must try to determine if the course of action will improve his ability to make a decision. For example, the involvement of the public is likely to bring more pressure to bear for a particular decision, with the pressure being exerted on both the planner and the elected decision-makers. In contrast the acquisition of additional geological information, while likely to reduce uncertainty, will not directly influence the pressures for decision making.

IV APPLICATION OF METHODOLOGY

The example of a particular situation consisting of a stream which flows through a developing area has been previously developed. Subject to flooding every few years, the stream caused estimated damages of $500,000 for the last flood. The flood damage is continually increasing, with estimated damage placed at less than $100,000 a decade earlier. The valley has been subjected to periodic flooding because a large part of the upstream portion consists of steeply sloping terrain which promotes rapid runoff of rainfall. In addition, the urbanization of the area is increasing the rate of runoff. (For this illustration, water supply, navigation and other water uses are not considered).

In considering this example, one could consider courses of action for dealing with uncertainties as they are encountered in six different stages of planning, e.g.

- Definition of goals and objectives
- Development of projections or forecasts of the future
- Definition of needs
- Identification of possible devices to satisfy these needs
- Formulation of alternative courses of action
- Evaluation of alternative courses of action.

The remainder of this chapter discusses the application of the proposed framework in the six different planning stages, these being broadly divided between those immediately encountered (stages 1, 2 and 3) and those others (stages 4, 5 and 6) encountered in the action-taking stages of the entire process.

A. IDENTIFICATION OF INITIAL OR EXISTENT UNCERTAINTIES

1 Definition of Goals and Objectives

In the given example, the overall objective is to mitigate the flood damage to the extent possible consistent with national and regional efficiency, and minimal adverse social and environmental impact.

The decision techniques and criteria for the objective of increasing national efficiency are well developed. The ratio of the possible benefits to the possible costs must be greater than 1.0. This criterion does not exclude alternatives with a BCR of less than 1.0, but does require that they be justifiable on grounds other than national efficiency. These other criteria are based on social and environmental concerns, an area in which there are no clearcut measures and criteria.

In this example, the measure of environmental and social impact and the decision criteria for these two objectives are uncertain, and will have an impact on any recommended plan. Therefore, these goals must be clarified and maintained to some extent by the planner since there is no good quantitative measure available.

(2) Development of Projections and Forecasts

Although we are dealing with existent uncertainty, the next task is the determination of existent conditions and the development of projections of future needs.

Among the many sets of data to be generated is the extent and frequency of flooding. There are a significant number of areas where, because of limited available data, it is impossible to develop flood frequency-duration-intensity data for the area of interest. One solution possible is the use of data from a similar watershed to estimate conditions in the watershed of interest.* For this illustration, assume that data are directly available. This simplifying assumption, of course, does not imply that the uncertainty associated with the estimate of the magnitude of the 10-year, 50-year or 100-year flood is insignificant. There may still be considerable uncertainty in these estimates.

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* There are inaccuracies in the use of this technique; however, there is considerable study being done in the area as evidenced by the recent "International Symposium on Uncertainties in Hydrologic and Water Resource Systems," held in December of 1972. This problem is primarily one of statistical accuracy, and not uncertainty as defined in this study, and therefore, will not be further considered here. (1)

(3) Definition of Needs

The next task is the definition of water resource needs. In this example, a significant measure of these needs is the difference between the economic and social impact of flooding conditions, both with and without flood protection.

The quantification of the present economic impact of flooding is fairly straightforward and presents no major sources of uncertainty. However, the determination of the future economic impact of flooding is highly uncertain. This is due to a number of reasons including local anomalies in pricing, inflation, uncertainty as to future damageable assets, and uncertainty as to future values.

Present Corps techniques address the first two problems identified above. However, there are no specified techniques for dealing with the two remaining sources of economic uncertainty listed above. It can be said that future values and damageable assets are likely to rise rather than fall, but the extent of such a rise is uncertain as is the rate of growth. In evaluating alternative courses of action, it is necessary to determine the impact of rising values on all the different alternatives.

An early step in the planning process is the determination of the damage-frequency relationship. This is a two-step process consisting of first, identifying frequency of flooding, and second, evaluating the economic and social impact of flooding. Once these two steps are completed, only then is it possible to combine the data to define damage-frequency relationships. At this point, it is also possible to identify several existent uncertainties which are described below.

One major uncertainty is the timing of specific floods. If the worst floods are assumed to occur early in a project life, the impact on project economics will be significantly different than if the worst floods are assumed to occur late in the project life.

Three cases could be examined to determine the project sensitivity to the timing of flooding. These are:

- Worst and least floods evenly distributed over time
- Worst floods early in the project life
- Worst floods late in the project life.

Such examination might reveal alternatives which are viable in all flood timing, others which are not viable under any assumed flood timing, and those which are only viable under limited flood timing assumptions. Elimination of those alternatives never viable would reduce the number retained for continuing consideration. Identification of those alternatives always viable would reduce the number of alternatives requiring an in-depth analysis of the effect of the timing of the different flood levels on economic viability.

In developing cost data, other uncertainties are to be considered. One is the cost changes which occur between the completion of a study and the actual start of construction. The existent procedure for handling this problem is updating via the post-authorization studies. However, the process for evaluating the social present and future impact of a course of action is presently undefined. It is obvious that policy and direction will have to be generated for the evaluation of social impact. It is also important to recognize that such techniques may become available during the planning study, and that proposed plans may be evaluated with techniques, and to standards non-existent today. The potential for new and different review criteria is another significant source of uncertainty.

A second problem is the impact of future technology on project economics. While a planner can and should identify and point out situations where changing technology would have significant impact, specific policy and methodology for dealing with uncertainty about technology rests with OCE, since OCE has the basic responsibility for promulgating operational policy based on legislative and executive direction.

4. Identification of Flood Control Devices

In this illustrative case, there are seven basic flood control actions possible, as listed below:

- Do nothing
- Build an upstream reservoir
- Build a levee
- Make channel improvement
- Divert flows
- Institute flood plain zoning
- Flood-proof

Additionally, it is necessary to consider possible combinations of all of the above devices and different levels of implementation of all of the above. Figure IV-1 is a listing of the options considered under each device.

In Figure IV-1, for the upstream reservoir, three options are available: No resevoir, a resevoir of 75% of the full size possible, and full size. Each of these is a separate and mutually exclusive option. Similarly for the levee, there are four possibilities: no levee, 50%, 75% and 100% of full size. For three devices, channel improvements, diversion, and flood-proofing, the choice is a binary one with the only option being whether or not to use that particular device. Finally, for flood plain zoning, there are three options available: no zoning; zone to the level of the 50-year flood; or zone to the level of the 100-year flood.

FIGURE IV-1

DEVICE OPTIONS **

DEVICES	OPTION			
	1 *	2	3	4
Upstream Reservoir	None	75%	Full Size	-
Levee	None	50%	75%	Full Size
Channel Improvement	None	Full	-	-
Diversion	None	Full	-	-
Zoning	None	50 Yr.	100 Yr.	-
Flood Proofing	None	Full	-	-

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* The device of "do nothing" is a combination of Option 1 of all listed devices.

** The number of options per device has been held low in this illustration, and the options have been described in a general procedure, percent of full capability or size, as opposed to specific sizes or heights. This was done to simplify the example and to avoid the distraction of detailed numbers, and are only meant to be illustrative.

To determine the total number of alternative courses of action possible, it is necessary to consider all combinations of these options. An alternative course of action is defined as any feasible combination of devices which can be utilized to achieve the planner's objectives. The number of such combinations is the product of the numbers of options available for each device. The number of possible combinations for this simple example is given below:

(No. of Reservoir Options)		(No. of Levee Options)		(No. of Channel Improvement Options)		(No. of Diversion Options)		(No. of Zoning Options)		(No. of Flood-Proofing Options)		
(3)	x	(4)	x	(2)	x	(2)	x	(3)	x	(2)	=	288

Thus, even a relatively simple case has a high number of combinations which should be considered as potential alternative plans.

The process of determining the feasibility of all these combinations is relatively simple since a number of combinations contain conflicting options, e.g. full size resevoir, and 100 year zoning are redundant, e.g. 50% levee and 100% levee. In this fashion, it is possible to systematically arrive at a limited number of potential plans as candidates for recommendation.

The point is that this procedure may enable the planner to identify alternatives consisting of combinations of options which are not immediately obvious.

6. Evaluation of Alternative Courses of Action

Once our planner has developed a set of feasible alternatives or plans, then he must estimate the outcome of each plan and the utility of each outcome. The problems of evaluation were discussed previously and are, in a sense, unique to the particular situation. This task requires the involvement of the public, and there is presently underway Corps programs in the area of public participation. However, the planner must determine the level of his uncertainty about both the outcome and the utilities of the outcomes.

In order to proceed with our illustrative case, assume that only two combinations of the above options are to be considered:

- Upstream reservoir with channel improvement
- Zoning (100-year) and flood-proofing.

B. REDUCIBLE UNCERTAINTY

In this case, the next step is to determine the so-called reducible uncertainty where reducible uncertainties are defined as those uncertainties which the planner can reduce or eliminate by obtaining additional information.

In this example, the two sources of uncertainty to be considered are the timing of the occurrence of the worst and least flood conditions, and the local government's attitude and ability to finance a zoning and flood-proofing program. (While it is possible to address other uncertainties, such as the uncertainty as to the range of options available, the two uncertainties selected above are representative of problems currently encountered).

In the case of the dam, the economics are assumed to be marginal on the evenly distributed assumption for the occurrence of flooding, acceptable for the case of worst flooding early in the project life, and clearly acceptable for the case of worst flooding late in the project life. In the case of zoning and flood-proofing, the major question is the willingness of local government to support and finance such a plan.

Again, in the case of the dam, it is not possible to reduce the uncertainty in that the planner has no available technique whereby he can predict when worst flooding will occur. This is a critical point in that the planner has determined that if his recommended course of action includes the reservoir, considerable uncertainty will remain as to the economic viability of the project. This fact must be documented and the information conveyed to the public decision-makers along with the reasons for the selection of a dam.

However, in the second case,(zoning and flood-proofing), the planner can take actions to reduce the uncertainty of the attitude of local government by undertaking an active program to enlist local government support and obtain financial and legal commitments. Whether the planner fails or succeeds in obtaining these commitments, he has succeeded in reducing the uncertainty as to the attitude and ability to pay of the local government.

C. COST OF UNCERTAINTY

In the case of the dam, there is the possible cost of an uneconomical project where total costs exceed benefits of the cost of operating with present information. The uncertainty is caused by the timing of specific flood conditions and is not amenable to reduction. There are no techniques which will allow a reduction of this uncertainty, and, at most, the planner can examine the project under different flood occurrence assumptions.

On the other hand, the planner must consider two cost components to the uncertainty of the flood zoning and proofing alternative. The first of these is the cost of existing uncertainty which consists primarily of planning costs incurred in the development of a plan which might not be acceptable to local decision-makers. The second cost, the cost of reducing uncertainty, is the cost of the program to enlist local government support.

D. SENSITIVITY TO UNCERTAINTY

As pointed out above, if either the dam and channel or the flood-proofing and zoning are recommended, either project's outcome is sensitive to initial uncertainties. The dam could be implemented with the uncertainties remaining, while the flood-proofing could not. One project might prove to have been a mistake, while the second might not ever get past the planning stage.

E. STRATEGY FOR ACTION

Using the procedures described in Chapter III, the significant parameters are shown in Figure IV-2.

FIGURE IV-2

FLOOD CONTROL EXAMPLE

DECISION MATRIX

OPTION	Alternative Plan	Sensitivity of Recommended Plan to Uncertainty	Cost of Uncertainty	Total Existent Uncertainty	Reducible Uncertainty
1	Reservoir & Channel	High	Low	High	Low
2	Zoning and Flood-Proofing	High	Low	High	High

According to the strategies shown in Figure III-4, Alternative 1, the reservoir and channel would require that the planner obtain additional information. This minimizes the risk of building an uneconomical project.

For Alternative 2, the indicated course of action is to obtain information, at the risk of increased damage while planning continues, and an increased cost for Alternative 1 at a later date, should Alternative 2 not be feasible.

If the decision is made to proceed with the reservoir, then there is no recourse. However, if the decision is made to obtain more information, both options are still available though the economics may be substantially altered. In this situation, the planner might well be inclined to test the feasibility of obtaining a commitment for zoning and flood-proofing before recommending a reservoir. In any event, the planner must document the nature of these uncertainties, their possible impact, the options available to reduce the impact of uncertainty and the costs in so doing, and submit this information to the decision-maker for review and action.

In sum, then, the lengthy example in the preceding pages to meet a flood-planning challenge was developed to illustrate how our methodology could be applied. Specific techniques for each component of the process have not been developed and in that sense, the process is incomplete. However, the illustration does represent a compact, systematic and practical framework for dealing with uncertainties; one that Corps planners can creatively and dynamically build on.

V. SUMMARY

This report has sought to provide a short description of the impact of uncertainty on water resource planning, and has offered one process for minimizing the impact of such uncertainties. We recognize that planners today live with uncertainty under many different names and in almost every decision which they face. We also recognize that there are as many techniques for dealing with uncertainty as there are planners.

What we have attempted in this brief report is to develop a working concept of uncertainty, to provide some frameworks for categorizing different uncertainties as to their origin and the specific lack of information which results. There are other categorizations possible, but we have limited ourselves to a few that are especially promising in order to develop a simple introductory model or process for dealing with uncertainty. This report proposes such a method for dealing with uncertainty, and identifies four parameters which must be explicitly considered in any decision as to how uncertainty should be dealt with. We have then applied this process to a particular case study.

In summarv, this report is intended to provide a single dvnamic and flexible framework for working with, and describing uncertainty. What is needed now are creative attempts to apply the methodology to actual water resource planning. Such application will help generate the data and experience necessary to develop the techniques, or the "muscle and bone", necessary to transform our framework into a particularly effective, efficient and operational tool.

Once satisfying the immediate forcing function, i.e, to develop the concept of uncertainty related to specific application scenarios such as corps planning functions, inevitably several desirable extensions of this study become apparent. The following presents three such concepts that are natural iterations of this work.

The first may be entitled Value Systems and Utility in Water Resources. The essence of this work would be to understand the interactions between the social, institutional, technological, and environmental perspectives. As has been shown in this work there are weighting factors unevenly emphasizing one influence more than another but not necessarily in a consistent manner. In decision making, improper evaluation of the positive and negative forces may result in an improperly derived decision and unduely long litigation, with commensurate time and cost penalties. Therefore, a further dissection of the above four arenas can assist the planner in formulating and executing his function with the most responsive to the sensitivities of the problem.

A second aspect of considering the impacts of uncertainty are readily recognized in practicing the "art" of Technological Forecasting, in this case as related, of course, to water resources. It was aerospace projects that uncertainty applications was first appraised for its influence on a final product (or decision). In the cases where clear state-of-the-art advances were desired or required in terms of the system mission, assessment of uncertainties both hardware and analytical planning, was mandatory to accomplish a successful mission. Examples of this would be navigational corrections for atmospheric, windage, various angular relationships associated with vehicle re-entry attitude as well as the more obvious allocation of manufacturing tolerances to within controllable limits to assure a lack of residual stresses and proper fit. This same methodology is equally applicable to water resources planning and technologies. Simple examples of this would be determination of assimilative characteristics of a waterbody subject to various outfalls from manufacturing plants, sewage treatment plants, and run-off. Some of these wastewaters may be mutually compatible and cancel their pollution effects while other effects may be aggravated and increase their impact on the natural ecological balance of the waterbody. Rechannelling is another example where uncertainties must be appraised. Having the knowledge of possible scenarios and conditions likely to occur is already a normal part of the planning process. However, the confidence levels of these judgments is subject to some controversy. A clear example of this might be nuclear power plant outfalls. The prediction of the thermal plume under varying tidal influences, both natural and those associated with major storm conditions, are complex in nature and couple to other bi-product influences such as scouring velocity affecting the equilibrium of the benthal layers in a naturally flowing waterbody. It is in these problems that a check list for a generalized procedure designed specifically for certain scenarios would be very helpful to the planner in, at least, recognizing his areas of uncertainly and defining those reducible and unreducible parameters that must be dealt with to make an intelligent decision based on purposeful evaluations.

There must be a broad number of strategies available for the planner to examine in reconciling his choices. Here again, it would seem that an ability to choose most appropriate strategies specifically applicable to commonly occurring Corps projects could avoid "intuitive" selection of a strategy or maybe, even more importantly, provide the planner with a few choices for attacking the specific problem, each having different emphasis, depending on which sector may be most affected by the project's implementation. In this era of public pressure and environmental impact, the planner must arm himself with the tools capable of reconciling these pressures in a positive manner with the least negative repercussions or lingering doubts.

These work extensions, promulgated from this study, cannot bypass the very basic requirement of the planner which is to think, deduce, and propose responsive solutions to his assigned problem. Realistically, however, the planner's perspective on what constitutes his problem, and what value is given to the recognized obstacles between the problem and its solution, is amenable to certain basic ground rules and guidelines satisfiable by additional work extending this concept of dealing with uncertainty, its formulation, and applicability to Corps water resources projects.

GLOSSARY

Absolute Uncertainty - those uncertainties which cannot be eliminated or reduced, e.g., specific years during which specific levels of flooding would occur.

Information - knowledge of the state of the world or the system under study. The opposite of uncertainty.

Operational Uncertainty - Uncertainties resulting from the changing nature of the system under study.

Reducible Uncertainties - those uncertainties which can be eliminated or reduced through various mechanisms, e.g. geotechnical.

Residual Uncertainty - that uncertainty which the planner cannot or does not reduce.

Risk - knowledge of all possible outcomes, with sufficient data to estimate the probability of occurrence of each outcome.

Strategic Uncertainty - uncertainties resulting from a lack of complete knowledge of the existent or future state of the world.

Uncertainty - lack of knowledge of the full range of occurrences possible, or a measurement of risk associated with change based on this lack of knowledge.

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This document is the product of a study to develop a methodology which Army Corps of Engineers' planners could utilize to explicitly consider uncertainties, i.e., uncontrollable and unanticipated eventualities, that can adversely affect water resource planning. The study attempts to broaden the planning process by considering the changing nature of the environment for water resource planning, and to provide a better way to recognize "uncertainties" and

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) anticipate their impacts prior to a decision to implement any specific actions. The ultimate purpose is to provide an anticipatory procedure that will assist the planner to avoid, where possible, the adverse consequences of unanticipated events.

In summary, the management of uncertainty in Water Resource Planning introduces a major choice involving risk taking:

- Delay action and pay more (in time and resources) to further reduce uncertainty/risk, or
- Take action now, and accept the presence of uncertainty/risk

This report describes the methodology for:

a) Making this choice, recognizing the vital importance of the manager's perception of, and willingness to take risk

b) Procedures for structuring uncertainty, having made the choice.

In essence, the methodology provides a quantitative basis for trading off resources (time and cost) to gain information versus the acceptance of uncertainty/risk.