A Methodology for Flood Plain Development and Management

INSTITUTE FOR WATER RESOURCES

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A Report Submitted to the

U. S. Army Engineer Institute for Water Resources
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by

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INSTITUTE FOR WATER RESOURCES

In 1969, the Subcommittees on Public Works, House and Senate Appropriations Committees, authorized formation of the Institute for Water Resources to assist in formulating Corps of Engineers water resources development planning and programming. Improved planning and evaluation concepts and methods are needed if development and utilization of these resources are to meet the public objectives of economic efficiency, protection and enhancement of the environment, regional development, income distribution, and general well - being of people. The Institute and its two Centers--the Center for Advanced Planning and the Center for Economic Studies--carry out both in-house and by contract, research studies to resolve conceptual and methodological problems involved in the development of our Nation's water and related land resources.

The Institute welcomes views and comments on its program and publications.

R. H. GROVES
Brigadier General, USA
Director

NOTE TO THE READER

This report is a product of research conducted by the TRW Systems Incorporated under contract to the Corps of Engineers.

The report presents a methodology by which the consequences (mainly economic in nature) of choosing various flood plain management alternatives may be evaluated so as to achieve a stated set of objectives. The methodology is commonly known as a trade-off analysis. It is illustrated by two case studies, one for the Reno, Nevada area, and the other in the Tuscon, Arizona area. The scale and depth of these case studies was not sufficient for making decisions among actual alternative plans and, although "optimal" plans emerge in each case from the application of the methodology, these "optimal" plans are illustrations which relate only in a general way to actual situations in the areas studied and are thus not the proper basis for specific regional decisions.

Since this study presents research results independently arrived at by the researchers, it does not necessarily reflect the official position of the Corps of Engineers. Any comment you may have on this report or on the research topic itself is most welcome.

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INTRODUCTION

STATEMENT OF THE PROBLEM

There is growing recognition of the need to broaden the scope of flood plain planning and place it in the context of total community development. The introduction of flood protection often has a significant impact on the course of community development; conversely, developments within the community affect the outcome of flood management programs. This interaction between the development of the flood plain and developments in the surrounding region requires that Corps planners take into account factors outside the flood plain.

The case for expanding the scope of Corps planning is further strengthened because important alternatives to structural flood control sometimes involve programs outside the flood plain not directly related to flooding. In fact, in many cases the major alternatives to a particular program for structural flood protection will involve the development of areas outside the flood plain and programs which are not related to flood protection. Consider the following example.

- A flood plain exists adjacent to an urban area and the demand for industrial sites is rising. Land in the flood plain can be made suitable for industrial development by constructing a series of dams and storage reservoirs to reduce the hazards from flooding. At the same time there exist other undeveloped sites beyond the flood plain. To make the sites beyond the flood plain suitable for development would require the construction of a new highway and the introduction of utilities. In the case outlined above, a program of highway construction is an alternative to flood protection and should be considered in the planning process.

The optimal plan in this case might be to construct the highway and utilities and use zoning to prevent encroachment onto the flood plain. While these programs would not be under the jurisdiction of the Corps, they must be considered for two reasons. First, the development of the other area is an alternative to structural flood control. Second, if this area is developed independently, it may result in a reduction in the benefits creditable to flood control. The latter situation might arise in this example if, on the basis of the present supply of industrial sites, it is estimated that, given flood protection, the flood plain will be fully utilized for industrial development. However, if alternative sites are developed independently, and the flood plain is not, a significant part of the development which was predicted for the flood plain may not materialize.

In addition to broadening the scope of the planning for the development of the flood plain to include a wider range of alternatives, there is a need for a planning methodology to explicitly incorporate objectives other than maximizing the present value of net benefits. Many times there are objectives which cannot conveniently be incorporated into the conventional benefit-cost framework, but which are obviously important and are given weight in the choice among alternative programs; they should, therefore, be considered in the decision process.

These other objectives can be put into two categories. First are objectives which could be incorporated into the benefit-cost framework if only the benefits and costs associated with them could be properly measured. The reduction of risk or the enhancement of environmental quality are important examples of this type of objective. Second are objectives which may not lend themselves to measurement in terms of willingness to pay and may, in fact, represent goals which conflict with the maximization of the present value of discounted net benefits. Such objectives might be an increase in the level of regional employment, the development of a stable industrial base for the community, etc.

Related to more comprehensive planning for the flood plain are the needs both for expanded local participation in planning and for development of local-state-federal relationships required for effective planning, and implementation. Consideration of state and local objectives and the involvement of state and local officials are essential because many programs require approval, partial funding, and implementation by state and local governmental units. Without the consideration of local objectives and cooperation among governmental units, worthwhile programs will either fail to elicit approval or fail to be implemented.

The need for local involvement becomes more acute when the scope of flood plain management is broadened because many alternatives are within local jurisdictions. At the same time by expanding the range of alternative programs and by developing a methodology in which local objectives can be considered explicitly, the opportunity for reaching agreement at all levels of government and for securing effective implementation is increased. Therefore, increased local participation is a necessary component of comprehensive flood plain management which itself contributes to the development of plans to simultaneously satisfy federal, state, and local objectives.

To summarize, there is a need to develop a methodology which broadens the scope of planning for the development of the flood plain which can also incorporate multiple objectives and make explicit tradeoffs among these objectives that are relevant to the final choice. Such a model should be able to incorporate within the same framework the objective of maximizing the present value of net benefits as well as other objectives. By broadening the scope of flood plain management, the planning and implementation of programs would require greater local participation and federal-state-local cooperation. At the same time, the opportunities to obtain agreement among governmental units would be increased. It is in recognition of the need for a more comprehensive methodology that the Corps of Engineers has contracted for this study.

SYNOPSIS OF PRESENT PRACTICE

Traditionally, when the Corps of Engineers has undertaken a study of a flood plain, the alternatives considered are structural alternatives. Here the terms structural alternative and structural measure are used as in Corps Circular EC 1120-2-40, where a structural measure is defined to be one which lowers flood heights or provides barriers against flood waters. All other measures to reduce flood damages and damage potentials, including the flood proofing of buildings and other structures, are included in the category of non-structural measures. Recently, as evidenced by Circular EC 1120-2-40, the Corps has begun to broaden the scope of its studies to consider some non-structural measures. The traditional approach of limiting consideration to structural, as opposed to other measures for coping with floods is understandable since jurisdiction of the Corps is limited to the implementation of these measures. To broaden the context of planning would require greater coordination with other government agencies and the private sector and would create a more difficult problem of coordination and cooperation with local interests. However, in spite of the problems involved, the evidence of the need for increased cooperation and coordination with local interests is growing since there are many cases where local groups oppose Corps recommendations. These include both groups which seek projects that are unjustifiable on the basis of benefit-cost estimates, and groups which oppose projects recommended by the Corps.

In addition, it appears that the increased cost and complexity of broadening the scope of planning may be more than justified by the achievement of more efficient programs of flood plain management.

The objectives pursued by the Corps in the design and evaluation of projects are not entirely clear because they are not explicitly stated in operational terms. Some objectives are explicitly stated in planning studies, but others appear to be implicit. While it is not the purpose of this report to establish a definitive list of objectives, at least two appear to be common to most plans. First, there is the objective of maximizing the present value of net benefits; and second, there is the objective of preventing disasters associated with very large floods. Therefore, multiple objectives are currently being pursued, and planning requires a methodology to incorporate these objectives and make tradeoffs between them.

SCOPE OF THE STUDY

The objective of this study is to develop an approach to flood plain development which explicitly incorporates alternatives in addition to structural flood protection, and which creates a framework within which rational decisions can be made in the face of multiple objectives. There are two types of flood management alternatives to be added for consideration. First to be considered are the non-structural measures to cope with the problem of flood losses within the flood plain. The most discussed of these measures are flood proofing, flood plain regulations, flood insurance, and flood warning and evacuation systems. The Corps of Engineers, as evidenced by Circular EC 1120-2-40, is moving in the direction of incorporating some of these alternatives into the planning and reporting procedure. Therefore, the work developed in this study is not a radical departure from present Corps thinking, but simply expands procedures to allow for new alternatives.

In addition to non-structural measures directly related to flooding, other alternatives will be considered which involve development outside the flood plain. These alternatives are not easily specified and a procedure is needed by which the planner can identify such alternatives and formulate plans to implement them. This report addresses the problem of generating such alternatives, but limits itself to programs which are essentially substitutes for flood control. As an example, alternative measures to provide land for industrial development or open space could be considered in the case of a project which would produce benefits in these particular forms. However, the question as to whether flood protection should be developed as opposed to increasing expenditure on general education would not be considered. A second example will sharpen this distinction. Suppose a flood control measure provides recreational opportunities by creating a lake which can be used for swimming. In this case it would be appropriate to consider the construction of parks and swimming pools, either alone or in combination with other measures. However, if providing flood control did not affect recreation, then the construction of parks and swimming pools would not be considered among the alternative plans.

This restriction is somewhat arbitrary since it can be legitimately argued that an even wider range of programs constitute alternatives to flood control in that these programs are all competing for the same scarce resources. However, to consider all programs as alternatives, including programs in the private sector, would require that the Corps take responsibility for planning the complete allocation of the nation's resources. The boundary which has been drawn in this study is designed to enlarge the set of alternatives for consideration to include the most important alternatives for the planning of flood plain management, but to limit the scope of the planning task to manageable proportions.

The methodology which will be developed will also contain a procedure to systematically consider alternative programs when there are multiple objectives. Since it is impossible to specify here the particular set of objectives which may be relevant for a given planning study, and since these objectives are likely to change with time, the methodology developed is completely general in that it can be stated without specific reference to the objectives to be considered. As a result, this model can be used for a wide range of studies involving different sets of objectives. In addition, the methodology which is developed can be seen as an extension of benefit-cost analysis and therefore extends the analytical framework within which the Corps evaluates projects at the present time.

While the methodology is completely general and not tied to a particular set of objectives, one motive for development of this methodology is the consideration of local objectives. The procedures to establish local objectives is being investigated in a companion study at the University of Chicago, directed by John R. Sheaffer. This study employs a variation of the "reputational method" to establish the local decision-making structure with regard to a particular issue such as flood plain management. This approach employs questionnaires given to a select group of community leaders. In addition to developing the methodology framework to identify local objectives, the Chicago study is employing it in a series of case studies in Lincoln, Nebraska; Waterloo, Iowa; Atlanta, Georgia; and other cities. This study should generate the procedures to be used in establishing local objectives, and therefore, the point of departure for this study is a set of established objectives which may include state and local, as well as federal objectives. Given multiple objectives, this study addresses the problem of how plans can be developed and evaluated.

The evaluation of plans to fulfill a number of objectives requires that tradeoffs be made among objectives. In this report, a procedure is developed to perform these tradeoffs with dollar values as the unit of measure. In this way the opportunity cost of achieving a particular objective can be stated in terms of a monetary unit which is easily understood. In addition the concept of willingness-to-pay values is introduced. This concept is a generalization of the standard concept of net benefits and can be used to evaluate plans with many objectives.

LIMITS OF THE STUDY

This study looks at the problem of planning for the flood plain from the point of view of the Corps of Engineers. The goal is to develop a methodology which will produce the best integrated plan for the flood plain. While this plan will be chosen in accordance with the values and objectives of the Corps, local and regional objectives may be accounted for to the extent that the Corps of Engineers considers them to be relevant from a national perspective. The plan which is chosen may include non-structural as well as structural measures and may include measures which involve development outside the flood plain. In many cases the best plan may contain components which are outside Corps' jurisdiction and which require local action.

This study does not consider the many problems surrounding the implementation of the best plan. As was stressed earlier, federal-state-local cooperation is essential to comprehensive flood plain management, and a detailed analysis of the relationships among various levels of government would contribute to our understanding of how the necessary cooperation can be obtained. However, this particular problem is not central to this study. Plans are developed without regard to the many difficulties which might arise requiring the cooperation of other grovernment units, firms and households in the private sector to implement the plan. While these problems are not central to this particular study, the methodology which is developed is flexible enough so that these considerations may be incorporated into the analysis in the form of constraints or restrictions on the set of feasible alternatives. This will give the planner a methodology which allows him to consider the best plan under varying assumptions about the possibilities for local action, local financing, and cooperation between intergovernmental units.

GENERAL OUTLINE OF THE REPORT

This report has been prepared in a fashion which, it is hoped, will maximize the comprehensibility of the concepts presented. The portion of the report subsequent to this introduction consists of the following major parts: Presentation of the methodology, several appendices, and two demonstration cases.

The presentation of the methodology is a thorough explanation of the various concepts contained in this study. In essence, this part represents the theoretical foundation for more specific procedures which may be generated in the future to implement the methodology. To illustrate how the methodology would apply, numerous examples are provided throughout the presentation portion of the report. The procedures developed in the presentation are applied to the various examples in order to clarify how they would be used in actual practice. The example presented in this part of the report may be viewed as a model for the analysis which will be applied in later demonstration cases. The purpose of the case studies is to demonstrate and test the methodology.

In the course of the report, it will be necessary to define terms in the body of the report, and a summary of the important definitions will be incorporated in the Glossary of Terms, Appendix B. The definitions which are given will whenever possible be consistent, at least in spirit, with the terminology used by the Corps of Engineers. However, at some point there may be questions as to the appropriateness of certain definitions. It is hoped that these questions will not be allowed to obscure the analysis which the descriptions are designed to facilitate.

PRESENTATION OF THE METHODOLOGY

The first section of this part of the report discusses the development and statement of various objectives. The term "objective" is defined and different types of objectives are enumerated and related to the standard objective of maximizing net benefits. The importance of specifying the objectives completely and explicitly is discussed within the context of the planning process. In addition, the general problem of developing appropriate measures for the achievement of various objectives is discussed in some detail.

The second section of this presentation discusses the generation of alternative plans. A procedure is developed by which alternatives can be generated and considered. This procedure begins with established practice and expands the set of alternative plans by steps. The second step in the planning procedure adds flood plain regulation, flood insurance, flood proofing, and flood warning and evacuation systems to the set of measures to be considered. This section includes a rather detailed discussion of how these nonstructural measures might be used to improve the existing plans for structural flood control. The third step introduces into the planning process the possibility of developments outside the flood plain which are substitutes for flood control. Plans are discussed which involve projects not directly related to flooding, but which, in many cases, appear to be promising alternatives to flood control.

The third section of the presentation addresses the problem of how to evaluate plans which perform differently with regard to a number of objectives. Three approaches are presented: the critical value approach, the decision analysis approach, and an approach which employs direct tradeoffs. The first two approaches make use of willingness-to-pay values and are designed to bring all relevant information concerning willingness to pay to bear in making the final selection. These approaches are exceedingly useful in cases where the benefits from some activities are difficult to measure. The three approaches are complementary in that features of more than one approach may be employed in selecting the optimal plan.

The final section of this part of the report involves a discussion of the problem of value judgments in the final choice. It makes it clear that value judgments usually cannot be avoided in making the final choice. At the same time it demonstrates that if the planning agency wishes to state its values in advance in terms of the rate at which it is willing to trade one objective for another, then the final choice as to the best plan can be fully incorporated into the planning model and the methodology can be carried through to yield the best plan.

At this point, the essence of the planning procedure developed in this study will become clear, as will the limits to which a rational planning procedure can go in establishing the best plan. In the final stages of choice, values simply must be introduced, and it will be shown that the standard benefit-cost procedure involves no fewer value judgments than the procedure developed here for handling multiple objectives. The only advantage of the standard benefit-cost procedure is that there appears to be greater acceptance among certain influential parties as to its validity and worth.

THE STATEMENT OF OBJECTIVES

In any planning effort which includes the development of alternative programs and a criterion for choosing among these alternatives, the first step is the specification of a set of objectives. Objectives must be specified early in the planning process so that the planners who are responsible for generating alternative plans know what the plans are to achieve. In addition, objectives must be clearly stated to provide a basis on which to evaluate the alternatives which are considered.

For the purpose of precision, an objective is defined as the desired final result or outcome. Objectives may differ among individuals and among various givernment units; however, for purposes of this study, it is assumed that the objectives under consideration will be chosen by the Corps of Engineers. The methodology will be sufficiently flexible to handle any set of objectives which may be chosen. This avoids the pitfall of creating and discussing long lists of possible objectives which may or may not be relevant to the future plans.

It is important that all objectives be stated clearly so that the effect of each alternative plan with regard to the objectives can be measured and evaluated. Failure to state all of the objectives explicitly in the planning process may result either in the development of a plan which does not take into account some important consideration or in the implicit consideration of an objective by placing a constraint on the alternatives for consideration. The latter may preclude the most effective plan from consideration. Suppose, for example, that the stated goal of flood plain management is the maximization of the value of net benefits and that the objective of preventing disasters from flooding is ignored. In this case the optimal plan might be to construct flood control measures designed to protect against smaller, more frequent floods, but to leave the flood plain unprotected against very large floods. This, however, might be unacceptable since it would not provide for protection against flood disasters. On the other hand, suppose that while the maximization of net benefits is the only stated objective, consideration of protection against disaster is introduced implicitly by requiring at least a certain level of structural protection. In this case the objective of preventing flood disaster is incorporated by placing a constraint on the planning process rather than by explicitly expressing it as one of the objectives and evaluating each plan with regard to this, as well as other objectives.

This procedure has several drawbacks. First, it presupposes that a certain minimum level of structural protection is required to achieve the objective -- a supposition which may be questioned. Depending on how a flood disaster is defined, programs of flood plain regulation, flood warning and evacuation, and flood insurance may all be measures which provide protection against such a disaster; they should, therefore, be considered as alternatives in the planning process. Second, this procedure obscures the tradeoff between the achievement of the objective of preventing disaster and the achievement of other objectives. Essentially such a procedure implies that regardless of the opportunity cost, in terms of other foregone objectives, a certain level of disaster protection is justified. Finally, by incorporating the objective of disaster prevention as a constraint on the planning process, the need for a precise description of this objective is eliminated, and there is no incentive to evaluate how effective the high level of protection is in achieving this objective.

Beyond stating all objectives explicitly, it is important that a stated objective be the final outcome which is desired and not some intermediate outcome. This observation is particularly relevant when considering alternative plans to accomplish the same stated objectives. Several examples will make this clear.

First, suppose that the introduction of a storage reservoir would facilitate low flow augmentation and thereby improve water quality downstream. If the stated objective were the improvement of water quality, but the true objective were to improve recreation opportunities by opening the stream to swimming, this misstatement of the objective would complicate the search for alternatives. A program of swimming pool construction would provide an alternative to beaches, but not to a program to raise water quality.

As a second example, consider the case where the stated objective is to minimize damage in the flood plain, whereas the true objective is to develop the flood plain to maximize the net benefits produced by the flood management program. In terms of the stated objective a program of flood zoning which would eliminate all encroachment onto the flood plain would be optimal. However, this would involve economic losses because profitable uses of the flood plain would be excluded. The optimal program in terms of maximizing the value of net benefits would most certainly involve some development of the flood plain even in the presence of hazard from flooding. The point that needs emphasis is that damage reduction is one of the benefits generated by providing flood protection, but damage reduction may not be an objective in itself.

The objectives which are chosen for a particular study may appear to be very different in kind and may be related only insofar as they are desired results of a particular program. For example, increasing net benefits, regional employment, and the number of recreational sites may all be objectives of a given program, although they appear to be different in nature. It should be noted that the achievement of one objective may at the same time produce the achievement of some other objective. For example, a program which leads to the employment of unemployed labor may produce benefits of the traditional type to the extent of the net value of goods and services produced by this labor, excluding labor costs. The fact that the level of employment is included as an objective implies that it is itself considered to be of value apart from any contribution to measurable net benefits or other objectives.

At this point it is useful to consider objectives other than the maximization of the value of net benefits and to introduce some definitions. In addition, it is useful to categorize the types of objectives which might be included among the stated objectives and discuss why the essence of these objectives cannot be accommodated within the standard benefit-cost framework.

The theoretical foundation of benefit-cost analysis in welfare economics has been systematically developed in the professional literature, and the principles which govern its application are well known. For this reason only the most fundamental tenets of the benefit-cost approach are outlined here.

Project benefits are measured in terms of willingness to pay and costs are measured in terms of the amounts required to compensate individuals who forego the use of resources required by the project. In principle, all benefits and costs of a project should be included in the process of evaluation; in practice, it is often difficult or impossible to measure the dollar value of certain benefits and costs. Examples of such cases are all too numerous. The value of open spaces, the cost of pollution, the value of aesthetic considerations, etc., are all cases in point. As a result of these measurement problems, benefit-cost studies often omit these benefits and costs from consideration. At the same time, it is widely recognized that these benefits are important, sometimes critical, and must somehow be taken into account.

It is useful to distinguish between benefits which lend themselves to measurement in monetary terms and those which do not. These two categories will change with time as ingenious methods are developed for the measurement of benefits and costs which hitherto have defied measurement. Efforts in this direction should be strongly encouraged, and wherever it is possible these measures should be incorporated into project studies. This process will be slow, however, as benefits result from many different actions, and the measurement problem is often unique for each case. It is unlikely that we will even be able to develop reliable methods of measuring all benefits and costs. It is therefore useful, at any point in time, to distinguish between measurable and non-measurable benefits and costs, and to treat them differently in the evaluation process.

To remain consistent with this distinction, the value of "net benefits" will be used in this study to denote the value for only those benefits and costs which yield themselves to measurement. In addition the term "benefits" will be limited to those outcomes of a project for which there is an acceptable technique to measure willingness to pay. This distinction is in some ways analogous to past Corps practice which makes a distinction between "tangible" and "intangible" benefits (EM 1120-2-102, p. 6). Clearly, some intangible benefits represent consequences for which there is a willingness to pay, e.g., the reduction in intangible damages. However, these damages are exceedingly difficult to identify and measure. Under the scheme used in this report, only those consequences of a project for which the willingness to pay can be measured will be counted as benefits. Other consequences of a project will be accounted for by incorporating them as objectives, in addition to economic efficiency. It should be clear that benefits and objectives are not the same. For example, damage reduction is a benefit which is not in general an objective. It is included under the objective of maximizing the value of net benefits. Conversely, improvement of environmental quality may be an objective but will not be considered a benefit.

Thus far we have distinguished between benefits and costs which are measurable and those which are not. Another category of outcomes, which do not fit into the benefit-cost framework but which may be important, in most cases involves some kind of income redistribution if evaluated from a national point of view. Income redistribution as used in this study implies a transfer of resources from one group or geographic region to another. The income redistribution may be among regions, among different income groups, or among groups representing special interests. Objectives generally characterized as goals for regional and local development usually involve some transfer of income from outside the area under consideration into a particular region, such as Appalachia; or a particular community, such as a ghetto. It is interesting to note that most of the secondary effects of Corps projects fall into this category. If full employment is assumed, the general economic expansion in a specific locality resulting from a project, for the most part, represents a diversion of economic activity from other areas into that particular area, and represents only a small net increase in the value of final goods and services produced within the economy. This is why the current attempt to include so-called secondary benefits within the standard benefit-cost framework has proved to be such an elusive task, except in cases where there is significant unemployment. In strict benefit-cost terms these secondary benefits appear to be negligible from the national viewpoint; however, practical planners are convinced they are important. The truth is that regional effects may well be of importance, but these effects are often included incorrectly in the standard benefit-cost framework. The benefits associated with income redistribution from a national viewpoint are not in the amount of the redistribution, but rather in the effects of the redistribution as related to the achievement of some national objectives. Rather than attempt to incorporate these regional effects into the benefit-cost framework, a more promising approach appears to be to introduce these effects into the analysis by considering them as other objectives.

Other classes of objectives which are frequently discussed and which may involve an implicit redistribution of income are exemplified by the objective of minimum income maintenance, which involves a transfer of income from higher to lower income groups, and by the objective of maintaining wilderness areas, which often may involve a transfer of income from commercial interests to sportsmen and naturalists.

The objective of income redistribution is one which is often mentioned in connection with government programs; however, it is seldom explicitly considered in the process of evaluating projects. The general assumption is that a project will probably result in more equitable distribution of income. This supposition should be questioned, since recent studies suggest that the effect of many water projects is to redistribute income from lower to higher income groups. If income redistribution is to be considered, it should be considered explicitly and the effect of each alternative plan with regard to the distribution of income should be assessed.

If a local or special-group point of view is adopted, a program which appears simply as a redistribution of income, when evaluated from a national point of view, may appear to generate a high value of net benefits when only local or regional benefits and costs are considered. This situation often arises when a community can benefit from a program without paying the costs. Therefore, the differences between national and local objectives may be differences in perspective rather than differences in kind. This case is important where programs require local action or approval, as the achievement of local objectives will significantly affect local cooperation. Therefore, different cost-sharing arrangements may either be introduced as objectives or as constraints. The latter procedure should only be adopted after considering the problem without that constraint, because, if the gains from relaxing the constraint are sufficiently great, it can often be accomplished.

While it appears that objectives which are not amenable to incorporation into the standard benefit-cost framework either involve a problem of measurement or some form of income redistribution, it cannot be conclusively demonstrated that these cases cover all possibilities. This is, however, unimportant since all objectives other than economic efficiency, measured by the value of net benefits as previously defined, will be treated in an analogous manner. The methodology which is developed applies to any stated objective. The foregoing discussion simply helps clarify the question as to why a criterion cannot be developed which incorporates all objectives into the benefit-cost framework.

It is assumed in this study that economic efficiency will be one of the objectives. There are two reasons for this assumption. First of all, economic efficiency is one of the primary concerns of the Corps in evaluating projects, and this is likely to continue. Second, the inclusion of economic efficiency, measured in terms of net benefits, as an objective provides a monetary measure in terms of which the opportunity cost can be calculated for various levels of attainment of other objectives. Thus the cost of including a particular objective at a specified level can readily be obtained in terms of dollars. This provides a common measure which can be used to compare the cost of this objective with the cost of obtaining this same objective through some alternative program. Therefore in the case of multiple objectives, the method developed to consider alternative programs can be seen as an extension of the benefit-cost framework so that tradeoffs between two objectives can be stated in dollars, which is the standard measure used to value net benefits and calculating project costs.

The proposed methodology is completely general and not tied to any specific sets of objectives. This is important because Corps objectives may not only change over a period of time, but different objectives may be appropriate for different projects. The problem which faces the planner is to select the set of objectives encompassing the intuitive goals which underlie stated policy.

The task of establishing objectives is, at best, difficult and must be carried out at the highest levels in the decision hierarchy. The choice of objectives is closely identified with the establishment of policy and cannot be delegated to the field without resulting in a program riddled with inconsistency. At the same time, the development of a planning methodology which incorporates more than one objective is, in part, motivated by the desire to cope with objectives which may be specific to particular projects. State and local objectives will certainly vary from project to project as will federal objectives. Federal objectives for water projects in Appalachia will differ from those in areas with high levels of income and employment. Therefore, in establishing objectives, there is tension between the need for high level decisions and consistent policy, and the need for flexibility in planning occasioned by local differences. Clearly, the setting of objectives should not be delegated to the field; at the same time it would be impractical to obtain high level decisions on all the details of how specific objectives are to be defined for each individual project. Therefore, general objectives must be specified at high levels which will serve as guidelines to planners in the field. Within these guidelines, specific objectives stated in operational form will be prepared on the basis of information about a specific project.

It should again be stressed that the formulation of objectives is so important in determining the final outcome that a review procedure is recommended whereby, once the objectives have been identified and defined by planners in the field, this work will be reviewed for approval at a high level within the Corps. To facilitate the development of reasonably consistent practices and the communication between field and higher levels in the Corps hierarchy, it would be useful to establish a group of experts within the Corps to work as consultants to the field on the structuring and formulation of studies. One of the functions of this group should be to assist field personnel in the establishment of objectives.

The procedure of setting general guidelines is consistent with present Corps practice in that the Corps now specifies benefits by categories and enumerates a long list of specific benefits to be considered. Some items on this list would appear as objectives under the new scheme, e.g., types of benefits which are not measurable. As examples, water quality, air pollution, and open space could come under the category of objectives entitled improvement of environmental quality. From a analysis of a long list of possible objectives constructed by considering national, state, and local perspectives, it is apparent that the objectives relevant for planning flood plain management can be put into four categories 1) maximization of net benefits to the nation; 2) regional economic prosperity; 3) environmental quality; and 4) the prevention of disasters. The maximization of net benefits to the nation is simply the standard objective of benefit-cost analysis, and the prevention of disasters is an objective of special significance for flood plain management. The latter will subsequently be discussed in more detail in this report.

The categories of environmental quality and regional economic prosperity deserve some attention. Such things as water quality, open space, and recreational opportunities may either be considered collectively as a separate objective under broadly defined environmental quality or they may be considered individually as one among many benefits and incorporated into the objective of maximizing national benefits. This will largely be determined by whether these products of a program can be given a monetary measure. It is possible, however, that some product could be accounted for, both as a benefit and as an objective in its own right. For example, the preservation of wilderness may create benefits of the standard type, but we may wish to give it additional consideration apart from its direct monetary value. This is not double counting but an example of the case previously mentioned where the achievement of one objective contributes to the achievement of another.

The objective of regional economic prosperity is so titled to include not only the standard objectives of regional development, but also objectives of transferring income into a region or locality. Therefore, net benefits accruing to a region could be an objective under this category, and the achievement of such an objective could be effected simply by changes in rules for cost sharing on a project. Most state and local objectives will fall either under the category of regional economic prosperity or the environmental quality category.

There is perhaps a class of objectives which impinges on the planning process, the inclusion of which is of questionable value for the evaluation plans. These are the political objectives of groups and individuals with an interest in a given project. The position taken in this report is that these objectives will not be explicitly considered and that they will come into the planning process through pressures placed on the final decision makers.

It is not difficult to construct long lists of specific objectives in each category. Several attempts at constructing comprehensive lists have shown that they degenerate into an unmanageable compilation of things that make for a good life. Such lists are of little value for planning and are not included in the report. The problem is not to enumerate the major objectives relevant to a specific project, but rather to limit the objectives to those which are critical to the final decision. The selection of objectives always involves judgement; however, there are several criteria that may be used to evaluate the importance of objectives. From the cases studied in the application of the methodology, it appears that the number of objectives can be reduced to manageable proportions. This is important because implementation of the methodology becomes more difficult as the dimension of the objective space increases.

In considering the important objectives, certainly the maximization of net benefits to the nation is important. In addition, there will be a number of other objectives which seem of primary importance, and a number of objectives which appear relevant. In deciding which objectives to include in the analysis, two questions are pertinent: first, does achievement of the objective involve large quantities of money, and second, is the objective held by large numbers of people. If the answer is no to both questions, one should seriously weigh their inclusion. Fortunately, many desired outcomes of a project can be accounted for by their impact on net benefits. An additional method to reduce the number of stated objectives is subsequently discussed in connection with operational statements of objectives.

Among the most difficult objectives to select for inclusion are state and local objectives. Procedures to identify critical local objectives are being developed (as previously mentioned) in a companion study at the University of Chicago, and therefore, are not discussed here.

Objectives not only must be selected, but stated in operational terms. The latter requires the specification of a unit of measure for each objective.

For some objectives a meaningful unit of measurement may be reasonably easy to establish. In the case of economic efficiency, the unit of measurement has been specified in terms of dollars, and the conceptual procedure to measure benefits and costs is fairly well understood. In other cases, the desired unit of measurement is not so clear. Suppose the provision of open space were an objective. One procedure might be to measure open space in terms of acres. However, the planner must carefully consider the properties of open space which are important. If the location, size, shape, contiguity, etc., of the open spaces are of critical importance, then acres may be the wrong unit of measurement.

In some instances one unit of measurement will not encompass all aspects of the objective of open space, and this objective will have to be replaced by several objectives relating to different properties of open space. For example, instead of the objective called "open space," one objective might be defined as area of open space to be measured in acres, and another as the number of large recreation areas measured by the number of plots of open space with an area greater than 100 acres. acres.

From the foregoing example, it is clear that the process of defining each objective in operational terms requires a deep understanding of the desired outcome. A second example of particular relevance for flood plain planning will further illustrate this point. Suppose a stated objective were the prevention of disasters from flooding. Before a program of flood protection with respect to this objective can be evaluated, the term disaster must be given an operational definition. At this point the question must be asked: what constitutes a disaster from flooding? Loss of life, clearly, is one thing that constitutes a disaster, but this is not the only thing. Therefore, it would not be appropriate to measure disaster prevention only in terms of deaths prevented. A second component of a flood disaster is that households and businesses suffer severe economic losses. In general, losses from exceptionally large floods constitute a major loss only for certain individuals, but not for the nation as a whole. Therefore, disaster prevention could be restated in terms of two new objectives—the prevention of loss of life and the prevention of severe property losses to individuals.

The first objective could be measured in terms of the expected number of lives saved. The second could be measured by the reduction in the expected occurrence of losses constituting more than a certain percentage of the total wealth exposed to the flood hazard. The reason for discussing the question of flood disasters is that in the following section of this report it will be shown that there are nonstructural measures which may achieve the objectives associated with disaster prevention more efficiently than structural measures.

As previously stated, the existence of multiple objectives may present a problem if the number of objectives becomes so large that it is unmanageable. With most projects, a long list of desired outcomes can be developed, therefore some attempt must be made to limit the number of stated objectives without omitting some important consideration from the analysis. In many cases where several objectives are highly correlated, only one needs to be explicitly considered. Suppose that increasing regional employment, regional income, and the value of production in a region were all stated objectives of a program. Because the level of employment, income, and production are highly correlated, only one needs to be incorporated into the planning model. This is because the achievement of one of these objectives will be accompanied by a similar level of achievement for the others. In this case, regional income is a good proxy for the other objectives associated with regional development.

One of the problems introduced by allowing consideration of objectives, other than economic efficiency, is the objectives will vary from project to project, and measures of performance will also vary. This creates a problem of comparability. Projects which contribute to the achievement of different objectives must be compared within the total Corps program. This problem is not restricted to this methodology, but to all methods of analysing projects which are designed to satisfy different objectives. The introduction of state and local objectives is bound to introduce these differences.

It may be possible, however, with experience, to establish a reasonably well defined list of objectives (which incorporate the major aims of most programs of flood plain management) and to specify how these objectives are to be measured. This task will require analysis of a number of projects with respect to the appropriate objectives and synthesis of this experience by analysing the frequency of occurrence of various objectives. Nevertheless, the problem of comparability will remain to some degree. The increase in comprehensiveness which is attained by introducing new objectives will entail greater complexity and higher planning costs.

Again, the need for greater central coordination becomes evident when the problem of comparability is considered. As previously suggested, a highly trained group of planning specialists within the Corps, who would serve as consultants to the field, would not only facilitate the introduction and implementation of more complex planning methods, but would also contribute to consistency throughout the Corps. The latter would greatly reduce the problems posed by differing objectives.

A final problem is that of relating to the planner how various plans will affect different objectives. For example, if the planner is told to develop plans with an eye toward increasing economic efficiency through optimal management of the flood plain, he still has to ask himself what types of benefits can be produced by various programs. Therefore, particular objectives have to be related to intermediate goals which may produce these objectives. This problem can be seen in the context of conventional flood control measures. Under the present Corps planning procedure, one of the objectives is economic efficiency. However, it is necessary that the design engineers understand the way in which different flood control measures will produce benefits. Typically in such cases benefits take the form of damage reduction and land enhancement.

In the future, therefore, the term "intermediate" goal will be used to specify various effects which produce the desired objective. One of the key elements in the planning program is to relate different programs such as structural flood control measures, zoning, and flood proofing to these various intermediate goals and to relate these goals to levels of achievement of the final objectives. In the case of programs involving the flood plain, the connection between various programs and their effects on net benefits is fairly well specified and will be discussed in detail in the following section of this report. However, in the case where alternatives which are outside the flood plain are considered, it may be more difficult to relate these programs to the specified objectives.

THE DEVELOPMENT OF ALTERNATIVE PLANS

The development of alternative plans is a critical part of the planning process, because the final decision on a course of action is completely circumscribed by the alternatives which are presented for consideration. Regardless of how sophisticated and refined the evaluation procedure may be, the optimal program cannot be selected unless it appears among the alternatives considered. This is the principal reason for expanding the range of alternatives considered in Corps studies. At the same time, the generation of all possible alternative plans for the development of the flood plain and the surrounding region would be infeasible if not impossible. The number of possible alternatives and their combinations would be prodigious, therefore a procedure is needed whereby a limited number of the most promising alternatives can be developed. The purpose of this section is to design such a procedure.

The procedure herein developed begins with the establishment of a set of objectives as discussed previously. A slightly expanded version of present Corps practice is then used to generate flood-related alternatives including structural and nonstructural measures. Structural protection is considered, then nonstructural measures are added to the list of alternatives and combinations of these plans are considered. Finally, measures not directly related to flooding are considered in combination with, or as substitutes for, the previously generated plans.

There are several advantages to this approach. First, the planning procedure developed is an extension of current Corps procedures and therefore should be easily understood and implemented. Second, by focusing on the flood plain and considering initially the more traditional approaches to flood plain management, a procedure is developed whereby only the most promising alternatives involving nonstructural measures need to be considered. This procedure significantly limits the number of alternatives which require consideration and also provides an approach to identify relevant alternatives which might otherwise have escaped consideration. Finally, this procedure provides a method of implementing many of the directives contained in EC 1120-2-40.

Before a procedure to generate alternate plans can be established, relevant objectives must be established. While the methodology developed to handle multiple objectives is completely general and is not restricted to any specific set of objectives, a detailed discussion of the process for developing alternate plans requires some specification of the objectives which are to be pursued. This is true because the development of alternate plans consists in part of a process to analyze backward from the objectives to intermediate goals which would meet the objectives and hence to the specific plans which would meet the intermediate goals. Therefore, a knowledge of objectives is a prerequisite to any generation of alternatives or to any meaningful discussion of the generation process.

For the purpose of illustrating the methodology, a set of objectives will be established and the process of developing alternative plans to achieve these objectives will be carried out. It is not the purpose of this discussion to select the objectives which are to be pursued by the Corps; nevertheless the discussion will be more relevant if objectives are selected which may be relevant to Corps planning. For this reason, the objectives which have been selected are either ones which have been considered by the Corps in the past or ones in which the Corps has shown some interest. In choosing the objectives for this discussion, it should be further noted that no attempt has been made at completeness as, for pedagogical reasons, it is preferable to consider only a few possible objectives.

As stated previously, the planning objectives of the Corps appear to fall into four general categories: 1) economic efficiency measured in terms of the value of net benefits, 2) disaster prevention, 3) improvement of the quality of the environment, and 4) regional and local economic prosperity. These broad categories of objectives may in fact contain many different objectives, such as open space, air, water, and aesthetic qualities, etc., which may be part of what makes up the quality of the environment. For purposes of this discussion at least one objective will be chosen from each of these four categories.

The first objective to be considered is that of economic efficiency which has been discussed previously. The achievement of this objective is measured in terms of the net value of all benefits valued in the market, produced by a flood management program. There are a number of types of benefits which may result from a flood control program, i.e., damage reduction, land enhancement, power, water for municipal and industrial use, recreation, etc. In this discussion, consideration will be limited to the benefits of land enhancement and damage reduction, as they appear to be significant in most cases where flood control measures are being considered.

Second, while the prevention of disasters does not appear in Corps literature specifically as a benefit, it is evident that the Corps is sensitive to this objective. The provision of protection against the Standard Project Flood indicates that the Corps is pursuing this objective since, in many cases, net benefits would be maximized at a lower level of protection. The concept of a disaster is discussed in the section on objectives; in the discussion that follows, two subobjectives will be specified in this category. The first will be prevention of loss of life, measured in terms of the number of lives saved. The second will be the reduction in the risk of severe property losses, measured in terms of the reduction in the probability of losses above a certain level suffered by individuals and firms with property in the flood plain. It does not necessarily follow that prevention of loss of life and reduction in the risk of property losses go together. A flood insurance program, for example, reduces the risk of property damage, but has little or no effect on prevention of loss of life. Likewise, a structural alternative may reduce the risk of property damage and at the same time give people a false sense of security, thus adding to the potential loss of life.

It should be noted again that this subobjective is not related to the losses per se but to the economic well-being of the people who suffer the losses. A program of flood insurance would eliminate the possibility of these large personal losses (while it would not eliminate the actual flood damage) and therefore, would meet the objective as it is stated here.

In the category of improvement of the quality of the environment, providing open space will be used for purposes of this discussion. This is appropriate because, in many cases of flood plain management, one of the relevant alternatives is to zone the flood plain to encourage proper use of the flood plain given the flood hazard. It should be noted again that enhancement of water quality, preservation of the natural landscape, fish and wildlife conservation, etc., may all be objectives which demand consideration. They are omitted here to keep the example reasonably simple.

Finally, although there are many components to regional economic prosperity, the specific objective considered in this study is the increase in regional employment measured in terms of the change in the number of persons employed. Again the choice of this particular objective is arbitrary. The objective to increase the level of regional income or to increase the value of net benefits accruing to the region could as well have been chosen.

Once objectives have been established, alternative plans must be generated and must be evaluated with respect to each of the objectives. The resulting information about the impact of each alternative on the objectives can be displayed in a matrix such as Table 1. The columns denote objectives and the rows correspond to various plans. Thus the element 85 in the third row in the column labeled B-C (benefit-cost) gives the value of net benefits produced by hypothetical Plan 3.

Table 1

Objectives Plan	B-C* ($1M)	Prevention of Loss of Life (Number of Lives Saved)	Reduction in Risk (% Decrease in Probability)	Open Space (1000 Acres)	Increase in Regional Employment (100 Jobs)
1	100	0	10	0	2
2	90	2	5	3	1
3	85	1	1	7	3

*Benefit-Cost

With this preliminary discussion of objectives, the presentation of the procedure to develop alternative plans can begin. The first step in this procedure is to consider structural measures to control floods. Among the alternative structural measures which should be considered is the alternative of providing no flood protection and leaving the flood plain to its present course of development. This <u>status quo</u> alternative should always be considered as action that is justified if the resulting situation is preferred to the situation which will prevail if no action is taken. In benefit-cost studies the status quo is considered to have net benefits equal to zero. However, when other objectives are considered, it may be desirable to associate positive levels of achievement with the status quo. For example, the status quo may provide for relatively large amounts of open space.

In addition to the status quo, other alternatives which should be considered include several lower levels of protection designed to prevent damage from the smaller, more frequent floods and a high level of protection designed to protect against the Standard Project Flood. These lower levels of protection are included because it is desirable to have among the alternatives that level of structural protection which maximizes the value of net benefits. In many cases this alternative will provide a level of protection far below that required to protect against the Standard Project Flood. This alternative, while it may be effective from the point of view of economic efficiency, will not, in general, be effective in achieving the objectives within the category called disaster prevention. Nevertheless, it is important that this alternative be considered for two reasons. First, it may be possible to modify this alternative by combining it with nonstructural measures which will achieve the objectives of preventing loss of life and severe personal losses. Second, the level of net benefits generated by this plan may be great enough to justify the lower levels of disaster prevention. This latter possibility can only be determined by the final tradeoff analysis and should not be prejudged in the process of developing alternatives.

Structural protection against the Standard Project Flood should also be considered for several reasons. First, since it is directed at preventing the flood waters from overflowing its banks, it would probably be the most effective measure to prevent loss of life and reduce the probability of catastrophic losses to firms and individuals with property in the flood plain, although this presumption should be analyzed. Second, the high level of protection would promote intensive development of the flood plain which, depending on the particular situation, could promote employment in the area as well as satisfy other objectives for regional economic development given a general scarcity of developable land in the community. Finally, since protection against the Standard Project Flood in many cases has been in the alternative chosen by the Corps, it will be of interest to evaluate this alternative within the expanded planning framework presented in this report.

These three alternatives are displayed in Table 2. Plan 1 is the status quo, Plan 2 is a level of structural protection which maximizes net benefits (in actual studies several lower levels of protection may be considered, since the level which generates the greater value of net benefits cannot be known in advance), and Plan 3 is structural protection against the Standard Project Flood. The numbers which have been chosen to represent the levels of performance reflect the following assumptions which are made only for purposes of illustration. Regional employment, prevention of loss of life, and the reduction in the probability of catastrophic losses will be assumed to increase with the level of protection. The amount of open space, since it is in conflict with intensive development, will be assumed to decrease with the level of protection. The numbers which are entered in Table 2 have been chosen only for the purpose of illustration and no significance, except for this example, should be attached to these numbers. Throughout the report numbers will be supplied in examples and, in all cases, it should be understood that these numbers have no significance beyond the example.

Table 2

Plan	Objectives B-C* ($1M)	Prevention of Loss of Life (Number of Lives Saved)	Reduction in Risk (% Decrease in Probability)	Open Space (1000 Acres)	Increase in Regional Employment (100 Jobs)
1	0	0	0	10	0
2	100	10	10	4	12
3	75	100	90	0	15

*Benefit-Cost

The second step in the process of generating alternatives is to consider the four major non-structural measures to cope with flood losses, either singly or in combination with other structural and non-structural measures. The four non-structural measures for consideration are flood warning and evacuation systems, flood plain regulation, flood insurance, and flood proofing.

First, consider the effect on the achievement of the stated objectives of installing flood warning and evacuation procedures. By providing sufficient warning so that people and property can be evacuated from the flood plain and precautions can be taken to lessen the damage of flooding, flood warning and evacuation result in benefits in the form of damage reduction. Some enhancement benefits may also accrue, since firms and households which previously located outside the flood plain may now find it to their advantage to move into a flood plain protected by the warning system; however, such benefits are not likely to be very significant. Therefore a program of flood warning and evacuation produces positive net benefits mostly in the form of damage reduction. For purposes of exemplification, it is assumed that the level of net benefits generated by this alternative is $35 million.

At the same time, flood warning systems along with appropriate evacuation measures may be an exceedingly effective way of preventing loss of life. In fact it may even be more effective with respect to this objective than some levels of structural protection. Studies of attitudes of flood plain occupants have shown that residents develop a false sense of security when structural protection is provided. This situation creates the hazard that if dams and levees are topped, the sudden inundation of the flood plain will surprise the unconcerned occupants, resulting in loss of life.

This alternative is not likely to significantly affect the probability of catastrophic losses because, while damage can be reduced in very large floods, the effects of these floods will still be very severe. Similarly, it does not appear that a warning and evacuation system will significantly affect the level of open space or the level of regional employment. The performance of a warning and evacuation system, considered by itself, is presented in Table 3 as Plan 4, and the numbers entered for this plan are roughly consistent with the previous discussion.

The second non-structural alternative, flood plain regulation, encompasses a number of regulations regarding use of the flood plain. These regulations take the form of building codes, zoning laws, etc. The type of regulation discussed in this example is flood zoning. Flood zoning used in this context is defined as a land use change brought about by legal action on the part of the community or state to encourage or restrict the way in which the resources of the flood plain are utilized. Residential development might be excluded while certain source forms of industrial development would not.

Flood zoning does not produce benefits in either damage reduction to existing development or land enhancement. It may, however, produce a positive or negative benefit of a third type which deserves some discussion. Flood zoning reduces flood damage by excluding firms and households from the flood plain. The rationale for flood zoning is that activities which are unaware of the hazards of flooding may move into the flood plain even though it would not be economical to locate there if they were fully aware of these hazards. To the extent that flood zoning prevents this uneconomic encroachment, it provides a benefit, and in some cases the magnitude of these benefits may be significant. At the same time, there are activities for which it is profitable to locate in the flood plain since the costs of flooding are outweighed by the advantages of the site. If zoning forces these firms to locate on sites outside the flood plain, the result is a net loss of income or a negative value for net benefits.

By preventing encroachment onto the flood plain, flood zoning may significantly reduce the number of deaths from flooding, as well as the probability of severe property losses. Flood zoning may also be used to maintain the flood plain in its undeveloped state thereby achieving the objective of maintaining open space. At the same time flood zoning by itself may inhibit the development of the flood plain which reduces the level of employment below the level achieved if the status quo were maintained. This would, of course, depend on whether there were alternative areas for development. Zoning is displayed in Table 3 as Plan 5.

The third non-structural measure, flood insurance, has been widely discussed in the past five years and is an alternative which requires careful analysis. Flood insurance does not affect the level of property damage from flooding and therefore does not produce damage reduction benefits. Similarly, it probably does not produce significant land enhancement benefits, although given the possibility of insuring against flood losses some activities which, in the absence of insurance would locate elsewhere, might locate in the flood plain. Insurance, however, may produce a benefit by preventing uneconomical encroachment onto the flood plain if the insurance is made mandatory. Suppose flood insurance is sold at a cost equal to the expected value of property damage. The expected cost of flooding has not changed for the flood plain occupant; he now simply pays these costs in annual insurance payments, thereby eliminating the risk to him associated with the uncertainty of sustaining flood losses. The fact that insurance is mandatory forces the potential flood plain occupant to consider the cost of flooding when he selects a location. A flood insurance program might, however, produce negative benefits if the cost of the program was such that it discouraged wise development from taking place.

If the advantages of a flood plain location outweigh the cost of flooding as represented by the insurance premium, he will locate in the flood plain; if not, he will locate elsewhere. Mandatory flood insurance is in one way superior to flood zoning as a method of preventing uneconomical encroachment onto the flood plain because it presents the potential occupant with the expected cost of flood damage and allows him to make the decision as to whether the advantages justify the costs. Flood zoning, on the other hand, specifies which types of activities can locate in the flood plain and, unless these specifications are chosen with extreme care, economical uses of the flood plain may be excluded. It is possible, however, that flood zoning may be less costly to implement and more easily administered. Flood insurance which is not mandatory does not discourage uneconomic uses of the flood plain since a potential occupant who is unaware of the hazards of flooding is not likely to purchase flood insurance.

Flood insurance is perhaps the most effective way of coping with severe property losses to individuals. While it does not prevent the physical loss of property, the insurance fund reimburses the losses so that the individuals with property in the flood plain are protected. If full coverage is obtained, all losses are reimbursed. In many cases, even the largest structural measures cannot protect against all possible floods and therefore cannot provide complete protection to the individual.

While flood insurance is very effective in preventing individuals from sustaining severe losses, it is only effective if individuals, in fact purchase the insurance. It could be argued that, if individuals are aware of the hazards of flooding and have the opportunity to purchase flood insurance but choose not to, then, if they sustain heavy property losses, society should not be concerned. However, if society accepts the responsibility of protecting these people against such losses, it may be appropriate to make flood insurance mandatory. In this case all occupants of the flood plain would be protected, and the risk would be eliminated.

Flood insurance obviously does not prevent the loss of life, nor does it affect the available supply of open space or the level of regional employment. Plan 6 in Table 3 represents the alternative of providing flood insurance. It is assumed that purchase of flood insurance is mandatory.

The final nonstructural alternative considered here is flood proofing. The term flood proofing encompasses a wide range of measures to make structures resistant to damage from flooding. Therefore, flood proofing produces benefits primarily in the form of damage reduction. In addition, flood proofing will, to some degree, contribute to the prevention of loss of life and the reduction of catastrophic losses. It probably would have little effect on open space or regional employment. Flood proofing is presented as Plan 7. It should again be emphasized that the numbers chosen, while realistic in some circumstances, may be completely unrealistic in others. For example, whether flood proofing is superior to structural protection from the standpoint of economic efficiency may well depend on the level of development of the flood plain. If there are only a few structures, flood proofing may be the most effective measure. On the other hand, with more intensive development, structural protection may be more efficient because the cost associated with flood proofing rises with the number of structures, whereas the cost of the structural measure does not.

It should be noted that flood plain regulations may be established which require flood proofing. In this case, flood plain occupancy becomes contingent on meeting certain standards for flood proofing.

Since these regulations make flood proofing mandatory, they serve to alert prospective occupants of the flood plain to the hazards from flooding. In this way, it has much the same effect as mandatory flood insurance, and the argument that people who are unaware of flood risks are unlikely to voluntarily seek protection applies here as in the case of insurance.

At this point in the procedure for developing alternatives, various structural and non-structural measures have been evaluated in terms of their performance with respect to each of the five stated objectives. The task now is to generate new alternatives by combining two or more of the plans presented in Table 3 into new plans. The object is to combine plans to take advantage of their complimentarity with regard to strengths and weaknesses. In this report only one combination of the first seven plans presented in Table 3 will be developed in detail as as example; however, other possible combinations, which appear in some cases to be promising, will be discussed.

When combining two or more plans, care must be taken to consider how combinations of these plans interrelate. For example, the most dramatic case would be one where plans are mutually exclusive and cannot be combined at all. It may not, for example, make sense to talk about combining a smaller structural measure with a larger one. Levees of two different sizes cannot be introduced on the same site. In addition, it cannot be assumed that plans can be combined in a linear manner. For example, a structural project providing for 75-year protection will not necessarily produce levels of achievement with regard to the objectives which are averages of the values generated by 50-year protection and 100-year protection. Another way of saying this is that values representing the objectives will, in general, be nonlinear functions of the level of protection.

A similar point is that the effects of two plans are not additive in that if two plans are combined to produce a new plan, the performance of the new plan cannot, in general, be evaluated by adding the performance levels of the two original plans. For example, Plan 7, flood proofing, is shown in Table 3 to generate net benefits of $40 million; Plan 3, structural protection against the Standard Project Flood, is shown with net benefits of $75 million. It is clear that by implementing both of these plans the total net benefits produced by the combination

Table 3

Plan	Objectives B-C* ($1M)	Prevention of Loss of Life (Number of Lives Saved)	Reduction in Risk (% Decrease in Probability)	Open Space (1000 Acres)	Increase in Regional Employment (100 Jobs)
1	0	0	0	10	0
2	100	10	10	4	12
3	75	100	90	0	15
4	35	97	0	0	0
5	5	80	80	12	-1
6	1	0	99	10	0
7	40	10	15	10	0
8	115	98	99	4	12

*Benefit-Cost

Plans

1. Status quo
2. Intermediate level of structural protection
3. Structural protection for a Standard Project Flood
4. Flood warning and evacuation system
5. Flood zoning
6. Flood insurance
7. Flood proofing
8. Plans 2, 4, 6 in combination

will not be $115 million, i.e., the sum of the two taken individually. This is because these two measures are substitutes in the production of benefits from damage reduction. The value of flood proofing structures is much lower if virtually complete structural protection is provided.

With the foregoing consideration, an example of a plan which is a combination of the plans presented in Table 3 can be developed. Note that Plan 2, an intermediate level of structural protection, will be preferred strictly on the basis of economic efficiency, but that it is not very effective in advancing objectives in the category of disaster prevention. On the other hand, Plan 4, a warning and evacuation system, is exceedingly effective in preventing deaths from flooding, and Plan 6, mandatory flood insurance, is effective in preventing severe individual losses. Since it is possible to implement all three of these plans simultaneously, consider the results of this combination labeled Plan 8.

An intermediate level of structural protection by itself produces net benefits from damage reduction and land enhancement of $100 million. While a warning and evacuation system results in some damage reduction, the level of this reduction is likely to be less, given some structural protection. Therefore, the overall effect of the plan combining these measures should generate benefits of between $100 and $135 million.

The warning and evacuation system is very effective in preventing loss of life, and the effectiveness of the three measures combined should be no less. Flood insurance can provide complete protection against severe losses to individuals, and again the combined plan should perform as well with respect to this objective. In the area of regional employment, the three measures together should perform at least as well as Plan 2 alone. Finally, the amount of open space which is preserved with the combined plan should essentially be the same as for the intermediate level of structural protection.

Plan 8 is displayed in Table 3. Except for providing slightly less protection against loss of life and less open space than Plan 1 and Plan 5, it generates levels of achievement for each of the objectives which equal or exceed those of the next best alternatives. For this reason it is a prime candidate for the "best" plan. This particular combination was chosen because it appears to be one which deserves serious attention in a large number of cases since it suggests that a high level of achievement towards the objective of disaster prevention can be obtained while at the same time the value of net benefits can be maximized.

There are many other combinations that may be important under differing circumstances. A complete description of all possible combinations which may be relevant for Corps planning is beyond the scope of this report. It seems probable that the generation of plans combining various structural and non-structural measures is better left to the ingenuity of the Corps' own field staff which has firsthand knowledge of each particular situation. Nevertheless, several other combinations deserve a brief comment.

In cases where the flood plain does not appear to be a promising area for development but where uneconomic development of the flood plain is taking place through ignorance and/or through the promotion of landholders who are seeking large windfalls, a program of flood zoning, warning and evacuation, and flood proofing may be the optimum plan. This is because the combination of flood proofing and the warning and evacuation system will provide relatively inexpensive protection against damage to property which is already located in the flood plain, and flood zoning will prevent further encroachment. The latter is necessary because, once the initial mistake has been made and the flood plain has been developed, the process may not be easily reversed. The situation may then be such that large structural measures are justified because of past mistakes. It should be noted again that a mandatory program of flood insurance could have been substituted into the previous plan in place of flood zoning.

Finally, in many situations, the timing of flood control measures is of key importance. This is largely because structural measures involve large capital outlays where the total opportunity cost of capital is large. In some cases the optimal plan for the flood plain may involve deferring structural protection until some time in the future when the flood plain is more fully developed and using flood proofing, flood warning and evacuation, and flood insurance, to achieve the desired objectives in the interim.

To this point the measures considered have been those traditionally considered by the Corps and those non-structural measures which have been widely discussed within water resource circles. All of these measures are specifically related to the problem of flooding. In many cases, however, there are important alternatives which involve developments outside the flood plain, not specifically related to flooding. These alternatives may achieve the stated objectives more effectively than would the traditional plans for the flood plain. To some extent, all public projects will have an impact on these objectives, and therefore should be considered. However, to allow the set of alternative plans to include such a wide range of alternatives would make planning a prodigious task. To circumscribe this, the procedure put forth in this report is a compromise. Instead of considering all possible alternatives outside the flood plain, only those which are close substitutes for flood-oriented programs are considered. Where the line is to be drawn as to what constitutes a close substitute is somewhat arbitrary, but the general procedure to identify a close substitute will become clear in the course of the discussion.

Consider the objective of economic efficiency. Most government investments are designed to contribute to the achievement of this objective, therefore, a rule must be developed to restrict consideration to those other alternatives which are in some sense close substitutes for flood-related measures. This is done as follows: the benefits which are produced by the flood-related measures are examined and attempts are made to find projects, not directly related to the flood plain, which produce benefits of the same type. In the case under discussion, benefits take the form of damage reduction and land enhancement. We now investigate whether there are ways of obtaining these benefits other than by the measures previously considered. In considering land enhancement, the question should be raised in most cases as to whether there are areas outside the flood plain which can be developed as substitutes for development of the flood plain. Suppose sites exist outside the flood plain comparable to those in the flood plain, assuming protection has been provided. In this case the movement of activities into the flood plain simply represents the diversion of activities from one location to another without any benefit being realized. The implication of this is that, in order to evaluate land enhancement benefits, sites for development in addition to those in the flood plain must be considered. Put differently, the "with and without" principle must always be applied in benefit-cost studies.

Suppose, however, that the planned development of the flood plain provided for industrial development, and that while there were alternative sites outside the flood plain, these sites would have to be developed in order to be roughly competitive with sites planned for the flood plain. In this case, a project for developing these other sites is a substitute for plans to develop the flood plain. It is not necessary that the areas provide identical benefits, since the difference in development costs will affect the overall attractiveness of the alternatives.

The above discussion has focused on land enhancement because this appears to be an important benefit which may be generated by the development of areas outside the flood plain rather than within the flood plain itself. However, there are other types of benefits to be obtained by projects unrelated to flooding. For example, if a flood control project includes a power plant so that one of the benefits is power, then other measures to obtain power should be considered. This may involve the installation of an atomic power plant. The case is similar for flood control works which supply water. It should be noted that seldom will any one alternative be a good substitute for structural flood control; however, a combination of non-structural measures, both of the conventional type and those unrelated to flooding, may be superior to the structural measure.

Suppose, in the example which has been developed, that a large fraction of the national economic gains associated with structural flood control were enchancement benefits and that there existed alternative areas for development requiring the construction of roads and utilities. Further, suppose the enhancement benefits were comparable to those which would accrue if protection were provided against the Standard Project Flood, but that development costs were far less.

Now consider a plan which would include this alternative plan for development: a flood warning and evacuation system, mandatory flood insurance, flood proofing, and flood zoning to retain part of the flood plain as open space. This combined plan would produce the enhancement benefits and stimulate regional employment. At the same time, the warning and evacuation system and flood proofing would give the present flood plain occupant some degree of protection. If there were limited development of the flood plain to begin with, a combination of these two measures may be superior to structural protection from the standpoint of economic efficiency. In addition, the flood warning system and flood insurance would take care of the general objective of disaster prevention, while open space would be provided for the community by zoning the land for open space uses. This combined plan is presented as Plan 9 in Table 4 along with the other plans from Table 3.

Table 4

Plan	Objectives B-C* ($1M)	Prevention of Loss of Life (Number of Lives Saved)	Reduction in Risk (% Decrease in Probability)	Open Space (1000 Acres)	Increase in Regional Employment (100 Jobs)
1	0	0	0	10	0
2	100	10	10	4	12
3	75	100	90	0	15
4	35	97	0	0	0
5	5	80	80	12	-1
6	1	0	99	10	0
7	40	10	15	10	0
8	115	98	99	4	12
9	125	100	99	12	15

*Benefit-Cost

It should be noted that Plan 9 is at least as good as every other plan with respect to the achievement of every objective. While this is what should be achieved in looking for ways of combining various plans, seldom will the final plan dominate all others.

Thus far the discussion has focused on alternatives which produce benefits roughly comparable to those produced by flood-related measures. The procedure is similar in considering other objectives. Where regional employment is a prime objective of a program, alternatives must be considered which also achieve this objective. For example, if projects are being considered which will stimulate the economy of Appalachia, then a highway project, a project for reforesting, etc., all become relevant alternatives to flood control. Similarly, the objective of maintaining open space can be achieved, not only by incorporating open space into the plan for the flood plain, but also by providing for open space outside the flood plain.

To summarize, the first step in the procedure to generate alternative plans is to consider structural alternatives providing various levels of protection, including the alternative of providing no protection. Next, four non-structural alternatives are considered, as are combinations of structural and non-structural alternatives. Finally, alternatives are considered which are not flood-related but which are close substitutes for flood-related measures. Finally, combinations of all the basic alternatives are considered.

Before proceeding with the analysis of tradeoffs, a legitimate question arises as to the procedure by which the effects of a particular alternative on each objective can be forecast and measured. In fact, to the planner in the field, this may be the most critical problem he faces. Unfortunately, there is no general and definitive answer which can be given as forecasting and measurement problems are highly specific to the objective and the particular measure used to achieve that objective. For example, if the objective improved water quality, the forecasting of the effects of a reservoir system used for low flow augmentation and that of increased sewage treatment will require very different analytical models. In addition the methods for making such forecasts will be very different from those used for estimating recreation benefits.

While very little of a general nature can be said on this problem and while a detailed analysis of how different measures will perform with regard to every possible objective is well beyond the scope of this report, there are some problems of forecasting and measurement that are central to most plans for flood plain management where some discussion is useful. The pattern of land use which results from a program of flood plain management is central to the level of attainment of many objectives relevant for flood plain planning. Closely related to this is the appropriate way of measuring benefits from land enhancement which result when a project alters the pattern of land use.

THE EVALUATION OF PLANS

At this point in the planning process a set of plans has been developed which includes structural and non-structural measures and combinations of the two. In addition, the performance of each plan with regard to each of the objectives has been determined and this information is presented in a performance matrix where the rows of the matrix correspond to the various plans and the columns correspond to objectives. The task that remains is to evaluate the plans to determine the "best" one. Clearly, if one plan is superior to another with respect to every objective, then the first plan is to be preferred to the second and the second is said to be dominated. In this case the dominated plan can be set aside because it will never be the best of the existing alternatives. If, however, the dominating plan were to be constrained from consideration, it would be appropriate to reintroduce the plan previously set aside. Plans which are inferior to others with respect to the achievement of every objective may, in fact, be the best plan if the plans which dominate it fail to satisfy one or more constraints. It is possible that after all dominated plans have been set aside, only one will remain. In this case, the remaining plan is superior to every other plan with regard to every objective, and the problem of choice is trivial.

In most cases, however, one would expect that, while a number of plans may be eliminated on the grounds that they are dominated by an alternative, the final set of nondominated plans will contain more than one plan. Then there will be a number of plans, all of which perform better than every other plan with respect to at least one objective. The problem of choosing among these plans is that of specifying how much society is willing to sacrifice some objectives for others. Put differently, choosing the best plan involves the introduction of value judgements regarding the relative worth of achieving different objectives. One of the fundamental points of this report is that the problem of values cannot be circumvented and then it is desirable that this problem be squarely faced and that value judgements be made explicit rather than having them introduced implicitly into the analysis. As will be demonstrated, every decision implies certain underlying values. The remaining section of this report is devoted to the question of how values can most effectively be introduced into decision making for flood plain management.

Three basic approaches are taken to the problem. The first is to confront the decision maker with the relevant tradeoffs and to have him reveal this value structure through his choice. In this case the tradeoffs must be made clear to the decision maker and to anyone reviewing the decision. From the decision certain underlying values can be determined. The other two approaches involve the introduction of value statements through willingness to pay values for society. It can be shown that values can be introduced through the concept of social willingness to pay and that the introduction of values in monetary terms is a natural extension of the benefit cost framework which greatly facilitates the analysis of tradeoffs. This concept of social willingness to pay, which will be discussed subsequently in detail, is essentially a generalization of the concept of individual willingness to pay. It is particularly useful in dealing with cases where the benefits or costs associated with some outcomes of a project are not susceptible to precise measurement, but where there is some information concerning the magnitude of these benefits. The two approaches which employ the concept of social willingness to pay are the critical value approach and the decision analysis approach. Both approaches are useful in bringing all available information to bear on the problem project selection. At the same time, they do not involve magic formulas to gauge benefits which are difficult to measure. The search for such magic formulas generally leads either to meaningless solutions or ends in complete frustration as the problem of benefit measurement is difficult and highly specific to each type of benefit. In many cases, there is simply not enough information to allow precise measurement. At the same time, the approach taken in this report has implications for research on benefit measurement. These implications are discussed in the conclusions.

It is useful to approach the problem of values and tradeoffs through an example. For simplicity suppose we were to consider a planning problem where there were only two objectives: net benefits and open space. Further, suppose that the set of nondominated plans is given in Table 5. There are six competing plans listed in descending order

Table 5

Plan	Benefits-Cost ($M)	Open Space (1000 Acres)
1	100	0
2	95	1
3	88	2
4	80	3
5	70	4
6	58	5

of net benefits and ascending order of open space. In this case the decision as to the best plan hinges on how much society, as represented by a decision maker, is willing to pay in order to obtain more open space. Table 6 presents the opportunity cost of each increment in terms of dollars of benefits foregone. It should be noted that if the objective other than open space had been regional employment measured in terms of numbers of jobs, the opportunity cost of open space could have been specified in terms of employment opportunities foregone. It is our contention, however, that it is much easier to grasp the meaning of a specific cost when it can be translated into monetary terms. For this reason, opportunity cost and social willingness-to-pay values have been stated in terms of a monetary unit.

Table 6

1000 Acres	Opportunity Cost ($M)
1	5
2	7
3	8
4	10
5	12

In deciding among the plans presented in Table 5, the decision maker must decide whether the value to society of each additional increment of open space is worth the cost in terms of dollars of net benefits forfeited. For example, in comparing Plan 1 and Plan 2, Plan 2 is to be preferred to Plan 1 only if society is willing to pay at least $5 million for the first 1,000 acres of open space provided by Plan 2. Similarly, Plan 3 is to be preferred to Plan 2 only if society is willing to pay at least $7 million for the second increment of open space and a total of $12 million for 2,000 acres of open space. This line of reasoning can be carried out with regard to plans which provide for more open space, the general rule being that the social willingness to pay for each incremental unit of open space must exceed the incremental cost if the plan providing the additional open space is to be preferred.

One might question why the decision maker does not simply place a value on the achievement of each objective, multiply each of the columns in the performance matrix by the value for each corresponding objective, and take the sum of the values in each row as a measure of the performance of the plan corresponding to that row. In essence, this would define an objective function which would convert any vector of performance into a one-dimensional measure of performance. Defining an objective function is the classical way of handling this problem; however, the problem is to get the decision maker to uncode his values in terms of such a function. In general, either it is not possible for the decision maker to define an objective function which he is confident reflects his values or he is unwilling to do it. To define such a function would limit his options and in many cases the decision makers will choose to be confronted with the alternatives on which to make a direct choice. The procedure outlined confronts the decision maker with the relevant tradeoffs stated in terms which can be easily understood, and with the value implications of any particular decision. This is all to the good. The difficulty with this procedure is that in cases where there are a large number of plans and more than two objectives, it is not always possible to present the relevant tradeoffs to the decision maker simply and clearly so that they can be easily understood.

In the previous discussion, it was pointed out that the problem of choice could be defined in terms of whether the society's willingness to pay for open space was greater than the opportunity cost of obtaining that space. We now formally define social willingness to pay per unit achievement of an objective as that increase in net benefits which would just compensate the members of society for a unit decrease in the level of achievement of the objective under consideration. Equivalently, it is important to make clear the relation between society's willingness to pay and individual willingness to pay which is used as the basis to measure benefits and costs under the standard benefit-cost procedure. Society's willingness to pay values represent the tradeoffs which society is willing to make among various objectives. These values will be determined through the political process and may or may not bear a correspondence to individual willingness to pay. In most cases the willingness to pay values of society will be determined explicitly or implicitly through policy decisions by public officials. It may, however, be decided that society's willingness to pay should correspond to the sum of the individual's willingness to pay. In this case the value of society's willingness to pay represents the dollar benefits measurable and unmeasurable, associated with the achievement of a particular objective. Such a decision underlies the benefit-cost criterion to evaluate public projects. Therefore, it can be seen that the use of social willingness to pay is an extension and generalization of the standard benefit-cost framework.

The motivation for the critical value approach comes directly from the previous discussion of the tradeoffs presented in Table 5 and Table 6. It was stated that in order for Plan 1 to be preferred to Plan 2, social willingness to pay for 1000 acres of open space had to be between 0 and $5 million. It is easily seen that for any value between these two limits, Plan 1 is optimal. The critical value in this case is the upper limit of $5 million. Similarly, if social willingness to pay is between $5 million and $7 million per 1000 acres of open space, then Plan 2 can be shown to be the optimal plan.

This can be seen as follows: Comparing Plan 1 and Plan 2, the social willingness to pay value lies between $5 million and $7 million per 1000 acres of open space. Since the opportunity cost of obtaining the 1000 acres provided by Plan 2 is $5 million, it follows that this cost is less than society's willingness to pay over the entire range of values within the stated limits. Therefore, Plan 2 is preferred to Plan 1, and Plan 1 can be eliminated from further consideration.

Now compare Plan 2 and Plan 3. The additional 1000 acres of open space provided by Plan 3 can be obtained at an opportunity cost of $7 million. Given that society's willingness to pay is between $5 and $7 million, Plan 2 is to be preferred to Plan 3 because, given the highest possible willingness to pay for open space, it is just equal to the opportunity cost of obtaining the additional increment of open space. By proceeding to make pairwise comparisons between the plans, it is established that Plan 2 is superior to all other plans if the social willingness to pay is between $5 million and $7 million per 1000 acres of open space.

It is possible to carry out this procedure in another way which can be used as a basis for performing the pairwise comparison of plans on the computer. Again, comparing Plan 1 and Plan 2, given the assumption that social willingness to pay for open space is between $5 million and $7 million, observe that Plan 2 provides more open space and Plan 1 provides a higher level of net benefits. Therefore, it follows that if the lowest value for open space is considered and the value of net benefits for Plan 2 is added to it, a low measure of society's total willingness to pay is obtained for Plan 2, since the willingness to pay for dollars of net benefits must be one. In this case, the total social willingness to pay for Plan 2 is $100 million, which just equals the willingness to pay for Plan 1. Since the lowest willingness to pay value for open space was assumed, it follows that Plan 2 is superior to Plan 1, except in the limiting case where social willingness to pay in fact was equal to its lower boundary of $5 million.

Now proceed to compare Plans 2 and 3. Plan 3 provides for more open space than Plan 2, but Plan 2 provides for more net benefits. In this case, the two plans are compared under assumptions most favorable to Plan 3 and least favorable to Plan 2. Since Plan 3 produces more open space, the most favorable assumption for Plan 3 is to assume that the true social willingness to pay value equals the upper limit of $7 million. In this case, the total social willingness to pay is $102 million for Plan 2 and $102 million for Plan 3. However, if the social willingness to pay for open space is below the upper boundary of $7 million then Plan 2 is superior to Plan 3. Therefore, except in the limiting case where social willingness to pay is at its upper limit, Plan 2 is superior to Plan 3, and Plan 3 can be eliminated from consideration. By continuing to make pairwise comparisons, it can be shown that Plan 2 is superior to every other plan in Table 5.

The procedure developed above can be summarized as follows. First, limits are established on society's willingness to pay for open space. The determination of these limits will be discussed subsequently. Second, plans are compared pairwise with respect to total willingness to pay, assuming the willingness to pay value most favorable to one plan and least favorable to the other. Third, if the plan for which the least favorable willingness to pay values were assumed yields a higher total than the alternative, then the alternative has been shown to be inferior for all possible willingness to pay values within the established limits and can be eliminated as a contender. If, on the other hand, the plan for which the most favorable assumptions were made yields the highest total, no conclusion can be drawn. This procedure will be generalized to the case where there are any finite number of objectives and the comparisons can be carried out on a computer.

While discussing the simple example in Tables 5 and 6, it is useful to note that setting limits on willingness to pay and using the above procedure does not necessarily eliminate all but one plan. For example, if the limits on social willingness to pay for open space had been $6 million and $9 million, all plans could have been eliminated except Plans 2, 3 and 4. Note the totals of willingness to pay for Plans 2 and 3 are 101 and 100 respectively, where it is assumed that willingness to pay is $6 million, which favors Plan 2 -- and 104 and 106 respectively when willingness to pay is $9 million, which favors Plan 3. Therefore, in this case no conclusion as to the relative merit of the two plans can be drawn since both plans are superior when the assumptions favor them. What this means is that there are some values for willingness to pay between $6 million and $9 million dollars for which Plan 2 is to be preferred, and some for which Plan 3 is to be preferred. From the previous discussion, Plan 2 is to be preferred for willingness to pay values for open space between $6 million and $7 million, and Plan 3 for values from $7 million to $8 million and Plan 4 for values from $8 million to $9 million. In this case the above procedure will eliminate three of the six plans in Table 5 from consideration, but there will still be three plans remaining. Either the limits will have to be further tightened or another procedure employed for making a choice between the remaining plans.

Given this introductory discussion, consider now the entire general procedure to carry out the pairwise comparisons. Consider a case where there are m nondominated plans which are to be evaluated with respect to n objectives. The information concerning these plans is presented in an m x n performance matrix (Oij) with rows corresponding to plans and columns corresponding to objectives. The entry Oij in the matrix represents the performance of the i^{th} plan with respect to the j^{th} objective. Each row of the matrix is a performance vector for the corresponding plan, e.g., $(0_{11}, 0_{12} \ldots, 0_{in})$ represents the performance vector of Plan 1. In addition suppose that the objective number one, 0_1, is net benefits measured in dollars with a willingness to pay value known to be one. Further, let $W_1 \ldots, Wn$ represent willingness to pay values corresponding to objectives 1 through n respectively. Further suppose that limits have been set on these values and are such that $W_{jL} \leq W_j \leq W_{jH}$, $j = 1 \ldots, n$, where W_{jL} and W_{jH} are the upper and lower limits on social willingness to pay for objective j.

Now compare Plan m and Plan i with regard to total willingness to pay, assuming willingness to pay values most favorable first to Plan i and then to Plan m. In other words, compare the sums

$$O_{i1} W_1 + O_{i2} W_2 + \ldots + O_{in} W_n$$

and

$$O_{m1} W_1 + O_{m2} W_2 + \ldots + O_{mn} W_n .$$

To choose willingness to pay values most favorable to it, willingness to pay values are set equal to the upper limit for those objectives for which Plan i performs better or equal to Plan m, and equal to the lower limit when the reverse is true. More precisely set $W_j = W_{jH}$ if $O_{ij} - O_{mj} \geqq 0$ and $W_j = W_{jL}$ if $O_{ij} - O_{mj} < 0$.

Then if

$$\sum_{j=1}^{n} O_{ij} W_j < \sum_{j=1}^{n} O_{mj} W_j$$

it implies that Plan m is to be preferred to Plan i. Again the reasoning is that if willingness to pay values most favorable to Plan i and least favorable to Plan m are assumed, the total willingness to pay for Plan m is greater than for Plan i, then for any values of willingness to pay within the specified limits the total for Plan m will be greater than for Plan i.

This can be seen as follows. First, note that

$$\sum_{j=1}^{n} O_{ij} W_j < \sum_{j=1}^{n} O_{mj} W_j$$

is equivalent to

$$\sum_{j=1}^{n} (O_{mj} - O_{ij}) W_j > 0$$

In this case

$$W_j = W_{jL} \text{ if } O_{mj} - O_{ij} > 0$$

and

$$W_j = W_{jH} \text{ if } (O_{mj} - O_{ij}) < 0 .$$

Therefore, any other set of willingness to pay values $W_1', \ldots, W_n'$ will be such that

$$W_j' \geq W_j \text{ for } (O_{mj} - O_{ij}) \geq 0$$

and

$$W_j' \leq W_j \text{ for } (O_{mj} - O_{ij}) < 0 .$$

Assuming all willingness to pay values are positive it follows that

$$\sum_{j=1}^{n} (O_{mj} - O_{ij}) W_j' \geq \sum_{j=1}^{n} (O_{mj} - O_{ij}) W_j \geq 0$$

This completes the proof.

Suppose, however, that

$$\sum_{j=1}^{n} (O_{mj} - O_{ij}) W_j < 0$$

under assumptions most favorable to Plan i, then no conclusion can be drawn as to whether one plan is better than another. The next step is to reverse the procedure using willingness to pay values favorable to Plan m. If

$$\sum_{j=1}^{n} (O_{mj} - O_{ij}) W_j \leq 0$$

for these new values of W_j $j=1, \ldots, n$, then Plan i is preferred to Plan m by the same line of reasoning.

The procedure outlined here requires that this pairwise comparison be carried out between every pair of plans. However, once a plan has been shown to be inferior to another for all possible willingness to pay values, that plan can be set aside and no more pairwise comparisons involving that plan need be carried out. This is useful because it can significantly reduce the number of comparisons which are necessary.

After all of the comparisons have been completed there will exist a set of plans which cannot be eliminated given the existing limits. Either the limits must be further tightened to eliminate all but one plan, or some other method must be used for selection among the final plans.

To this point the discussion has focused on the procedure to evaluate plans, and little has been said about its usefulness. There are a number of ways in which this procedure may be useful in evaluating plans. First, consider the case where the benefits of some objectives cannot be measured with sufficient precision to incorporate these objectives within the standard benefit-cost framework. At the same time, there may have been studies which have produced some information about the appropriate measure for these benefits. In many cases even where benefits cannot be measured precisely upper and lower limits can be established from estimates which are known to be biased upward or downward. In other cases there might be widespread agreement that benefits fall into a certain range. In cases such as this the above procedure incorporates this information into the evaluation procedure and uses it to narrow the range of plans.

This technique is not only useful in the case where benefits are difficult to measure, but also in the case where it may be possible to get agreement among the relevant policy makers about the range of social willingness to pay values. In many cases policy makers may be able to specify a range of values without being able to agree on a specific number. In this case the critical value approach can be used to eliminate those plans which are not consistent with the stated range of values.

Finally, this approach is useful where willingness to pay can be measured, but data collection and processing is costly and time consuming. In this case it may be possible to establish rough limits on willingess to pay and compare alternative plans. This procedure can be tested to see how critically dependent the result is on a particular limiting value. If it turns out that the evaluation is insensitive to some parameters, then rough estimates can be used and there is little to be gained by committing resources to the refinement of this measure. On the other hand, if the results are highly sensitive to changes in the limits of some parameter, the value of this parameter should be studied carefully. Suppose for example that the upper limit on the value of open space is critical in determining which plans are to be eliminated. Then it is necessary to analyze very carefully the assumptions and data underlying the establishment of this boundary. It might be worthwhile to perform additional studies to obtain more information concerning this parameter value.

The efficient use of the critical value approach requires that the pairwise comparisons can be carried out efficiently. This is particularly important for the sensitivity analysis where the entire procedure must be carried out each time one or more of the limits on willingness to pay is changed. Fortunately, the comparison can be performed on the computer and requires a very simple computer routine. Rough estimates indicate that even with large numbers of plans and objectives the required computer time can be measured in seconds. A brief discussion of the computer routine is presented in Appendix A of the methodology.

In all of the examples one pair of limiting values was set on the social willingness to pay for each objective. It is a simple extension to consider different limits on willingness to pay over different ranges of objective achievement. This can account for diminshing returns to society from the achievement of some objective. Such consideration are demonstrated in the limits placed on willingness to pay values for open space in the Tucson demonstration case.

The critical value approach can often greatly reduce the number of plans for consideration even when rather broad limits are set on willingness to pay. This is demonstrated in the study for Tucson. Once the number of plans has been reduced it is often possible to perform direct tradeoffs among objectives to arrive at a final selection.

The foregoing procedure was developed to facilitate the selection of plans given incomplete information about willingness to pay values. The final approach, which is simply an application of statistical decision theory, is also designed to bring all relevant information to bear on the question of project selection; however the emphasis is on the uncertainty of the social willingness to pay values.

Before proceeding to present a detailed description of how decision analysis might be applied to the problem of flood plain management, it is interesting to point out that Corps planners face two types of uncertainty: the first is uncertainty about future events such as the level of stream flow or amount of future development in the flood plain; the second is uncertainty about social willingness to pay for various products of a program of flood plain management. The Corps has long used the expected value of damage reduction as a measure of uncertain benefits from flood control. At the same time the Corps has predicted future development and, given the uncertainty surrounding such development, such estimates can only be considered in terms of expected future growth. It is clear that the Corps has long followed the procedure of maximizing expected net benefits where the underlying probability distributions were based on the available data and informed engineering judgment. If that judgment enters into the evaluation of probable future outcomes - and it always does - then it is appropriate to consider these probabilities to be subjective probabilities in the Bayesian sense.

In the same way that probability distributions are assigned to different hydrologic events, probability distributions are assigned to willingness to pay values. Under this procedure the values of willingness to pay are considered to be random variables with a given probability distribution. This distribution is based on the data and the informed judgment of the decision makers, which takes all available information into account. Given this interpretation the total willingness to pay becomes a random variable determined not only by the distribution of possible future outcomes but also on the distribution of willingness to pay values. If the objective is to maximize expected social willingness to pay and if the probabilities on distributions defined on the willingness to pay values are independent, then each plan can be evaluated using the expected value of willingness to pay for each objective as the weight assigned to the corresponding objective. More elaborate decision rules can also be developed which take into account possible variations in total willingness to pay in addition to the expected value. However, since the Corps uses the expected value of damage reduction as its stated measure of these benefits, it would be inconsistent with Corps practice to change the expected value rule here, although an exploration of this possibility should be considered. This however is well beyond the scope of this report.

The use of decision analysis can be illustrated by returning to the simple example presented in Table 5. Suppose that the true value of open space is between $6 million and $9 million for each 1000 acres. In addition assume that any value between $6 million and $9 million could with equal probability be the true value of social willingness to pay. Therefore, a uniform distribution on social willingness to pay is assumed and the expected value of willingness to pay is

$$\int_{6,000,000}^{9,000,000} \frac{1}{3,000,000} \, x \, dx = 7,500,000$$

It is easily demonstrated that Plan 3 will maximize the expected value of total social willingness to pay. A further example of this approach is presented in the demonstration case for Tucson.

It is interesting to note that when the limiting values on open space were set between 6 and 9 million dollars, the critical value approach eliminated all but Plans 2, 3, and 4, but did not determine the best plan, whereas the use of decision analysis did. This is because more information was assumed for the decision analysis approach in that distribution of the willingness to pay values was assumed to be known. In addition, the decision rule was to maximize the expected total of society's willingness to pay. Actually, where the expected value decision rule is followed, only the mean of the distribution is required.

Whether one chooses to use the critical value approach or apply decision analysis depends on the information available and how confident the decision maker feels with the use of subjective probabilities. In many cases a decision maker may wish to use the critical value approach to reduce the number of alternatives to manageable proportions and then use the method of direct tradeoffs to make the final selection.

SUMMARY AND EVALUATION

The methodology developed in this report is designed to facilitate the consideration of alternatives other than the traditional ones and to provide an approach to evaluation where there are multiple objectives. There are a number of advantages to this overall approach to flood plain management. First, the objectives are stated explicitly and in operational terms to facilitate the informed consideration of how alternative plans perform. Second, consideration is given in the planning process to important nonstructural measures and to measures which are not flood-related. By increasing the range of alternatives for consideration, the probability of selecting the optimal plan is increased. Third, an approach designed to facilitate the development of promising alternatives is incorporated into the methodology. This approach includes the step by step procedure to generate alternatives and use of opportunity costs to identify promising new plans. Fourth, the evaluation procedure includes an analysis of the tradeoffs among objectives. The relevant data with respect to possible tradeoffs is presented so that tradeoffs are made explicit and the value judgements underlying them are clear to the persons making the decision as well as to persons reviewing it. Fifth, several procedures are developed for evaluating alternative plans which go beyond present Corps practice in bringing all relevant information concerning willingness to pay values to bear in making the choice among plans.

Intuitively, it seems probable that by expanding the scope of flood plain planning and by making the decision process more explicit, the quality of the selected plans will actually improve. This, however, can only be tested by comparing the results of planning, based on the procedure in this report, with other planning procedures. Some tentative conclusions about whether the expanded planning procedure outlined in this report will lead to significant improvements in the plans adopted by the Corps of Engineers can be gained from exemplary studies. Such studies, however, can only demonstrate the methodology, and the results will not be conclusive since it is not feasible to carry out such studies on a scale comparable to typical Corps surveys. Therefore, final determination of the value of this methodology will have to await its application in a number of pilot studies where it is used as a basis for planning by the Corps. The design of the methodology makes it particularly amenable to testing of this type.

The point of departure for the approach taken in this report is present Corps practice and the alternatives which are developed include those traditionally considered by the Corps. It is therefore possible to compare how the choice of plans would differ, given the two planning procedures.

Even assuming that the final plan can be improved by taking this approach, there is still the question of whether the additional time and effort spent in implementing the expanded planning procedure will be justified by the results. The explicit consideration of objectives other than economic efficiency creates a problem of formulating objectives which in some cases will be specific to a given project. This will require additional policy decisions from the appropriate policy makers and greater communication between the field and the centers of policy determination. Further, the fact that more alternatives are considered is certain to increase the cost of Corps studies, assuming present methods. In addition, the introduction of new alternatives is likely to complicate the tasks of the planning staff because they will have to collect data on alternative projects with which they are less familiar. In fact the implementation of the present approach (which calls for the consideration of a wide range of nonstructural alternatives) may require some additions to present Corps planning capability. In summary, the approach to planning outlined in this report will probably be more costly and more difficult to implement. There are, however, several ways in which this difficulty may be minimized; this will be discussed subsequently.

One of the reasons that costs rise when the number of alternatives increase is that more data is needed to evaluate these alternative plans and there is also an increase in the cost of data processing. There is, however, a way of approaching this problem which does not involve as much data collection as would in-depth studies of each of the alternatives. This approach is based on statistical decision theory, and alternatives would be generated and evaluated on the basis of rough estimates supplied by the planner. Where hard data was not readily available the planner would estimate the average value of the variables under consideration, drawing upon his insight, intuition, experience, and whatever evidence was available. Using this data the plans would be screened, and in-depth studies would be carried out only for those which appeared most promising. It is sometimes argued that such a procedure is not reliable and therefore of no value. It may be true that the results are not completely reliable; however, better results can be achieved by incorporating the best estimates of experienced professionals than by ignoring certain alternatives altogether.

The use of decision analysis in Corps planning appears to be very promising particularly for long range projections where, at best, these estimates are subject to great uncertainty. Decision analysis could be of use with either the procedure outlined in this report or present Corps practice. In particular, it is of use in making preliminary evaluations of alternative plans. While this study does not focus on the handling of uncertainty and the role of decision analysis, this is an area which deserves consideration.

As was pointed out in the section on evaluation the critical value approach can also be used to reduce the cost of data collection and the consideration of large numbers of plans. The procedure is to set very broad limits on willingness to pay values and eliminate as many plans as possible. In addition, by performing sensitivity tests on the limiting values of various parameters, one can identify those parameters which are critical to the evaluation of plans and devote his resources to gather data on the parameters. In this way both the number of plans and the effort put into data collection can be reduced.

While no final answer can be given to the question of whether the additional cost of the procedure outlined will be justified by improved planning decisions, it should be noted that the cost of providing high levels of structural protection is often large in comparison with nonstructural measures. Therefore, if in a number of cases, high levels of protection can be replaced by plans incorporating lower levels of structural protection along with non-structural measures, the overall saving will be significant.

In the course of presenting the critical or limiting value analysis and the application of decision analysis, it became clear that information about willingness to pay could be exceedingly useful in evaluating plans even though precise willingness to pay figures cannot be established. This suggests that research designed to establish limits of willingness to pay and to provide information about the possible distribution of willingness to pay values can be of immense value. Therefore, research in this direction might be more productive than a frontal attack on the precise measurement of benefits. For, example, much more use might be made of consumer survey data and other questionnaire approaches even though it is known that there are biases built into such procedures.

Some critics of the method of evaluation presented in this report may complain that it involves value judgements whereas other hard numerical measures of performance, such as the maximization of net benefits, do not involve such judgements. The fact is that any criterion for choice involves value judgements and these are made explicit in the procedure developed in this report. The planner can develop the relevant plans for the final decision without reference to values, but in the final choice, values must enter. If the decision maker is willing to specify the weights he wishes to attach to the various objectives, the analyst can then proceed to determine the optimal plan. In general, however, the decision maker will feel more confident about his decision if his choice is made by considering the various alternatives rather than by specifying, in advance, weights on each of the objectives.

The apparent absence of value judgements in benefit-cost analysis is illusory. These judgements are simply implicit. Two of the most sweeping value judgements underlying benefit-cost analysis are that the distribution of income is irrelevant to the decision and that all objectives other than economic efficiency, measured in terms of willingness to pay, are to given zero weight. Put in these terms, the use of benefit-cost analysis implies very strong value judgments.

This report developes an approach to planning for flood plain management which is broader in scope and more comprehensive than existing procedures. A methodology is presented for the evaluation of alternative plans given multiple objectives and the range of admissible alternatives has been significantly increased. While the methodology spells out the approach and could be used as a guide to a creative planner in the field, it is not a planning manual which can be followed slavishly by people in the field. It does not spell out how to define every objective or how to generate each relevant alternative; it does not specify all data requirements, nor does it present a formula to measure the performance of each plan with respect to all possible alternatives. The basic reason for this is that the methodology must be general in order to cover a wide range of cases. By broadening the range of alternatives and objectives, data requirements, predictive models, etc., which are necessary for project planning will often be specific to a given project. At the same time, much of the data required is already collected by the Corps. Hydrologic information, forecast of land use, data on structural alternatives are all generated under the present procedures which would form the first step in the planning process described in this report. Therefore, the need for generality, the existence of much of the requisite information, and the specific nature of certain planning requirements makes it impossible to present a broad approach to planning which is also a recipe book for planning in the field. The success of each planning effort will depend on the creativity and imagination with which this approach is implemented.

INTRODUCTION TO DEMONSTRATION CASES

The purpose of this section of the report is to demonstrate how the methodology can be applied to actual field situations. For this purpose two demonstration case studies were undertaken. Because of time and resource limitations two parallel approaches were taken in these studies.

The first approach does not utilize detailed data. Rather, the approach in this case was to develop a description of the procedures which an analyst would go through if he were applying the methodology to an actual case. Here the emphasis is on the generation of alternative plans and on the considerations that must come to play in developing these alternatives. In addition, there is a fairly lengthy description of how some of the more detailed types of information required for the study could in fact be obtained. Because actual data was not generated for this case, the study ends with an array of alternatives for final consideration. This lack of data therefore, did not permit the performance of the tradeoff analysis nor the calculation of opportunity costs described in the methodology.

The second approach was to demonstrate the proposed methodology with a case using detailed data. In order to do this it was necessary to use whatever data was available, since there was neither time nor resources to generate new data. The purpose of this approach was to develop a case complete with the data necessary to perform the tradeoff analysis discussed in the methodology. Therefore, the emphasis in this case is on the generation of new alternatives using information contained in the data and on the analysis of tradeoffs among alternatives as it was outlined in the methodology. In many cases the data is rough and wherever it was necessary modifications were made to make available data consistent. Because the emphasis in this demonstration case is not on the actual methods of obtaining data nor on the procedures to measure different types of benefits, the exact procedures which were used in generating the data are not discussed in detail.

The two studies are complementary in that one is designed to give the planner insight into the thought process which is required for the implementation of the methodology and the other is an actual demonstration of how tradeoffs might in fact be performed and how, by combining alternative plans, it is possible to generate plans which are superior to those in the initial set. The latter also demonstrates that the methodology may lead to significant improvements in the planning process.

Two flood plains were chosen for the demonstration study; one in Reno, Nevada and the other in Tucson, Arizona. The characteristics of these areas are typical of many communities with flood problems. Each faces continuing urban growth with the flood plain being an attractive site in terms of development cost and locational advantage. Although there are similarities in the two study areas, there are also a number of significant differences. The most important differences are the types of flooding and the types of development planned in the respective flood plains.

Flooding in Reno is a consequence of overflow, principally from the Truckee River. This flooding is caused by rainstorms which, during the winter months, combine with normal snowmelt to exceed the normal channel capacity. With this type of flooding, adequate lead time exists to take emergency measures. In Tucson, on the other hand, flooding is characterized by extremely short advance warning. The normal channel of the Rillito Creek is dry. Its shallowness severely limits the capacity of runoff it can handle. Fortunately, the nature of the topography is such that even major floods cover a relatively narrow area. A major flood in Reno, on the other hand, would cover a large area in Truckee Meadows.

Another major difference between the two areas is the type of development planned for the flood plain. In Reno, the undeveloped portion of the flood plain is undergoing rapid industrial development without adequate protection against major floods. In the minds of the developers and local authorities, the locational advantages of the Meadows appear to outweigh the flood consequences. In Tucson, there is less pressure for development. The development in the Rillito Creek is residential, which is consistent with zoning in that area. Even with complete flood control, no change of use is contemplated, simply an increase in density of use.

In the course of preparing the demonstration cases experience was gained which led to some revisions in the methodology. Therefore, to some extent the demonstration cases served as a test of the applicability of the methodology. At the same time the tentative and incomplete nature of these demonstration cases makes further testing necessary. This could best be done if the methodology were used as the basis for an actual Corps study.

ANALYSIS OF THE RENO STUDY

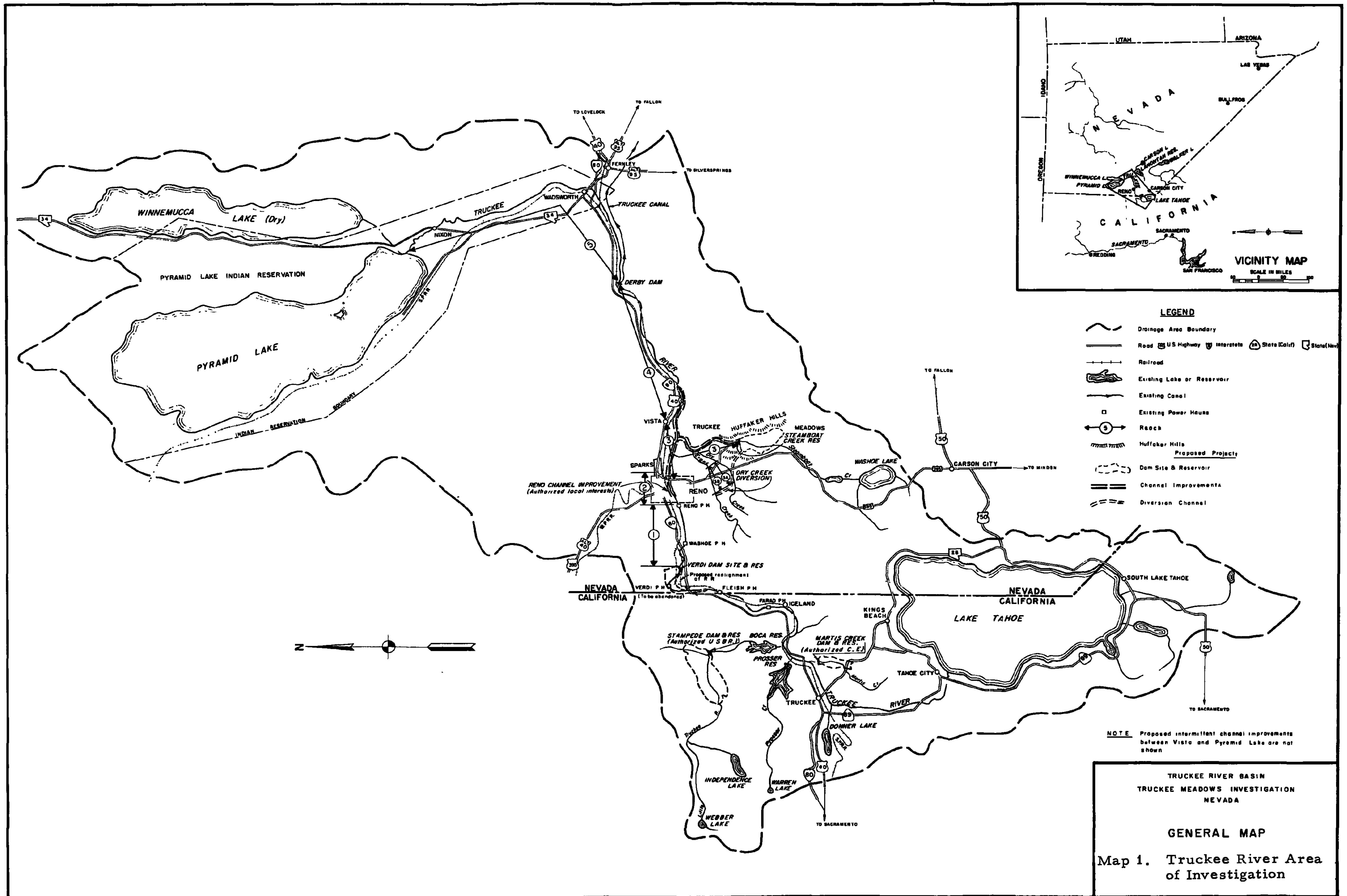
Reno was selected as a study area because it is characterized by several conditions which have contributed to the need for this methodology. In the first place, the structural measures already investigated appear to be only marginally justifiable on the basis of economic efficiency alone. This is a consequence of the nature of the topography which offers no highly favorable damsites. Second, a large part of the flood plain is as yet undeveloped and therefore offers opportunities to apply measures which will restrict land use to flood-complementary uses. Third, since land supply is not a constraining factor in the Reno area, opportunities exist to develop areas other than the flood plain. In subsequent pages, these three conditions will be developed to underscore the need for taking a more comprehensive approach to flood plain management. Before proceeding with the presentation of the procedures developed and tested in the Reno area, however, let us first familiarize ourselves with the characteristics of the study area* and then review the various projects proposed by the Corps to this point.

The Reno-Truckee Meadows area comprises most of the developed portion of Washoe County and a small portion of Storey County. (See Map 1, illustrating the Truckee River Basin included in this study.) Every significant economic indicator shows a high rate of growth for the area. As an example, in Washoe County during the period 1960-1968, population grew by almost 50 percent. Further evidence of high growth is shown by the 120 percent increase in property valuation during that same period in Washoe County.**

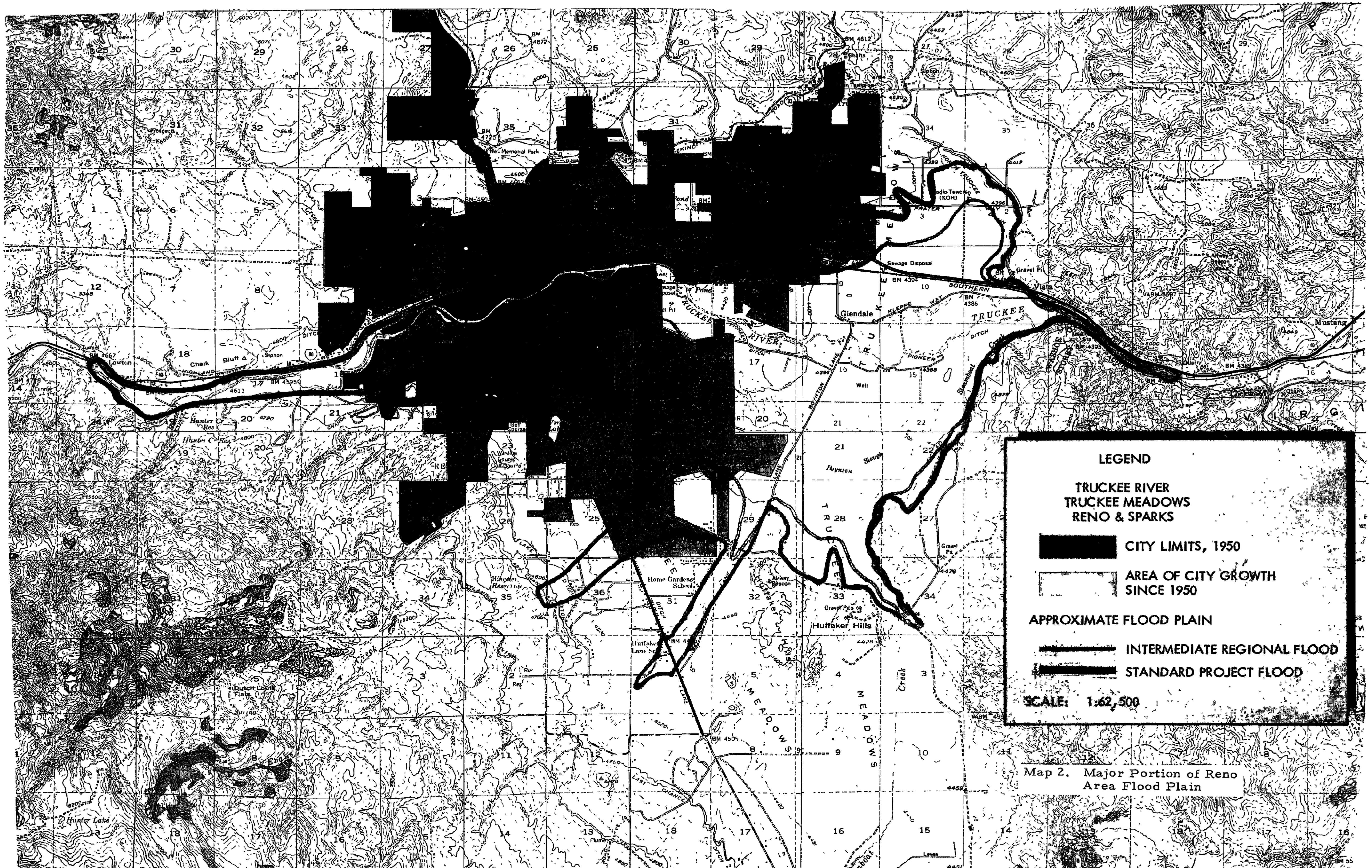
The area subject to overflow from a flood of SPF magnitude extends from the town of Verdi to Pyramid Lake, about 60 miles and measures about 13,000 acres (see Map 2). The flood plain is relatively narrow with the exception of a downtown section of Reno and Truckee Meadows. In

*The information to be presented here is by way of summary. For a more detailed description, see the June 1966 Office Report of the Truckee Meadows Investigation by the Corps Sacramento District.

**From data compiled by the Greater Reno Chamber of Commerce.



Map 1. Truckee River Area of Investigation



Map 2. Major Portion of Reno Area Flood Plain

the city of Reno, flooding extends for several blocks on each side of the river and for a considerable distance along the length of the river channel. Residential, commercial, and industrial establishments, as well as utilities and public institutions are located in this part of Reno. In Truckee Meadows, the agricultural land flooded is devoted to field, row, and truck crops, livestock production, dairy production, and grazing.

Recent consequences of the high growth rate experienced by Reno in the 1960's include an increasing tendency to develop the flood vulnerable lands in Truckee Meadows. The western and northern part of the Truckee Meadows area is being rapidly converted to an industrial and residential area. This portion of the Meadows is subject to much less frequent flooding than the eastern and southern portions which are developing much more slowly due to frequent and prolonged flooding. The northern part of the Meadows includes a fringe area of the city of Sparks which is contiguous to Reno's eastern city limit. It is questionable whether adequate assessment is made by those who are developing the Meadows area of the flood risk which must be borne by those assuming subsequent ownership.

Floods in the Truckee River Basin are of two distinct types, general rain floods and snowmelt floods. Snowmelt floods result from the melting of the accumulated snowpack and are characterized by relatively low peak flows and long durations. Snowmelt floods have large volumes, and usually the peak runoff occurs in May or June. Rain floods result from general rainstorms over a large part of the basin. They normally occur in late fall or early winter, but might occur anytime between October and April. Such floods are characterized by high peak flows of short duration and comparatively small volumes of runoff. Rain floods are by far the most destructive type of flood.

The most recent significant floods occurred in 1950, 1952, 1955, 1963, and 1964. The 1952 flood was a snowmelt flood; all the others are considered rain floods. Damages caused by these floods in the area below Verdi damsite, based on conditions at the time of the flood, are shown below:

Flood	Damage ($)
1950	3,000,000
1952	230,000
1955	2,000,000
1963	1,700,000
1964	1,330,000

In early 1964, the U. S. Senate Committee of Public Works authorized a study of the flood problem in the Reno area. The responsibility for this project was assigned to the Corps of Engineers Sacramento District. In June 1966, the District completed an office report titled "Truckee Meadows Investigation, Nevada: Truckee River Basin Flood Damages and Flood Control Benefits." The report was a thorough examination of Reno area economic characteristics, expected economic development, hydrological data, flood damages to be expected with and withouth the implementation of a recommended project of flood control measures, and the benefits to be derived from the proposed project. Its most controversial finding was that more than 80% of the total benefits from the proposed project would be derived from land enhancement. Furthermore, since a significant portion of the flood plain consists of large tracts, a large portion of the benefits were classified as "windfall benefits of 'unconscionable' magnitude accruing to limited special interests..." Benefits of this type were considered to accrue to protected properties in excess of 160 acres per ownership parcel, excluding a large parcel owned by the University of Nevada. On this basis, approximately half of the land enhancement benefits (40% of total benefits) would be of the "windfall" type accruing to special interests, the remaining half being termed "widespread" land enhancement benefits.

In January 1967, the District published a "Proposed Plan of Improvement," an office report which included estimates of flood flows and flow frequencies, a description of the tentatively selected plan, preliminary cost estimates and their allocation to project purposes and their division between the federal government and local interests, and an evaluation of project benefits. The proposed plan of improvement consists of a 37,000 acre-foot reservoir for flood control located on the Truckee River near the town of Verdi, Nevada; channel improvements on the Truckee River through the Meadows Area; a 20,000 acre-foot reservoir for flood control on Steamboat Creek at Huffaker Hills; channel improvements on Steamboat Creek between Huffaker Hills and the Truckee River; a diversion channel to divert flood flows at Evans Creek, Dry Creek, and Romas Creek into the Steamboat Creek Reservoir; and intermittent channel improvement along the Truckee River between Vista and Pyramid Lake.

The plan of improvement would provide protection through Reno and the Truckee Meadows against floods equal or nearly equal to the Standard Project Flood. The proposed plan would limit flood damage to values no greater than they were under preproject conditions in the reach below Vista. This plan was found to produce more net benefits than any other combination of structural measures.

The January 1967 report was first reviewed by the technical personnel involved at the various non-federal levels in water resources planning and evaluation. Involved in the review process were personnel from the State Engineer's Office, the Carson-Truckee Water Conservancy Board, the Public Works Departments of Washoe County and the Cities of Reno and Sparks, and the Washoe County Engineer. Reaction to the technical aspects of the plan were generally favorable. In subsequent public hearings and further review by political and civic leaders, however, significant opposition developed to the location of the Verdi Dam, a major plan component. An industrial park had been developed at the Verdi site in 1966 and its occupants were able to convince local government that the required relocation would be undesirable. Furthermore, the Nevada State Department of Fish and Game expressed opposition due to possible damage to a fishery and the need to relocate an existing State fish hatchery.

In response to resolutions of the Washoe County Board of Commissioners, the Reno and Sparks City Councils, and the Washoe County Legislate Delegation, the Corps agreed to study alternate storage sites on the Truckee River and tributaries above Reno. A report to this effect was published by the Sacramento District in May 1968. Four alternate sites were studied and data regarding the Verdi site was updated as well to provide comparability. The Corps concluded that, even taking into consideration the costs of relocating the industrial development in question, the Verdi site was still the most desirable in terms of economic efficiency. A second site, at Lawton, Nevada, was presented as an economically feasible alternative although it was pointed out that this site would have a lower benefit-cost ratio.

When the results of this analysis were presented to local interests in October 1968, one aspect of the plan which was questioned was the justification of taking out of use 6,500 acres maximum pool area for the two storage reservoirs in order to protect 6,300 acres of flood plain. A counter proposal was offered by a local civil engineer opposing the construction of any reservoirs whatsoever and instead using a combination of channel improvements, flood proofing, and downstream flood easements to combat the effects of flooding. The details of this plan will be presented later. It is interesting to note, however, that the Corps had rejected channel improvements only as economically infeasible, whereas the plan presented by the local engineer claimed a total estimated cost of less than 25% of the Corps' proposed plan of improvement. At the time of this writing, this imbroglio has not been resolved.

We will now begin "walking through" the proposed methodology on a step by step basis to see if the more comprehensive approach to planning could have been effective in avoiding some of the divergence between the federal and local interests. The approach to presenting the Reno study is to illustrate how the methodology could be applied in a proceduralized manner. The methodology has been reduced to a number of steps. The steps are grouped under the three main procedural headings comprising the methodology. The headings are: Define Objectives, Develop Alternative Plans, and Analyze Tradeoffs. The study first seeks to define all pertinent objectives, local as well as federal, in order to set basic guidelines for further flood plain planning. Given these objectives, alternative plans are generated all of which are alternative proposals for the prudent use of the flood plain. Finally, the alternatives are compared against each other by trading off the achievement level of each objective of one plan against the levels achieved for the remaining objectives by each of the other plans. The procedures developed and tested in Reno, as well as the results of the study for that area are presented in the following paragraphs.

DEFINE OBJECTIVES

1. Compose an initial set of objectives for the flood plain. To begin this discussion, there are a number of national objectives which are of concern to the federal planner in his analyses. The first is to maximize net benefits to be derived from a program of flood protection. This particular objective has previously been discussed in some detail and will not

be further pursued at this point. In the Reno case, the objective is included since it is obvious that maximization of net benefits will be the principal Corps objective for some time to come.

A second objective which seems to be of particular relevance in the Reno area is to prevent inequitable income redistribution among the local beneficiaries. Of particular concern is the distribution of land enhancement benefits. If the federal government, through its implementation of structural measures, provides flood protection in Truckee Meadows, a large percentage of the benefits will include the enhancement of land uses and land values. In this particular area, there are a number of large tracts owned by single owners who would receive a disproportionate amount of benefit from having their property protected from floods by action in which they make no direct investment.

Naturally, these owners wish to see a measure implemented which will make their property flood-free. If they wish to do so by their own action such as flood proofing or taking out insurance (if it is available), they might receive large benefits resulting from their own investment. Only to the extent that these owners receive <u>public</u> subsidies or reap direct benefits from <u>public</u> investment, the redistribution objective is concerned with cost sharing by these large landowners. In other words, to the extent that benefits are not widespread, there should be some adjustment made to make certain that large landowners participate in the tax dollars allocated to make the flood plain free of flood danger.

It is particularly difficult to establish which of the land owners should share in the cost of flood plain measures. The Corps policy, for example, has been to let the local interests determine how to proceed in this matter and the Corps simply determined whether a significant amount of inequitable income redistribution would occur. In Reno, it has been decided that 50% of the land enhancement benefits of a flood control project would be received by owners of large tracts of land (defined as single ownership plots in excess of 160 acres) in the Truckee Meadows flood plain. Therefore, the total local contribution for a Reno project is determined on the basis of this judgment by the Corps.

It is not within the scope of this report to comment on the methods used for determining cost allocation based on land enhancement benefits. On the other hand, it is recognized that the basic objective of preventing inequitable benefit distribution is valid and an attempt has been made to incorporate this objective into the analysis for the Reno area.

In addition to these generally accepted objectives, there exist a number of objectives whose effect from the national viewpoint may be negligible or even conflicting. They are of great concern, however, at the lower jurisdictional levels and therefore have significant impact on the acceptability of any given federally proposed program.

Although it is beyond the scope of this report to detail how the planner determines non-federal objectives, for the purpose of this demonstration study it was necessary to use a technique to determine relevant flood plain objectives of non-federal interest. This is especially important in cases such as Reno where a relatively high capital contribution by the non-federal interest is required in construction projects.

A means to determine relevant non-federal objectives is to contact the various organizations and individuals known to be concerned with what happens in the flood plain. This includes not only those who would be affected by the relatively infrequent flood occurrences but also those who wish to use the flood plain for various purposes. A companion study conducted by the University of Chicago has explored in detail how one determines the community sources of information, the relevant persons to be contacted, and the approach to these contacts.

Briefly, the approach involves determining a community pattern of influence, determining who are the principal flood plain policy makers at the local and state levels, and thoroughly interviewing these sources. The innovative part of this approach, aside from the thorough presurvey analysis aspect, is the determination of who, by their reputation in the community, actually influences development policy in the flood plain. Furthermore, it should be apparent that this procedure allows the identification of various sources of potential opposition to future plans. If the diverse viewpoints are taken into consideration at an early stage such opposition can be neutralized by broadening the objectives and expanding the scope of planning.

The process of setting down all possible objectives is analogous to performing a "requirements analysis." In essence, those persons who are directly affected by a proposed "system" should be consulted as to why they require such a "system," what they expect of it, what problems they require solutions for. Once this information is known, the planner can generate various alternatives which he knows from experience to be realistic approaches in view of the requirements of the system end users.

In Reno, this technique was applied, though as a result of the short time available, on a small scale. The following persons who were known to be technically experienced in questions related to Reno's flood problem, were interviewed:

Regional Planning Director
Regional Planner
A Civil and Structural Engineer in private practice
County Engineer
Chamber of Commerce
    Director for Business and Industrial Development
State Engineer
Sierra Pacific Power Company
    Director Advertising-Publicity
    Director for Land and Water Rights
Member, Carson-Truckee Water Conservancy Board

One can see from this list that no elected officials were included in the interview sample. The reasons for this are twofold. First, the limited time available for this study dictated concentration on personnel who had been close to the problem for some time. Second, it was essential to avoid giving the erroneous and unrealistic impression that the study team was in Reno to propose yet another alternative plan of improvement offered by the Corps. The study team believed that involvement by elected officials would have given such an impression and thereby divert the effort from its true intent which was to demonstrate the methodology.

Naturally, in a full-blown study a much larger interview sample would be required to draw conclusions with reasonable certainty. However, in this study it was possible to skim the cream of the sample of experts by visiting a number of persons who are and have been involved in flood plain decisions to a fairly high degree of technical detail for a number of years. As we shall see, the interviews in most instances showed a surprising degree of consistency in the kinds of problems and goals of the community.

First to be interviewed were the Director and a planning professional of the Regional Planning Commission of Reno, Sparks, and Washoe County. The Commission is responsible for planning and zoning functions in Washoe County. Through its full-time staff, the Commission has produced, and updated about every five years, the "General Plans of Development for the City of Reno, City of Sparks, and the County of Washoe." This plan provides not only relevant problem statements, but also is meant to promote the public health, safety, convenience, and welfare of the citizens of the three jurisdications by:

1) Proposing a comprehensive plan for the orderly development and use of land resources.

2) Proposing a functional plan for streets and highways with a view to minimizing traffic congestion.

3) Proposing a comprehensive plan for the location of all public buildings and community facilities.

4) Recognizing the importance of the Truckee River as a major asset of the community and emphasizing its scenic and recreational potential.

5) Encouraging the tourist oriented economy of the area.

6) Encouraging selected industrial development in cooperation with other community agencies.

Discussions with the representatives of the Regional Planning Commission were first centered on problems related to water resources in the Greater Reno area. The following were noted:

- The possibility of flood disaster is generally recognized in the community. A disaster plan is set up for Sparks and will be developed for Reno and the county by the Civil Defense Agency.

- A great deal of industrial development is now taking place in areas of high flood risk in Truckee Meadows.

- Land prices in this area have apparently discounted structural flood protection expected to be provided. Prices are two to three times as high as alternate sites with similar topography.

- Alternate sites which have no flood problem are available for development. Truckee Meadows is at present more attractive than these areas, however, due to its locational advantage, its rail service, its ready access to water and utilities, and its superior road access.

- With the exception of several minor areas downstream, bank erosion from rapid flow is not a significant problem.

- The level of Pyramid Lake, into which the Truckee River drains, is dropping over 1 foot per year because the water is diverted to an irrigation project east of Reno.

- Extensive water-based recreation is not readily accessible to Reno inhabitants. The closest lakes are 45 minutes to 2 hours driving time from Reno.

- The industrial development at the Verdi damsite totals about 15 to 20 acres.

- Flood regulations by the County are minimal, and include

  - Draining requirements for subdivisions

  - Setback regulations preventing encroachment (only in the immediate area of the channel)

The next person interviewed by members of the study team was a local civil engineer in private practice. He had been driven by his sense of community responsibility to analyze in detail the plan of improvement proposed by the Corps with which he disagreed sharply. It was his contention that the damsite at Verdi, even though it might be the best of the available sites, was a very marginal location. He did not believe that reservoir storage would be the most suitable solution to the Reno flood problem. His alternative proposal consisted of a combination of channel improvements, flood proofing, and flood easements. This plan will be more fully described when we consider various alternative combinations of measures.

The next visit was with an executive of the Greater Reno Chamber of Commerce. It was learned that this person had been instrumental in helping to relocate the present occupants of the Verdi industrial park from a heavily urbanized area in California to the relatively pastoral setting at Verdi. He believed that relocation of the industries at Verdi to another site in the Reno area was unacceptable to the owners and hence that this investment would be lost to Reno. He indicated that total employment presently was about 85 persons, and that significant growth was expected for the area.

The Chamber of Commerce executive further believed that a dam at Verdi would be unsightly. It has been explained by the Corps that the normal pool area behind the dam would be 2000 acrefeet to be devoted primarily to recreation. During flood conditions the pool area would expand to about 35,000 acrefeet. The general impression appears to be that in order to use the recreation facility during normal times, one would have to traverse large muddy areas before reaching the reservoir edge. The unsightliness associated with this condition would be especially critical because the reservoir would be located along highway routes heavily traveled by incoming tourists (of which there were about 60 million in 1968).

In addition, a number of developable flood-free areas were discussed as alternatives to developing the flood plain. Development can be classifiable in two groups: the type which is rail-dependent, and that which does not require rail transport. Areas served by rail (other than the flood plain) are in Sparks, east of the Sparks city limits, west of Reno towards Verdi, and north of Reno as far as the abandoned Stead Air Force Base. Areas not dependent on rail transport are north of Sparks into Spanish Springs Valley and south of Reno toward Carson City.

Finally, the Chamber of Commerce executive expressed his belief that there would be no significant increase in the rate of development of Truckee Meadows on account of flood control implementation. This implies conflict with the significant land enhancement benefits projected by the Corps. He expressed the opinion that the Corps should consider further improvement of the downstream channel below Vista in order to prevent backup flooding in Truckee Meadows.

Next visited was the Washoe County Engineer. He stated that his responsibilities with respect to the flood problem were to enforce the County subdivision draining regulations and to maintain the County setback regulations to prevent channel encroachment. He also expressed his concern over flooding by the various tributary creeks draining into Truckee Meadows.

A staff engineer in the Nevada State Engineer's Office of Water Resources in Carson City was visited next. The principal responsibility of the State Engineer is to establish and regulate water rights. In this connection, the State Engineer must review all plans for water resource projects. With the rule that first in use has first priority, all Truckee River water has long been fully allocated.

The State of Nevada is responsible for the maintenance of the Truckee channel at Vista, at an annual cost of $75,000 per year. In 1960, the Corps lowered a series of reefs in this area, which appears to have been effective in reducing some of the backup flooding in Truckee Meadows. The staff engineer believed that the annual maintenance cost to the State could be eliminated if channel flow could be kept below 6,000 cubic feet per second. Note, however, that no project proposed to this point is able to accomplish maintenance of this capacity at peak flood conditions. The Corp plan, for example, has a design capacity at Vista of 18,000 cubic feet per second at peak flow.

In regard to location of development in the Reno area, the State Engineer's staff member related that warehousing activity in Truckee Meadows has quadrupled in the last three years, and development is continuing at a rapid pace. Concerning alternative areas for such development, he stated that the main disadvantage is the lack of adequate rail service. On the other hand, it was his opinion that in two of the areas which could be considered for alternate sites, the Stead area and Spanish Springs Valley, the underground water supply is quite adequate.

The study team next interviewed two executives of the Sierra Pacific Power Company which distributes gas, electricity, and water in large portions of Western Nevada. In addition, Sierra Pacific develops industrial parks on some of its extensive land holdings, including the one at the Verdi damsite and various sites in Truckee Meadows.

The discussions centered principally on the cost and other implications of making alternative sites at least as attractive to developers as the Meadows area. Although there appears to be some differences of opinion on this, it appears for example that the Stead area water supply would be inadequate to support a significant magnitude of development.

If, however, it is possible to pump water to the area (along with improving its highway and rail access) at a cost which compares favorably with the cost required to provide flood protection to the Meadows, flood plain objectives might be achieved more effectively.

With this in mind, the study team inquired into the ramifications of providing additional water to the Stead area. To duplicate the present capacity of 3.8 million gallons per day, for example, would cost $2 million including pipelines and pumping, but not distribution. Besides the capital cost, however, there are two major problems which must be faced. First is the fact that Sierra Pacific is prohibited by Nevada statute to use water metering. The company therefore must charge flat monthly rates per connection. Since customers may use (and waste) as much water as they desire, this situation has led to a tradition of water overuse. Thus, until the statute is changed, required capacity must be planned far in excess of what would be expected to be normal consumption.

A second major problem deals with the water rights to the Truckee River. Sierra Pacific officials estimated that only 10%-20% of the Stead area water required by a projected population of 30,000-50,000 can be met by local wells. This means that the remaining 80%-90% of the water needs should come from the Truckee watershed. However, with such a large proportion of the water supply coming from the fully allocated Truckee, it becomes very difficult to meet the total supply requirements significantly unless compacts with others owning Truckee water rights can be made.

The question of water rights becomes extremely complicated because of historical inaccuracy and controversy. There is for example the plight of the Paiute Indians who owe their livelihoods to Pyramid Lake, which is included in a 500,000 acre reservation. This 100,000 acre lake, fed by the Truckee, is the principal source of income to the Indians who depend heavily on fishing and the sale of recreation permits. The level of the lake has dropped 82 feet in the last 58 years resulting in losses of scenic and ecological value. Increasing salinity will make the lake uninhabitable to fish, according to the Sierra Club, and various wildlife species are or will shortly be extinct.

The level of the lake is dropping because Truckee water is being diverted to serve the Newlands Irrigation Project east of Reno, an area also served by the Carson River. The Newlands project was established in 1902 with apparent disregard for the needs of the Indians. Although no specific water rights were established in the reservation agreements made with the government in 1859, the Indians contend that these rights were implied.

Problems such as these illustrate the importance of water rights in any decision on water resource projects. These problems crop up not only in terms of use of the water for pumping to alternate sites but also relative to the impact of reservoir storage on the total water supply. Particularly, in regions such as Western Nevada where desert temperatures often soar, the evaporation rates of reservoirs is of concern to planners.

The last formal interview was with a member of the Carson-Truckee Water Conservancy Board. He described the Board's reaction to the Corps proposals. First, the Board believed that the planned improvements were too expensive. The cost of the project proposed by the Corps was $65 million, in July 1968 prices, of which $13.1 million was to be borne by the local interests. Secondly, the Board believed that it would be difficult to justify a plan that in order to protect 6,000 acres of land proposes to take out of use over 6,000 acres elsewhere for the purpose of reservoir storage. It was indicated that in view of these difficulties, the Board might be willing to consider plans designed to provide protection against floods of lesser magnitudes than the Standard Project Flood.

On the basis of the various interviews conducted by the study team, it was possible to list an initial set of objectives as articulated by those who were interviewed. They were as follows:

1) Maximize net benefits

2) Prevent inequitable distribution of benefits

3) Prevent flood damages

4) Encourage continuing economic growth in the Greater Reno area

5) Minimize the risk of flood disaster in terms of deaths and extensive property damage

6) Prevent channel erosion caused by high velocity flow

7) Provide added water-based recreation (especially fishing and water skiing) in the immediate Greater Reno area

8) Preserve Pyramid Lake Cutthroat Trout (which can be raised at only one location in the world, a State hatchery located at a preferred damsite at Verdi)

9) Preserve the present industrial development at the Verdi damsite

10) Reservoirs used for recreation must be aesthetically pleasing.

2. Eliminate those objectives which do not appear to be important. Although the methodology is able to handle any number of objectives, as a practical matter it is useful to reduce them only those which are most important to the analysis. If this is done early in the analysis, a great deal of data collection and processing can be avoided. Furthermore, the decision to rule out a specific objective is not irreversible. If, at a later date, it is decided that the importance of this objective has been prematurely minimized, it can be reentered into the analysis at that point in time.

Reducing the list of objectives to a more manageable number is a process requiring judgment in any case. There are, however, two central criteria which important objectives should meet: 1) the number of people directly affected by or involved in the achievement of the objective, and 2) the amount of money involved in attempts to achieve the objective, or conversely in ignoring the objective.

The set of pertinent local objectives generated for Reno were tested against the above criteria. The discussion with the various local people brought out that several of the objectives probably would not meet the criterion that the goals were of concern to any but a very small minority. The risk of disastrous floods with a significant number of deaths and extensive property damage seems insignificant to most persons interveiwed. In fact, even the worst floods seem to allow adequate leadtime to take measures to protect lives and personal property. Several of those interviewed expressed the view that since the 1950 disaster, the flood plain dwellers are now much better prepared to deal effectively with all but the worst floods. They maintain that if SPF conditions were mitigated to a lesser magnitude flood, this would be considered adequate protection.

Channel erosion is also not considered a widespread problem. Several downstream ranchers claim to have experienced some difficulties but the problems do not appear widespread enough to warrant consideration as a major objective in the management of the Reno area flood plain. Channel erosion prevention can thus be eliminated as an objective in and of itself. Instead, we can include it in the benefit-cost objective and measure performance by the change in the cost to the State of Nevada of maintaining the channel bank.

The preservation of the State Fish Hatchery at the Verdi site is another objective which does not meet the criteria that it has significant economic value or affects a significant amount of people. Note that preservation of the hatchery is important, but, since it could be relocated elsewhere we are speaking here only of its preservation at the present site. Although some discussions mentioned that the present site was the only one at which Pyramid Lake Cutthroat Trout could be raised, on the face of it this is difficult to accept. The study team was not able to obtain an authorative statement in this matter, or whether some sort of temporary protective measures in case of flood danger would be feasible. Therefore, if one does accept the thesis that the preservation of the hatchery at the present site is inviolate, this should be treated as a constraint rather than as an objective. In this way, we can later examine the willingness to pay for maintaining this constraint against the losses (not necessarily economic) associated with the inundation of the hatchery.

Preserving the industrial development site at Verdi also does not appear to be an important objective on the grounds that the development can be relocated. While a great deal of discussion was heard by the study team of what were assumed to be debilitating effects on the Reno economy of inundating this area, a trip to the site left the impression that statements by a few individuals had exaggerated the significance of the development as well as its future potential. This lesson points to the awareness with which a planner must treat statements of objectives where a highly articulate and persuasive person can give weight to an objective totally out of proportion to its appropriate significance. Certainly, if relocation of the industries to another site in the Reno area were not acceptable to its owners, the number of people involved and the amount of economic activity is so small that it should not be permitted to affect decisions involving the welfare of the significantly larger number of people occupying the flood plain.

One stated objective was to "prevent flood damages." As previously discussed in detail in the presentation of the methodology, this objective is in actuality a subobjective or intermediate goal which is part of the benefit-cost objective. Since it is not an objective in itself, but only another means of maximizing net benefits, the statement is eliminated from the list of objectives.

Finally, the objective that reservoirs used for recreation must be aesthetically pleasing is actually a design constraint. It is economically an insignificant component of any plan to be proposed, involving landscaping and proper design of access areas. This requirement therefore also can be eliminated from the list of objectives. This completes the parsing of the initial list of objectives to a more manageable set.

3. <u>For each objective, select a unit of measure.</u> Once the various objectives have been selected it now becomes necessary to find a unit of measure on the basis of which it can be determined whether a particular objective is being achieved. Such a unit of measure must have several attributes. First, it must have maximum correlation with what is being measured. In other words, the unit of measure should be able to convey accurately just how well the objective is being achieved. Second, it should be easy and convenient to use. It should be clearly shown that the unit measures achievement at various levels and it should be easily comprehensible in analysis. Third, it should be economical to use. An example of this economy is the amount of data necessary for measurement. If the amount of data that the planner needs to originate can be minimized and instead he can use data already collected by other agencies, the unit of measure has passed the test of economy.

On the basis of these criteria, the following units of measure have been selected to evaluate the various objectives.

OBJECTIVE	UNITS OF MEASURE
Maximize net benefits	Present dollar value of the difference between benefits and costs
Prevent inequitable benefit distribution	Widespread benefits as a percent of total benefits
Contribute to regional economic development	Number of acres made usable for industrial development
Provide added water-based recreation	Additional acres of water surface

We shall now consider the reasons for selecting these units of measure. In the Reno study prime emphasis was on the availability of data. Although with more time better units might have been selected to measure some of the objectives, every effort has been made to reasonably meet the criteria described above. In order to meet the criterion of ease and convenience, for instance, the units of measure have been constructed so that a relatively higher value for a given objective means that a more desirable level of achievement is reached. For example, prevention of inequitable income distribution could have been measured directly by the "amount of benefits not equitably distributed." However, in this case a relatively lower amount would reflect increasingly desirable levels of achieving this objective. To avoid such confusion, the converse unit was chosen which measures attainment of the objective by looking at increasing values of "widespread benefits as a percentage of all benefits" from a given plan. Note that widespread benefits are specifically, although perhaps somewhat arbitrarily, defined as those land enhancement benefits received by owners of parcels of less than 160 acres. To compute this conveniently, we would tabulate the benefits accruing to the special interests and then subtract the result from the total land enhancement benefits.

The selection of the "number of acres made usable for industrial development" as a measure of the capacity of a plan to contribute to regional economic development is based on a strong desire by the community to diversify its largely tourist-oriented economic base. That is not to say that continued expansion in tourism will not prevail, but simply that flood-related programs are going to have their principal impact on the land made available for upgraded use. In a broad sense, tourism in Reno is an industry which requires facilities just as other industries. Therefore, no real restriction in the selected unit of measure exists.

If regional economic development is to continue taking place, a highly important contributing factor is the supply of sites amenable to industrial development. Such sites should have a number of characteristics already alluded to in previous discussion. The sites should be free from flood danger, relatively flat, accessible by either rail or highway transport or both, and serviced by the appropriate utilities in adequate quantities. The total present supply of land in the Reno area including Stead zoned for industrial used is about 5000 acres, of which 40% is currently in use. However, much of the remaining 60% which is not now developed comprises land which is lacking in at least several of the characteristics just enumerated. As an example, a Regional Planning Commission staff member reported that about half of the industries interested in locating in the area indicated a need for railroad facilities. If sites with these characteristics are and will be made available, then in light of its other amenities Reno can expect continued growth. Finally, the continuing increase in industrial land prices is at least partial evidence that the demand for desirable sites has been outstripping the supply. Thus, the total number of acres comprising such sites is a proper and easy-to-use index of the contribution which flood plain management can make to regional economic growth.

The selection of acres of water surface to measure the magnitude of water-based recreation is perhaps more controversial because the Corps traditionally allocates costs by purpose according to the number of acre-feet provided for recreation. It would appear, however, that a measure of <u>area</u> would be more precise than a measure of <u>volume</u> in estimating the supply of a recreation resource where water-skiing and even fishing are activities conducted at or near the surface of the water.

A third alternative measure of water-based recreation might be the coast length of the water body being evaluated. This is a measure of perimeter which implies that the longer the coast length the better the recreation objective is being achieved. This measure would have to take into account the quality of the coast line, however, since it is implied that the recreation activities are conducted primarily on the banks of the water body. The area measure on the other hand is independent of bank quality and assumes only that sufficient boat-launching areas are available. This concludes our discussion of how objectives were defined in the Reno demonstration study. Based on our findings, we shall now develop alternative plans which attempt to meet the stated objectives.

DEVELOP ALTERNATIVE PLANS

The procedures in this section, concerned with the development of alternative plans, are grouped under four major headings. The first deals with generating appropriate structural measures only, the second with only non-structural measures, the third with the synthesis of structural and non-structural flood plain measures to generate additional alternatives, and the fourth with substitute measures which could conceivably replace flood plain measures if objectives could be achieved more effectively in this way.

The procedure assumes that the flood plain has been delineated, including the areas flooded respectively by, say, the 50-year, 100-year, and Standard Project Floods. In addition, the flood plain is assumed to be segmented intc a number of reaches each of which is hydrologically homogeneous. Furthermore, it is assumed that depth-damage data is available for various flood zones and stream reaches. Information of this sort is normally found in the flood plain information reports and other studies of the Corps of Engineers.

The practice of dividing the study area by reaches and contour levels is highly desirable because it permits studying the impact of combining different measures in different areas. In addition, the effect of installing a given measure in a particular reach on the levels of flooding in other reaches can be studied. This is particularly important in the Reno-Truckee Meadows area, where the proposed channels will accommodate different levels of flow at different points along the river.

Structural Measures

1. Identify appropriate structural flood control alternatives. This step concerns the basic engineering considerations for a flood plain. It includes the determination of the locations and general design features of structural alternatives. This work is conducted in a manner similar to present Corps practices. Included also in this step is the examination of hydrological and geological (including subsurface) conditions to assist in the development of appropriate designs.

Since the methodology is applied in a presurvey stage where the planning is of a comprehensive framework nature, detail study should be avoided. To the extent feasible, use should be made not only of sound engineering judgment, but of previous studies by other federal, state, and local agencies as well. Since there exists a wealth of experience and workable procedures and practices in conducting this step, no further comment is required.

A number of possible structural alternatives have been generated for flood control in the Reno area. One approach to structural flood control is improvement of existing channels. This includes deepening, widening, and increasing bank height. Although in Reno channel improvement alone is probably not an economically feasible means to control the standard project flood, it should be considered initially as a feasible method. This is so that adequate data is obtained for evaluating possible combinations with other measures at a later stage.

To provide protection for Truckee Meadows against the Standard Project Flood (SPF) using channel improvements only would require a channel capacity of 50,000 cubic feet per second at Vista and very large channels through Reno and the Meadows. This is based on an estimated 34,400 cfs peak on the Truckee River and a 15,000 cfs peak at the mouth of Steamboat Creek under SPF conditions*. This level of channel improvement at Vista would require extensive modifications to present transportation facilities. Using channel improvements alone to protect against the SPF is probably not a practical or economically feasible solution. However, this measure is feasible for protection against lesser floods and if combined with other measures can provide the equivalent of SPF protection.

*Source: Proposed Plan of Improvement for Truckee River and tributaries, an Office Report by the U.S. Corps of Engineers, January 1967, pp. 2, 3.

Estimates of the effects of various levels of channel improvements should be made to indicate the extent of residual flooding associated with each.

The Corps, in studies made in connection with a currently authorized storage reservoir (Martis Creek Reservoir) on a Truckee River tributary, has shown that enlargement of the Truckee through Reno to a capacity of more than 14,000 cfs is not economically feasible. This level of improvement would provide protection against the equivalent of an 80-year flood. It should be noted that the Corps' conclusion on the economically feasible upper limit of channel capacity has been disputed on the grounds that alternative and less expensive means for channel improvements were not considered. It has been argued for example that, contrary to Corps proposals, there exist methods for channel enlargement in downtown Reno which do not require rebuilding of the six bridges spanning the river in that area. However, since detailed information on other levels of protection is not available to support these contentions, the 14,000 cfs capacity channel will be used as a baseline for comparison and combination with other measures.

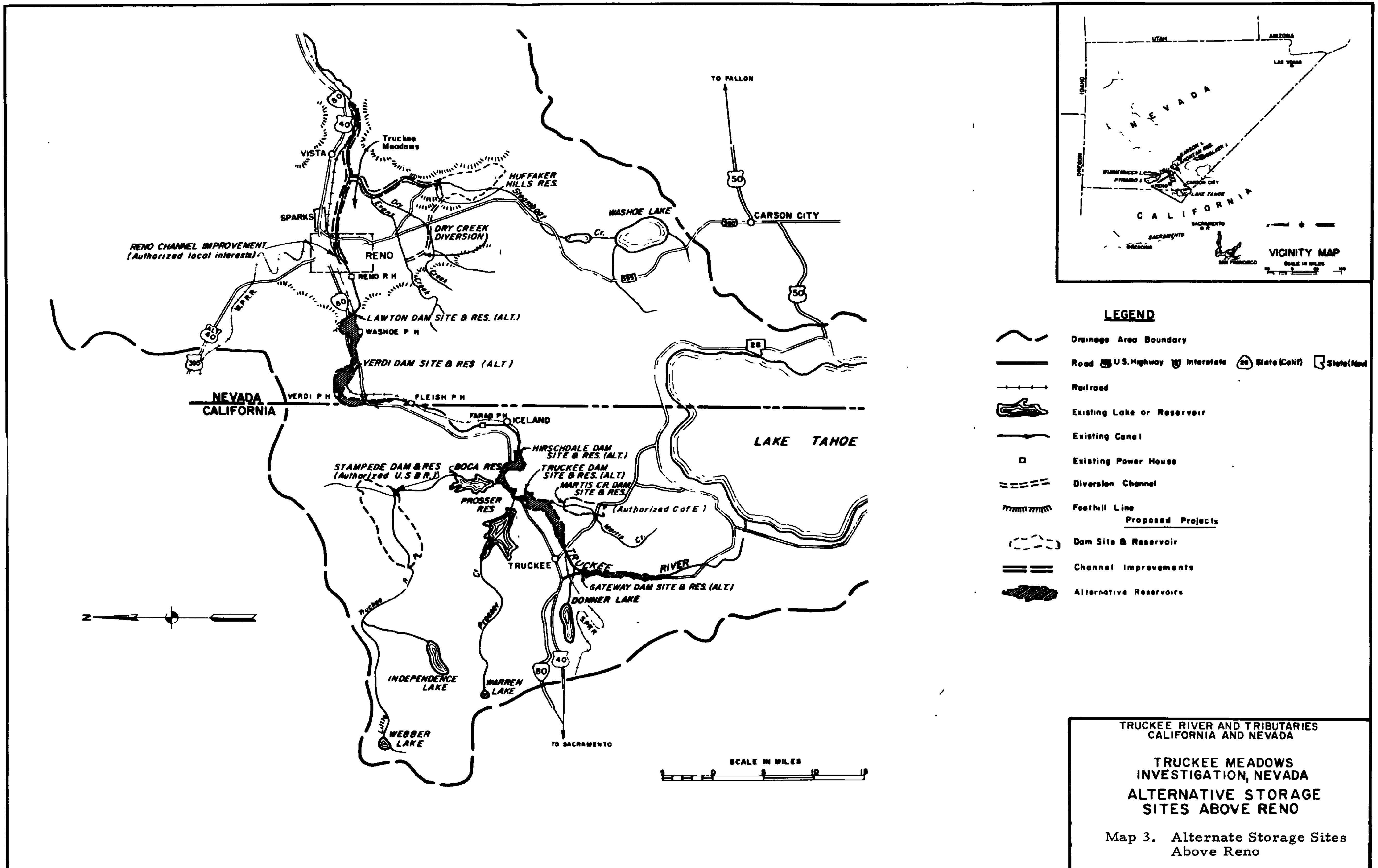
Another approach to structural protection is reservoir storage. With no enlargement of the present channel through Truckee Meadows (capacity 6,000 cfs), it has been estimated that 80,000 acrefeet of reservoir storage would be required on the main stem of the Truckee River and 30,000 acrefeet on Steamboat Creek for control of the SPF. Storage units of this size are totally impractical and need not be considered. However, smaller units should be considered even if they provide protection only against floods of lesser magnitude than the SPF. In combination with other flood plain measures the equivalent of SPF protection can be provided. However, it is proper to consider only reservoir storage with less than SPF protection at this point because, a) this may turn out to be the most acceptable alternative, and b) the data obtained in studying this alternative will be needed to evaluate potential combinations with other measures.

In Reno, information for units with less storage pertains to an assumed increase in channel capacity through Reno to 14,000 cfs. Corps studies indicate that several feasible alternative damsites exist for control of the Truckee River. They are located at Verdi, Lawton, Hirshdale, Truckee, Gateway, and on two Truckee tributaries, Dog Creek and Hunter Creek (see Map 3). To control the SPF peak at Reno to 14,000 cubic feet per second, it has been estimated that 35,000 acrefeet of reservoir storage are needed at any of these sites. Preliminary engineering appraisals show that sites near the towns of Verdi and Lawton, Nevada, and Truckee, California are practical candidates for storage reservoirs of such size. The succeeding steps show how the effects of these structural measures were computed.

2. Estimate the benefits and costs for each structural flood control alternative. Again, this methodology employs as a basic starting point present Corps practices for estimating benefits and costs of structural alternatives. Therefore, there is no need to point out here in any detail how this step should be accomplished. However, since a large number of alternatives will be considered in the early stages of planning, it would not be cost effective to perform detailed benefit/cost analysis. Instead, broad estimates based on sound engineering judgment and generated from maximum use of secondary data sources are normally adequate in this phase of planning.

Benefits and costs should be estimated for each stream reach. They should be estimated for a minimum of three different levels of protection which might be provided for reaches having a significant flood problem. Even though it may not appear justifiable to provide less than Standard Project Flood protection in a given area, the planner is urged to follow this procedure. The reason is that it may turn out in later analysis that if the given measure is combined with a nonstructural measure, the resulting combination would represent a highly feasible alternative plan.

In Reno, for example, it has been noted that increasing the channel capacity to more than 14,000 cfs is not considered economically feasible. This capacity, however, is not adequate to handle floods of an exceedence interval in excess of 80 years. On the other hand, if the channel capacity were increased to more than 14,000 cfs and combined with a flood proofing and/or flood insurance program, this combination of physical and financial measures may comprise satisfactory flood protection against the consequences of floods. Moreover, it could well be more effective in meeting



Map 3. Alternate Storage Sites Above Reno

the bundle of stated objectives (including economic efficiency maximization) than purely structural measures. This combination of measures will be considered in greater detail later in this study.

The structural measures proposed to this point will provide a high degree of flood protection to the Reno-Truckee Meadows area. Under present conditions there are about 6,300 acres of low lands in the pool area of the Meadows where ultimate higher use potentialities are retarded because of frequent and prolonged flooding. High groundwater conditions also prevail over parts of this area. This condition would be alleviated by structural measures, allowing full use to be made of the area for urban-suburban development.

Tremendous pressure to develop this area is evident from encroachment in the perimeter area of the pool. Warehouses, wholesale houses, truck terminals, light industry, and other development are taking place in this area. This initial development is being achieved by building up the ground elevation with costly fill operations, and by locating in the somewhat better protected island areas within the pool area. A low level of protection is now afforded because ground elevation of these localized developed islands appears to be somewhat above that of the general area. Based on population projections for Washoe County, it is evident that large areas of land will be required to accommodate the projected population. By 1980, for example, almost 150,000 additional people are expected to reside in Washoe County. This pressure for land is especially evident in Truckee Meadows because of a number of advantages it possesses over alternate locations within the region. Transportation facilities and basic utilities are superior to the more remote areas. It is close to the labor market, and is a natural area to expand as an integral part of the Reno-Sparks metropolitan area.

From this analysis it appears that a major benefit from flood control measures is the enhancement of land use in areas which would be protected. One way to measure the extent of these benefits is to find the difference between a) estimated values of the land with higher or more intense use made possible by protected conditions, and b) estimated values based on capitalized income of the land without this same protection. Substituting current land values for b) would result in a smaller difference because the area is subject to considerable land appreciation on the speculation that flood protection will eventually be provided in the area.

Additional benefit elements, all of which increase land values, include annual average damages prevented, the locational savings in providing transportation and utilities to the Meadows area versus more remote areas, locational advantages in travel time from the Meadows to central Reno, emergency costs saved, and business losses prevented. These various benefits are important but in Reno they constitute a small portion of the total benefits. No further discussion of them is warranted here because the measurement of these benefits would be conducted by established procedures which have previously been discussed in the presentation of the methodology.

3. For each alternative, estimate effect on non-dollar objectives.

The effects of each structural alternative must now be considered in each of the stream reaches. The only effects which the analysis is concerned with are the impacts on the objectives developed in the previous section. Any corollary effects should be noted as special conditions but are not included in the main analysis. In the Reno case, the relocation of the State hatchery, which is required if a reservoir were to be built at Verdi, has no measurable impact on any of the stated objectives other than net benefits (i. e., the cost of relocating the hatchery is a cost component of B-C). This special condition should be noted, however, because of the potential willingness of non-federal parties to pay a premium (i. e., in excess of relocation costs) to retain the hatchery at its present site.

In Reno, the objectives being pursued have been defined in the previous section. With the exception of the objective to maximize net benefits just discussed in the preceding step, we shall attempt to determine the effects of the structural measures on the remaining objectives which, for want of a better name, have been called "non-dollar objectives."

First consider how structural measures would offset regional economic development in Reno. Based on historical records and frequency-of-flow curves previously prepared, it is possible to determine roughly the area delineated by floods of various exceedence intervals. Using this information in Reno, it is relatively simple to determine acreages which would be made flood-free as a consequence of the various structural alternatives. Due to a number of beneficial characteristics of this land as previously discussed, a certain portion of this acreage would be expected to develop into industrial uses. To the extent that the measures enhance the probability that this acreage would indeed be used for job-attracting industrial and commercial uses, the impact of the objective of contributing to regional economic development is being achieved.

The question now is what difference in effect would there be if one structural approach were taken rather than another. In Truckee Meadows, the answer is that the difference is not so much in the use of the land as in the intensity of its use. Unless restrictive flood plain regulations are adopted by the County, the present trend of development can be expected to be interrupted only by a severe catastrophy. This is because land buyers and developers have discounted the price of land in full expectation that some kind of flood control will eventually be provided. In view of the confidence which seems to pervade the community that it can handle large floods, there appears a willingness to accept improvements to a level of protection which would only reduce the effects from a Standard Project Flood to a level equivalent to a lesser flood, say, an Intermediate Regional Flood. This is true simply because the community appears to be willing and able to live with the lesser flood if this occurs at a much lower frequency. At the same time the community will be totally protected from floods more severe than the lesser floods.

Preventing inequitable benefit distribution is another objective of concern in the Reno region. To measure this objective it must be determined what portion of total economic benefits are widespread within the community. To do so, an inverse approach is taken by determining which part of the total benefits accrues to owners of large tracts of land in the flood plain. Information relating to land ownership was obtained from the Washoe County Assessor Department. This information indicates that well over 50% of the land area in the flood plain are large tracts owned by single owners. Thus, any benefits which are received by flood plain land owners are not widespread if this ownership represents a significant percentage of the total flood plain area.

4. Set aside dominated structural alternatives. All structural alternatives generated thus far are ranked in a comparison matrix according to Step 1 in the next section. The alternatives are listed in the rows and the objectives in the columns of the matrix. All alternatives can now be compared to every other alternative. In the course of this pairwise comparison, if any alternative plan does not achieve at least one of the objectives better than the plan it is being compared with, the first plan is dominated and is set aside and eliminated from consideration unless it is in combination with another plan or it is introduced later because constraints have ruled out all of the dominated plans.

Non-structural Measures

5. Identify appropriate non-structural measures. The principal non-structural measures dealing directly with flood problems have previously been described. They are flood proofing, flood insurance, flood warning and evacuation, and flood plain regulations. In most cases, each of these measures is at least partially feasible.

Generally, the degree of appropriateness of a non-structural measure depends on local conditions. Thus, the appropriateness of flood proofing depends on the stage and duration of flooding, the flow velocity, and the types of structures to be flood proofed in the flood plain. Flood insurance, if available, is effective in reducing the risk of large losses to individuals and can be combined with other measures as part of an effective program of flood plain management. Flood warning systems can be considered if the nature of flooding permits adequate leadtime for emergency measures to be taken. Flood plain regulation (public acquisition, zoning, and building codes) is appropriate if the flood plain is in initial stages of development, and if the area of the flood plain does not constitute an excessive portion of the land supply available for community development.

In the Reno area, each of the non-structural measures is physically and/or economically feasible, although some only to a limited extent. Flood proofing is suitable in all locations in the flood plain. If available, flood insurance is also appropriate in all flood plain locations. A warning system is feasible for Reno and Truckee Meadows since advance warning of floods is a minimum of 6 hours, adequate time for evacuation of persons and, assuming appropriate precaution and a state of readiness, temporary flood proofing or evacuating valuable personal property. Flood plain regulations are feasible for parts of the flood plain. Public acquisition of flood easements, zoning to control development density and channel encroachment, and building codes to set elevation limits on structures are all appropriate responses to the flood problem in Truckee Meadows. In downtown Reno, these measures are largely inappropriate due to the relatively high level of development. In the next step, we shall examine in more detail the feasibility of each of the non-structural measures.

6. Estimate benefits and costs of non-structural measures. The benefits and costs should be estimated for various levels of protection provided by structural measures, from SPF, 100-year and 50-year floods through no physical protection at all. Also, these outcomes should be estimated by stream reach. If estimation is done on this stepwise basis, it will be straightforward in subsequent analysis to measure the results of new plans generated by combining various measures in various reaches.

Below are discussed some methods for estimating benefits and costs of non-structural measures. It must be understood that the methods given here are quite gross, but are considered adequate for pre-survey analysis.

Flood Proofing

A large variety of flood proofing measures exist, each one of which is costed out differently. The similarity, however, lies in the fact that flood proofing is applied to individual structures, which each have their own locational and structural characteristics. Dealing with these individual characteristics is what makes the costing of flood proofing difficult. Though the unit costs of the different flood proofing methods vary, it is the approach to the fragmented nature of this measure that is of importance here.

The approach suggested calls for examination of the flood characteristics in a given reach to determine the most suitable method of flood proofing. Once a particular method has been selected, it will be evaluated on the basis of at least three different design floods. Assume for example that land fill is used to protect structures in Truckee Meadows from the 100-year flood. The total cost of flood proofing would then be computed on the basis of the unit cost of land fill and the average amount of fill needed to protect residential, commercial, and industrial structure, respectively, against the average design depth in an area slightly larger than the 100-year flood plain (to account for the modified hydrology caused by flood proofing). Operation and maintenance costs should also be estimated and added to the equivalent annual charges of the initial cost in order to arrive at total flood proofing costs.

Another type of flood proofing which may be appropriate in the Meadows is to surround individual developed tracts with dikes.* To be economically feasible, this measure would be applied to tracts of approximately 50 to 100 acres. As in land fill operations, the costing of this approach is fairly straightforward and is in fact according to standard procedure.

For areas which are already well developed a different approach to flood proofing is required. In downtown Reno for example, extensive dirt moving operations would not be practical. Even for new development, diking would be unattractive as well as uneconomical, and land fill would cause neighboring structures to be at different elevations which is contrary to acceptable pedestrian traffic patterns not to mention the unsightliness of such an approach. An alternative method is to flood proof individual buildings. Examples range from temporary wooden barricades enforced with sandbags to sophisticated arrangements in which panels would be bolted onto pre-installed brackers during emergency situations. In many instances, permanent flood proofing of most openings to ground floors and basements is a reasonable alternative. Depending on the method chosen and the height to which flood proofing is required, the initial cost will vary from $0.30 to $1.00 per square foot of ground floor. If a measure is selected which requires temporary installment during emergencies, annual setup charges should be included.

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*This approach to flood proofing straddles the dividing line between non-structural and structural alternatives. Generally, flood proofing pertains to single or connected structures and dikes could be considered as a category of flood control when they protect several unconnected structures. However, flood control also carries a connotation of a communal effort, usually financed from government funds. In the case of small tracts, the dikes would have to be provided by the tract owner as part of the costs of development. Hence, it is here considered as a non-structural alternative.

Estimation of the benefits of flood proofing are based on the damages prevented for all floods equal to or less than the design flood. Various studies and previous experience indicate that a conservative estimate of damage avoided by flood proofing is 80% of damages prevented by structural protection for the same design flood. *

Flood Insurance

Until recently, flood insurance has not been available from private underwriters except at prohibitive rates. However, congressional action has been taken to begin flood insurance programs under the Department of Housing and Urban Development and a pool of private insurers. Therefore, it is well to consider this as a feasible approach to aid in protection from large financial losses of flooding.

The costs of a flood insurance program are comprised of the average annual charges to administer the program, including the cost of administering a subsidy program, if any, provided to policy holders. The magnitude of this component can be conservatively assumed at 30% of the average annual damages. Average annual damages are not included in the costs of flood insurance since they are presumed to be exactly offset by the premium, less administrative costs. The amount of the subsidy would be fixed by law and in all probability would be some percentage of the average annual damages. Inasmuch as the subsidy goes to cover average annual damages, the identification of those providing the subsidy is of no consequence in the benefit cost analysis.

Economic benefits of flood insurance are the future average annual damages prevented as a result of the program. Assuming that the premiums represent a significant additional cost of development some growth will be deferred or prevented. To the extent that development does not occur at an otherwise unimpeded rate, some flood damage will be avoided. The amount of this benefit must be estimated on an individual basis because of its close relation to the type of development and the proportion of the cost of premiums to total development costs.

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*See for example the studies of Gilbert White, John Sheaffer, et al. at the University of Chicago.

Flood Warning and Emergency Measures

Economic analysis of this measure is severely complicated by its dependence on the skill and judgment of those endangered by floods. In most areas where this measure is applicable, the U. S. Weather Bureau provides adequate warning of impending floods to local officials. These warnings must be communicated to local residents to permit immediate emergency measures to be taken according to an up-to-date plan of action. The cost of such a system and of the evacuation process itself varies widely between communities, and depends on the state of preparedness of each community.

The effectiveness of a warning system is also difficult to measure. Damage prevention by emergency measures depends to a great extent on the time between the warning and flood crest. Various studies indicate a range of 5 to 15% of flood losses can be prevented. These estimates vary depending on local conditions. Probably the best estimates of both the costs and the benefits can be obtained from the experience of local Civil Defense Officials, and long-time local residents, and from inspection of newspaper accounts of past floods.

Perhaps the most important aspect of a flood warning system is the community state of preparedness. This factor, in most instances, appears to be correlated with the number of years since the most recent severe floods. Community regard for flood danger appears to decrease year by year until reinforced by a severe flood. Reno, for example, experienced a very severe flood in 1955 (peak was 20,800 cfs at the Reno gauge), the damage from which was estimated at $2 million. This figure can be compared with the estimated $3 million damage from a less severe flood in 1950 (19,900 cfs at the Reno gauge). Thus, even though property values in the Reno area (including the flood plain) increased by an average of about 50% in the period 1950-1955*, property damage from the more severe flood was 33% less.

*Source: From data compiled by the Greater Reno Chamber of Commerce.

Flood Plain Regulation

The most significant cost of flood plain regulation from the local point of view is the loss of productivity caused by restricting development. If this loss is translated into a transfer of investment outside the community, it is all other things being equal not a cost in the economic efficiency sense. However, the loss would be properly considered as a degradation of the objective of contributing to regional economic development. If, on the other hand, it can be assumed that development planned for the flood plain will take place elsewhere in the community, the only net cost is the loss of the advantage which may exist due to location in the flood plain. Locational advantages accrue from the differences in the construction costs because of physiographic advantage, and the differences in cost of occupying a site (e.g., cost of transportation and provision of public facilities and services).

In addition to the loss of productivity, there are a number of more obvious, though no more easily estimated, types of costs. These include the costs of setting up the program including formulating the regulations, and the annual costs of administering, enforcing, reevaluating, and adjusting the regulations. In programs involving public acquisition of flood plain property, the start-up costs are relatively much higher because acquisition costs are included. (Note, however, that acquisition costs represent loss of productivity of excluded firms; they are therefore not a cost in addition to productivity loss.) Reasonable estimates can be made on a per-program basis.

Dollar benefits attributable to flood plain regulation are the average annual damages incurred by future development which would have taken place without regulation. On the basis of traditional Corps project evaluation studies, this information is available if structural measures have been considered for the study area. In addition, certain dollar benefits may be measurable for the regulated uses, such as open space and recreation, to which the flood plain is put. To the extent that such benefits are expressible in dollar terms, they are incorporated in the net benefit maximization to dollar terms, they are treated in the next step which deals with the impact on non-dollar objectives.

7. Estimate effect of non-structural measures on non-dollar objectives.

The effects of introducing non-structural measures for various levels of protection in various reaches include those not directly measurable in dollars. These effects may be just as important, or more so, as the economic consequences. Estimating impact on non-dollar objectives requires a high sense of familiarity with the study area. The federal planner, who probably has not yet acquired this asset in this early stage of analysis, must rely heavily on the advice of local experts. He will of course be able to evaluate this advice against his prior experience in other localities.

In terms of contributing to Reno's economic development, the various non-structural measures can have significant negative impact on this objective. For example, flood plain regulation, by itself, would generally have a negative effect by limiting development in what is usually the least expensive* land available, the flood plain. However, if an adequate supply of land other than the flood plain is available, as it is in Reno, this negative impact may be very small.

In some cases, it may have to be assumed that any development not occurring in the flood plain will be lost to the community. To compute this loss, one would employ the net rate of return of private investment projected for the flood plain. From this rate would be subtracted the "rate of return" which measures the productivity of the land when placed in the restricted use it is zoned for. For example, in Truckee Meadows the net rate of return of industrial development may be 10%. If this use were restricted and instead the area was used for open space and recreational uses, the assumed "rate of return" on this restricted use might be the equivalent of the interest rate on the acquisition costs by government. The net loss of productivity is the difference between these two rates.

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*"Least expensive" when the cost of flooding is not included.

Flood proofing and flood insurance, especially if mandatory, would add to the cost of locating in the flood plain. It is doubtful that most developers have the farsightedness to recognize that these added costs would be offset by damage reduction benefits. Thus, the general effect of these measures would be to defer or slow down development. In Truckee Meadows, the present high rate of industrial development would probably be reduced if developers were required to install some form of flood proofing at their own expense as a condition for receiving building permits.

To estimate the extent to which development would be inhibited by such a requirement can be gauged by discussion with Sierra Pacific Power Company, Southern Pacific Railroad Company, and others actively engaged in large scale industrial development projects in the Reno area. If this is not done, it may be easy to overestimate the inhibiting effect of mandatory programs. Presumably, such programs would only be implemented if the expected benefits exceeded the expected costs. If this is generally recognized by investors (and this is a big "if," in view of the general lack of concern for flood damages in the Meadows), then the net effect would be a positive in terms of contributing to economic growth.

A flood warning and evacuation system would not have any material effect as a factor contributing to economic development.

Concerning the effect on income redistribution, the non-structural measures are significantly more effective than the structural measures in avoiding this problem. The principal types of benefits inequitably shared in the community are the land enhancement benefits. The non-structural measures, however, normally do not produce this type of benefit. Thus, a principal source of inequity is eliminated.

The non-structural alternatives have no capability for <u>increasing</u> water-based recreation since no reservoir storage is involved. A prudent program of public acquisition and improvement of river banks can enhance recreation opportunities on the river itself. This approach is effective only if adequate stream flow is available in periods of critical recreation needs.

8. Set aside dominated non-structural alternatives. All non-structural alternatives generated thus far are ranked in a comparison matrix according to step 1 in the next section. The alternatives are listed in the rows and the objectives in the columns of the matrix. All alternatives can now be compared to any other alternative. In the course of this pairwise comparison, if any alternative plan does not achieve at least one of the objectives better than the plan it is being compared with, the first plan is dominated and is thus set aside for the time being.

Synthesis of Flood Plain Measures

9. Combine structural and non-structural measures to generate better alternative plans. In the analysis of structural and non-structural measures a great deal of information was gathered which can now be used to evaluate the consequences of new plans generated by combining various measures. Structural measures may be combined with other structural measures; similarly, non-structural measures may be combined; and structural measures may be combined with non-structural measures. Any number of measures may be combined with each other in any stream reach, if two conditions are met:

1) The measures being combined are physically compatible.

2) The new plan appears to be superior to previously generated alternatives to achieve the stated objectives.

Generating new plans by combining measures known to be applicable in the study area is an art. Its success is based on the imagination of the planner. The possible combinations of measures in all of the reaches is so staggering that human judgment rather than a mechanical set of procedures is needed to reduce this number to managable proportions. Consequently, only those plans will be generated which the planner feels have a reasonable probability of satisfactorily achieving the stated objectives.

Normally, the most reasonable alternative plans will entail combinations of various measures. In Reno, a plan has been generated by the Corps which calls for combining various structural measures only. Details of the plan were previously discussed in the introduction of this study. Since the Corps in the past has not considered nonstructural measures and non-dollar objectives within its domain of alternatives, no plans had been generated for Reno which considered these approaches. If flood plain planning is to expand in scope, however, a number of additional plans can be generated which would take these approaches into consideration.

For example, a second alternative plan, proposed by a local civil engineer, calls for combining channel improvements along the Truckee River at Reno and Vista and along Streamboat, Evans, and Dry Creeks with acquisition of flood easements below Vista and flood proofing in Reno. The plan eliminates the need for the storage reservoirs both at Verdi and at Huffaker Hills. The plan is based on the premises that 1) channel improvements through Reno are economically feasible to a capacity of about 20,000 cps, 2) the so-called Vista Reefs can be further deepened and removed, 3) flood plain easement can be acquired from Vista to Pyramid Lake, and 4) channel improvements on Steamboat, Evans, and Dry Creeks along their present courses would be as effective as the more costly construction of Huffaker Hills Dam and the Evans and Dry Creek diversion canals (assuming that Vista Reefs were lowered).

This second plan does not provide the physical protection from the SPF as does the plan proposed by the Corps. However, all floods experienced in recent history would safely pass without causing damage. With the proposed measures, the damage and inconvenience which would be caused by an SPF would be no greater than the problems caused by the worst of the previous floods. Moreover, the damage caused by a flood of SPF magnitude would be reduced by a concentrated flood proofing program. The basic argument with which this plan is supported is that the slightly higher residual damages are more than offset by the lower total costs including the benefits from <u>not</u> inundating the Verdi area.

Additional combinations using flood zoning, flood insurance, warning and evacuation systems, etc., together with various structural techniques can be readily formulated. One example is a third alternative plan which avoids several problems created by a reservoir at Verdi required in the Corps proposal. The proposed alternative would be to locate the required reservoir at a site less favorable in terms of flood protection provided (such as for example, Lawton, Nevada), but offsetting the higher residual losses with a program of mandatory flood proofing of new construction and some form of mandatory flood insurance for existing development.

A fourth proposal would require no structural measures whatsoever in order to achieve the stated objectives. This plan would combine the following measures: for existing development, mandatory and partially subsidized flood insurance with rate reductions for voluntary flood proofing; for new development, mandatory flood proofing as a condition to receive a building permit; flood zoning in areas of frequent flooding and high flood risk; a warning and evacuation system.

Measures can be combined practically ad infinitum in order to generate additional alternative plans. For the purpose of example, however, let us consider only the above four proposals. In the next step, methods for measuring the consequences of each of the proposals are examined.

10. Estimate benefits, costs, and effect on non-dollar objectives of new plans. The degree of implementation for each of the measures comprising a new plan depends of course on the benefits, costs, and other consequences which would result from these new plans. The extent to which the flood plain ought to be zoned, the elevation level of flood proofing, the sophistication of a warning system, and the level of protection for which structural measures should be designed are all interrelated variables which can be manipulated to develop various plans. These variables present opportunities for tradeoff between the levels of achievement of objectives and the resources required to achieve them.

Much of the information needed to evaluate the new combinations is already available as a consequence of the analysis of the individual structural and nonstructural measure. In most cases of course one cannot simply add the benefits and costs of one measure to those of another to compute the consequences of the combination of measures. However, if the basic data has been properly collected in the manner previously suggested, very little additional information is required to evaluate new approaches.

As an example, consider the plan combining channel improvement and flood proofing. The various combinations of levels of each measure in a particular stream reach might be as follows for a SPF design flood: channel improvement for 50-year flood (50-year channel, for short) and flood proofing for areas with residual damage of a 50-year channel; 100-year channel and flood proofing in the residual damage area; SPF channel and very limited flood proofing needed for the residual damage area. The consequences including residual damages of the various types of channels were previously computed in steps 2 and 3. The increased channel capacity reduces peak flow of the design flood to the equivalent of a flood of lesser flow with no structural protection. The consequences for this lesser flood can be interpolated from the previously computed consequences. Similarly, the cost and benefits of flood proofing for the lesser flood can be interpolated from data previously computed for flood proofing. Although interpolation may produce inexact figures, they will in most cases be adequate for the type of analysis with which this methodology is concerned.

Substitute Measures

11. Determine feasible substitute projects. Not infrequently, the planner can devise projects which, although not directly flood-related, are close substitutes for flood measures. In the Reno area, for example, the stated objective of regional economic development may perhaps best be served by developing industrial sites in areas other than Truckee Meadows. In-depth analysis might show that the costs associated with attracting development to alternate sites and preventing further development in the flood plain are far exceeded by the average annual damages which would be born by industries in the flood plain. In other words, since the benefits would be approximately equal but the costs unequal for the two approaches, the least expensive alternative is obviously preferable.

There are a number of sites in the Greater Reno Area which, having adequate space for growth, bear consideration as alternative sites for development. Three directions of growth, alternative to easterly growth into Truckee Meadows, can be considered: northerly from Reno towards Lemon Valley and the abandoned Stead Air Force Base; southerly from Reno along U. S. Highway 395 towards Carson City; and northeasterly from Sparks into Spanish Springs Valley.

Each area has shortcomings in relation to Truckee Meadows which must be overcome before developers can be expected to invest in these alternative sites. The groundwater supply in both the Stead Area and in Spanish Springs Valley, though adequate for present development, cannot support substantial growth. Hence, an investment is required in facilities to pump water to these areas from the Truckee River supply. Many of those contacted by the study team considered bringing water to these various areas a prohibitively expensive proposal. When staff executives of the local utility firm were questioned about this, however, it seemed that ballpark figures were one degree of magnitude less than building a dam of one of the proposed sites. The point is that alternatives such as this are now not seriously considered in the planning process because they fall outside traditional project-structured jurisdictions. In this proposed methodology, consideration of substitute measures is considered one of the keystones to comprehensive planning.

Concerning transportation, each of the areas is served by adequate highways, although the roads serving the Spanish Springs area require expanded capacity if further development takes place there. In addition, a relatively large proportion of Reno industry is warehousing, a highly rail-dependent industry. None of the three alternate areas has the locational advantage of Truckee Meadows which is bisected by a Southern Pacific mainline. The Stead Area is served by a Western Pacific spur which would have to be improved if it were to be used to a greater capacity than at present. Spurs would have to be built to the other two alternative areas. In the case of transportation, as with water supply, the expense of expanded services may totally offset the cost of expensive structural proposals and reap essentially the same benefits. By collecting information from highway departments, rail companies, and public commissions regulating transportation matters these alternatives can be easily evaluated.

It is not difficult to perceive that numerous alternatives to developing Truckee Meadows exist. In the final analysis, a degree of government intervention, whether local or federal, is required. If development is allowed to course freely, it will probably occur first in the Meadows area which appears more attractive to developers. Massive investment will be required, however, to prevent excessive flood damages. If on the other hand, further development in the Meadows is restricted thus avoiding flood damages, and alternate areas are improved for development, it is possible that greater net benefits can be generated and other objectives be better achieved.

12. Estimate the cost, benefits, and impact on non-dollar objectives of the substitute measures. In most instances, the combination of close substitute measures with structural and/or non-structural measures can result in highly feasible plans. Such combinations must of course meet the same criteria as any other combination of measures. These criteria, described in Step 9, concern the physical compatibility of the measures and the superiority (in the sense of achieving objectives) of the new combination over previously considered plans.

Theoretically, the evaluation of combinations of substitute measures and flood abatement measures is more straightforward than evaluating combinations of structural and non-structural measures. This is a consequence of the fact that the substitute measures are mutually exclusive of the level of flood control which would be assumed. The effects of the substitute measures, in other words, tend to be additive since they occur in different geographic areas. In Reno, for instance, the planner would obtain estimates of water supply enhancement from Sierra Pacific Power Company, estimates for highway improvement from the Nevada State Highway Department, and estimates for rail spur improvements from the railroads serving the Reno Area.* These estimates would

*The required estimates include not only the capital costs of these improvements, but also annual expenses over and above those that would be incurred without these substitute measures. Noteworthy among these annual expenses are the cost associated without the locational disadvantage manifested by increased travel time and expense from the center of economic activity.

then be combined with previously computed consequences of the appropriate flood related measures to arrive at the evaluation of the plans which include substitute measures.

When this step is concluded, the planner has generated an extensive array of alternative plans, all of which are feasible and any of which may be optimum in meeting the stated objectives including maximized net benefits. The next section deals with discovering which plan is indeed the best.

Analysis Tradeoffs

In this section, an evaluation of the previously generated plans will be performed to determine which of the various alternatives best meets the stated objectives. Methods for performing the tradeoffs are discussed in some detail here. In keeping with the goals of the Reno demonstration study, specific data is not used. However, a qualitative description of the various tradeoffs will be presented. To see how actual data would be processed using these procedures, the reader may refer to a description of the Tucson demonstration study.

1. Rank all plans in a comparison matrix. In order to gain perspective, the plans generated to this point should be placed in a comparison matrix. In the matrix, the objectives are ranked according to order of importance in the Level of Achievement columns from left to right. The plans are then ranked in the rows of the matrix according to their level of achievement in the maximization of net benefits. For the Reno case, the comparison matrix is given in Table 7.

2. Eliminate all dominated plans from the comparison matrix. The comparison matrix contains all plans generated to this point. It may be possible that since all plans are now viewed together, several may be dominated. To determine if this condition exists, it is necessary to perform a pairwise comparison of all the plans. If any one plan does not record at least one of the objectives at a higher level than the plan it is being compared with, the first plan is dominated. It should therefore be eliminated from consideration at this time.

Table 7. Comparison Matrix of Flood Plain Management Alternatives

No.	Brief Description	Level of Achievement				
		Avg. Annual Net Benefits $000	Effective Level of Protection (Exceedence Interval)	Regional Development (Developable Acres)	Prevent Unequal Benefit Sharing $\left(1 - \frac{\text{Windfall}}{\text{Total Benefits}}\right)$	Develop Water-Based Recreation (Surface Acres)
1	Dams at Verdi and Huffaker Hills, and channel improvements	O_{11}	O_{12}	O_{13}	O_{14}	O_{15}
2	Channel improvements, flood proofing, and flood zoning	O_{21}	O_{22}	O_{23}	O_{24}	O_{25}
3	Dams at Lawton and Huffaker Hills and channel improvement	O_{31}	O_{32}	O_{33}	O_{34}	O_{35}
4	Combination flood proofing, zoning, insurance, warning system	O_{41}	O_{42}	O_{43}	O_{44}	O_{45}

3. Determine tradeoff pairs. Tradeoffs are made between pairs of choices. To accommodate this requirement, one of the alternatives plans is selected as a "base plan." The base plan will be compared with each of the remaining plans to determine the conditions which will permit making a tradeoff decision as each pair of plans is being examined.

Let us examine how this procedure is applied in Reno. As a first step, select Plan 1 from the comparison matrix as the base plan. Let us postulate some relationships between the levels of objectives achieved by Plan 1 and 2. Assume that Plan 2 will have higher net benefits ($0_{21} > 0_{11}$) because, although the damage reduction benefits are almost the same and land enhancement is only somewhat lower in Plan 2, the costs of Plan 2 are much less than Plan 1. In addition, Plan 2 is more effective in avoiding unequal sharing of benefits ($0_{23} > 0_{13}$) because a larger share of the costs of the measures which produce these benefits will be borne by individual property owners rather than accruing from federal action.

Plan 1, however, is superior in achieving the remaining objectives. Plan 1 will provide more developable acres in the flood plain, a measure which we have assumed to correlate with regional development ($0_{12} > 0_{22}$). Also, since Plan 1 includes a reservoir which presumably is a more effective measure to provide water-based recreation, the plan is superior in achieving this objective ($0_{15} > 0_{25}$). Hence, we are faced with the requirement to make a choice. Which is better: a plan achieving higher net benefits and more equitable sharing of those benefits, or a plan providing a higher level of protection, having greater impact on regional development, and achieving more extensive recreation opportunities?

Similarly, Plan 3 and then Plan 4 can be compared with the base plan, Plan 1. If at any time during these comparisons we can definitively say that one plan is indeed better than another, the second plan can be eliminated since it obviously cannot be the best plan if another plan is superior to it. It is easy to see, however, that such decisions are rarely obvious. Let us therefore proceed to the next step and see how we can use the information at hand to simplify the decisions which must be made.

4. Compute opportunity costs relative to the base plan. The opportunity costs of each plan as compared with the base plan are computed by normalizing the comparison matrix. Assume that opportunity costs are to

be stated in dollars. To normalize the matrix, in each column of objectives, the value of the base plan is subtracted from the values of each plan. Table 8 shows the normalized matrix with Plan 1 as the base plan.

Table 8. Normalized Matrix

Plan	Objectives				
	1	2	3	4	5
2	$0_{21} - 0_{11}$	$0_{22} - 0_{12}$	$0_{23} - 0_{13}$	$0_{24} - 0_{14}$	$0_{25} - 0_{15}$
3	$0_{31} - 0_{11}$	$0_{32} - 0_{12}$	$0_{33} - 0_{13}$	$0_{34} - 0_{14}$	$0_{35} - 0_{15}$
4	$0_{41} - 0_{11}$	$0_{42} - 0_{12}$	$0_{43} - 0_{13}$	$0_{44} - 0_{14}$	$0_{45} - 0_{15}$

Note that there is no restriction as to whether an entry in the above matrix is a positive or negative number. The next step shows the significance of positive versus negative results.

4. Determine the conditions under which the base plan is superior to alternate plans. Using the above matrix, it is now possible to establish a set of inequalities for the plans to express the conditions under which they are inferior to the base plan. (Remember that a plan inferior to any other can be eliminated from further consideration.) To set up the inequality, assemble all negative levels of achievement for a particular plan and combine them into an expression on the left side of the inequality sign. Then combine the remaining results of achievement levels and place these on the right side of the inequality sign. Each level of achievement has a value or, since in most cases this value cannot be exactly determined, a range of values which may be expressed by the function $V(0_{cj} - 0_{bj})$, where

0_{cj} = Level of achievement in objective j by plan being compared

0_{bj} = Level of achievement in objective j by base plan

Using the above example (in which Plan 1 is the base plan), the inequalities would be stated as follows: "Plan 1 is superior to Plan 2 if

$$V(0_{22}-0_{12}) + V(0_{23}-0_{13}) + V(0_{25}-0_{15}) > V(0_{21}-0_{11}) + V(0_{24}-0_{14})"$$

The expression on the left of the inequality sign is the price that the planner believes the community is willing to pay to achieve the net increases in levels of achievement measured by the expressions on the right side of the inequality sign. If the inequality is true, then Plan 1 is superior to the plan to which it is being compared. Therefore, the latter plan is dominated by Plan 1 and it can be eliminated from further consideration. If the inequality statement is false, the conclusion is that Plan 1 is dominated. If not enough information is available to determine the validity of the inequality, the planner can defer his value judgment until he has more information available.

Similarly, the relationships between the remaining plans and the base plan can be established. In the Reno case, we are considering four plans. With any one plan as the base plan, there will be three inequality statements which express the conditions when the base plan is superior or inferior to any of the remaining plans. In many cases, the opportunity costs for various objectives are very small or zero and can be dropped from the inequality expressions. This stems from the fact that most plans, although different in some aspects, are very similar in other aspects. This results in a number of very simple inequality statements about which we can often make immediate decisions.

Usually, not enough information to make decisions can be derived from comparing plans against just one base plan. To obtain additional data, the planner may select a new plan as the base plan and repeat steps 3, 4, and 5. This will provide him with additional inequalities for different values of the same objectives. If this process is repeated until each plan has been evaluated as the base plan, and some of the inequalities in the judgment of the planner are true statements, a significant number of plans can be eliminated from further consideration. If by this time one plan dominates all others, that plan is the optimum. If more than one plan remains for consideration, proceed to the next step.

6. Analyze the cost of obtaining additional information. If no optimum plan can be selected at this point, more information may be required in order to validate the truth of the inequality statements. Before the expense of renewed data collection is incurred, however, the following tradeoff must be considered. Is the cost of additional data collection justified

by the consequences (in terms of the expected value of the losses) of selecting a non-optimum plan? If the answer is yes, a new data collection effort is initiated to acquire an improved knowledge of willingness to pay factors. If the answer is no, value judgments must be made to resolve the lack of explicit information.

ANALYSIS OF THE TUCSON STUDY

There were two basic objectives of the Tucson demonstration case. The first was the demonstration of the methodology with emphasis on the uses and manipulation of data. The second was to gain insight into strengths and weaknesses in the methodology and to identify possible difficulties to be encountered in its application. At the same time it should be pointed out that it was not the objective of this demonstration case to select the best plan for the flood plain in Tucson. Two factors militated against a demonstration complete with the selection of the optimal plan. First, time and resources were limited and were insufficient to permit full discussions with local officials, formulation of the full range of plans, and the collection of new data. As a result of the data problem, several plans favored by some local officials were excluded from consideration.* Second, the methodology requires certain value judgments from decision makers and in this case some of these judgments would have had to have come from the TRW staff and, therefore, would not have represented the judgments of Corps or Tucson officials. In summary, this demonstration lacks the comprehensiveness and value inputs required for the selection of the optimal plan.

The availability of data was critical and heavy reliance was placed on data provided by the Los Angeles District of the Corps of Engineers. Because data relating to some of the alternatives considered were not readily available, these alternatives were not presented and evaluated. In a full scale Corps study this data would be collected and these alternative plans would be considered. In other cases where data was not readily available, rough estimates, based on discussions with Corps and local officials, were used. This is consistent with the procedure outlined in the methodology; however, one must take a Bayesian approach and consider the data used in the planning process as subjective estimates of the desired parameters based on available information. While the Corps does not explicitly recognize this procedure to generate

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*Some local planning officials favored the concept of a scenic highway which would run parallel to the Rillito Creek. The highway they contented would serve as a barrier to flood waters as well as providing a form of greenbelt.

estimates used in planning, it is clear from Corps reports that the data presented is often very rough and is the informed estimate of the district engineer. This practice was employed here and some of the data presented in this study should, therefore, be considered to be best estimates available, given the existing information and time and resource constraints placed on the study.

In the course of generating the necessary data and in setting willingness to pay limits, many assumptions and different lines of reasoning were employed. These assumptions and processes of inference are not presented here for several reasons. First, they were quite specifically related to the situation in Tucson and would be of little value elsewhere. Second, to include them here would more than double the length of the report and distract from the central ideas presented in the methodology. A third and final reason for omitting this material is that the assumptions and inferences employed are not necessarily the best possible; however, this is not critical as the demonstration of the methodology requires only that data be employed. Including a discussion of assumptions which may be controversial would only divert attention from the central points in the study. Since there is no pretense of selecting the optimal, there is no need to question the precision of the data.

To summarize, the Tucson study should be viewed as a demonstration of the methodology using real data and evaluating real plans, but at the same time the limitations with regard to the quality of some data and the range of plans should be kept in mind. Given these limitations, this study is an application of the methodology to a real situation and demonstrates the major points of interest.

Several interesting results are obtained in the study. First, using the critical value analysis it is possible to reduce the number of final plans for consideration from sixteen to four. This was done using very wide limits on willingness to pay. Second, this form of analysis eliminated the plan with the highest net benefits, because it did not perform well with regard to other objectives. The conclusion to be drawn is that other objectives do play a critical role in determining the best plan given the new procedure for selection. Finally, the tradeoffs which are critical to the determination of the best plan become clear in the process of the analysis.

BACKGROUND

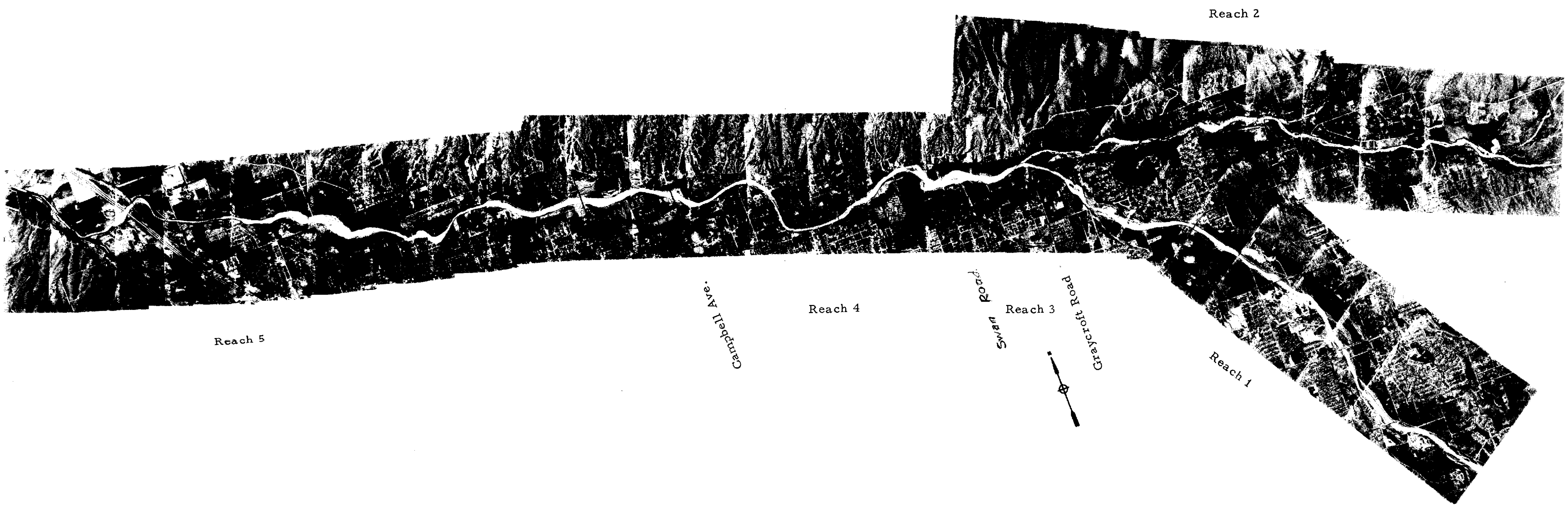
Rillito Creek, which is just north of the City of Tucson, is formed by the confluence of Pantano Wash and Tanque Verde Wash and flows northwestward for some 13 miles to its confluence with the Santa Cruz River (see Map 4). The creek is approximately 100 feet wide and 6 feet deep, with a stream gradient of about 17 feet per mile. The drainage area of Rillito Creek and tributaries comprises approximately 918 square miles. Ground water recharge in the creek is primarily from flood flows, and the average annual runoff is about 12,000 acrefeet. The ground water is used principally for agricultural purposes. Floods in Rillito Creek and tributaries cause damage by cutting stream beds, changing the shape and location of the channel, and by inundating residential, commercial, and public properties, highways, and utilities. The largest flood of record, with a peak discharge of 24,000 cubic feet per second, occurred in September 1929.

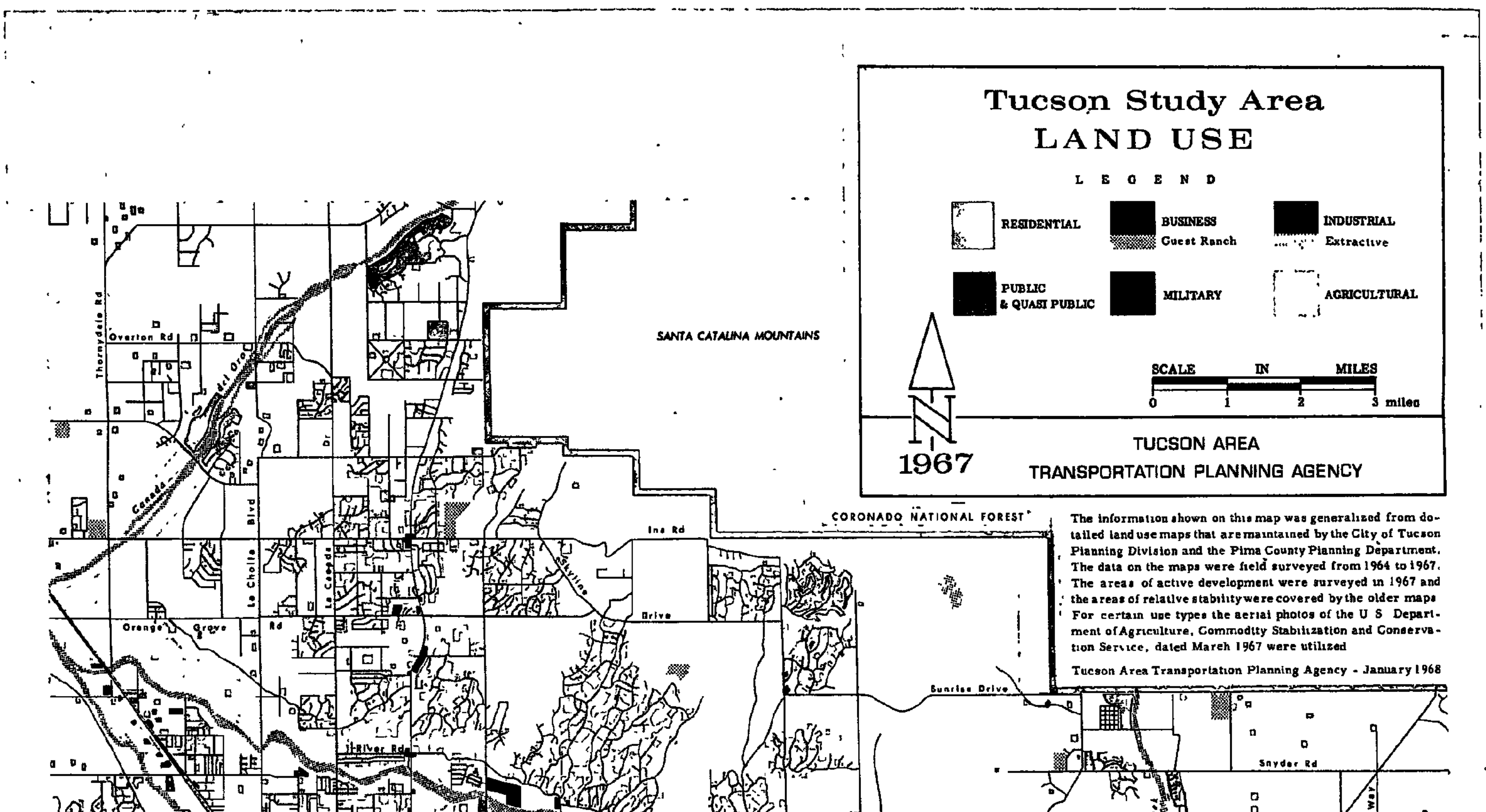
Present development in the flood plain is essentially low density residential. The general land use plan for the Tucson region shows that this area will continue the same type of development (see Map 5).* Advantages to developing the flood plain include the following:

- Proximity to downtown Tucson
- Favorable terrain (relatively flat)
- Cooler temperatures than in other parts of Tucson
- Access to water

It is projected that without flood protection, the flood plain will be completely developed in 25 years. This projection is based on the assumption that present zoning regulations favoring low density residential development will continue over this period. This assumption was

*Pima County Planning Officials, taking into account the potential flood hazard, had previously zoned the land primarily for low density residential uses. In light of the extensive amount of hazard free residential land in or adjacent to Tucson, it would be hard to justify occupancy of the flood plain for a higher density use. The Corps of Engineers (LA District) based on its own land use studies of the area concluded that low density residential was a proper use of the flood plain.


Reach 2
Reach 5
Campbell Ave.
Reach 4
Swan Road
Reach 3
Graycroft Road
Reach 1



Map 5. Tucson Study Area Land Use

made by the Corps and the dependence of this demonstration study on Corps data necessitated its adoption here. It does, however, exemplify the fact that projections of future land use are not only dependent on basic economic factors but on local decisions as well.

For the purpose of the generation and evaluation of data, the flood plain was divided into fifteen subdivisions. These subdivisions had been delineated by the Corps and were based on the division of the flood plain into five reaches and each reach into three flood risk zones.

Reach 1 is approximately 13,000 feet long and covers the Pantano Wash from Sabino Canyon Road to Craycroft Road. Reach 2 is approximately 18,000 feet long and covers the Tanque Verde Wash from Tanque Verde Road to Craycroft Road. Reach 3 is approximately 6,000 feet long and runs from Craycroft to Swan Road. Reach 4 and Reach 5 are approximately 55,000 feet long and run from Swan Road to Campbell (Reach 4) and Campbell to its confluence with the Santa Cruz River (Reach 5). Flood Risk Zone 1 is defined as the area which would be flooded in the event of the occurrence of a 50-year flood. Flood Risk Zone 2 represents the area between the 50-year flood plain and the outer limits of the 100-year flood plain. Flood Risk Zone 3 represents the area between the 100-year outer flood limits and the limits of the Standard Project Flood (SPF). The reaches can be viewed as being perpendicular to the channel and the flood risk zones as being parallel.

For each subarea, data was generated on property values, acres flooded, dollar damage from an SPF, and average annual dollar damages. As plans were being generated, data was obtained on project costs and on the amount of the reduction in damages due to the project. Data was also obtained relating to the achievement of objectives other than economic efficiency and, where applicable, this data was organized by the subareas.

Data related to the generation of objectives and willingness to pay values was obtained principally from discussions with Corps and local officials in Tucson. As has been pointed out, the data is not intended to represent the views of either the Corps or local officials.

DEFINE OBJECTIVES

The first step in any planning effort is the specification of the set of relevant objectives. Five objectives were considered to be of sufficient significance for inclusion in the study. Of the five objectives, one was intended as a measure of Economic Efficiency (net benefits), two were related to Environmental Quality (erosion reduction and preservation of open space), one was related to Regional and Local Development (ground water recharge), and one was related to Disaster Prevention (reduction in losses from catastrophic floods).

Three of the objectives were identified in initial contacts with the Corps' Los Angeles District (net benefits, increased ground water recharge, and erosion reduction). The objective of open space preservation was formulated after discussions with Tucson planning officials. The other objective (disaster prevention) was never formally identified by the Corps or local officials. It was included to make explicit an objective heretofore considered implicitly. It should be pointed out that one of the major study objectives was to develop methods to allow comparison of economic and non-economic benefits and costs. It was felt that the traditional devices for measuring costs and benefits discriminated against non-structural alternatives largely because of data measurement problems. Traditional Corps of Engineer methods are considered to be valid as far as they go; however, they generally do not permit evaluation of non-economic objectives. Additional techniques are needed not only to measure economic effects but to measure the effects generated from non-economic objectives.

The first objective, to increase net benefits, is evaluated in the traditional Corps manner. All desirable outcomes measurable in monetary terms (benefits) and all project, operation, and maintenance costs associated with the production of these benefits should be included in the measure of net benefits. In addition, any measurable benefits accruing from regional development, enhanced water recharge, erosion reduction and recreational opportunities should also be included in this objective. Regional benefits in this context refer to benefits which have an effect on the National Account. Benefits which are strictly regional in nature are included as separate objectives. In the case of the recreational opportunities associated with open space, no benefits were measured and included in net benefits. The value of recreational opportunities was considered incorporated when willingness to pay values for open space were established. In some cases the benefit and cost values are provided virtually automatically, while in other cases they must be obtained by indirect means.

The following benefits are included in the economic efficiency objective:

- Damage avoidance benefits
  - Residential damages
  - Commercial damages
  - Property damages
  - Loss of business income
  - Public damages
  - Agricultural damages

- Improvement in quantity, dependability, quality, and physical convenience of water use. Again, this benefit measures only the results of water improvement which can be given a dollar value. The potential improvement which cannot be so measured is included under the objective of ground water recharge.

- Increases in the net return from higher uses of property made possible as a result of a project (land enhancement). This benefit was calculated in keeping with current Corps practice.

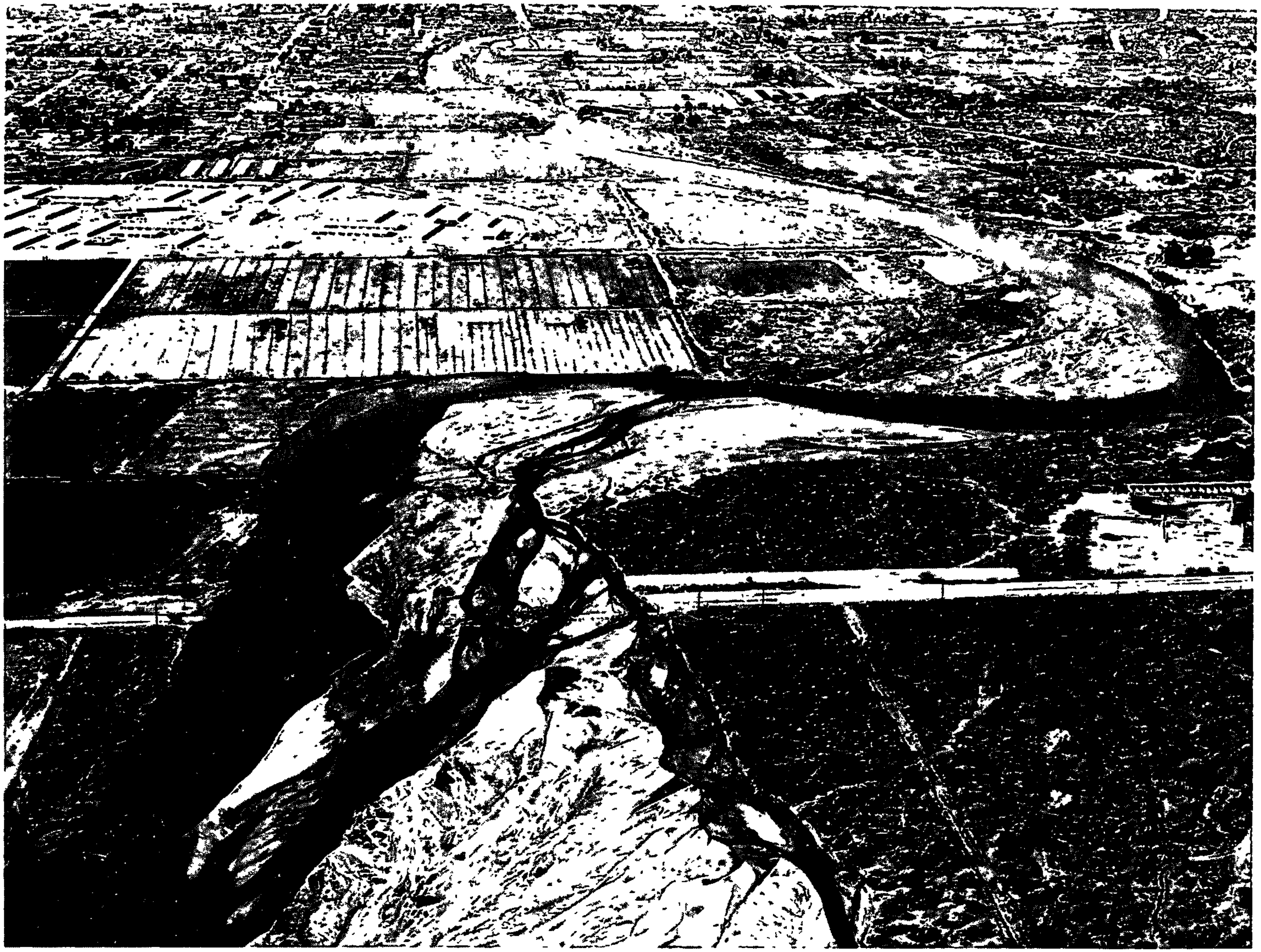
The second objective is the decrease of the risk of catastrophic losses from a single flood. This objective is concerned with losses of such a magnitude that reconstruction by those located in the flood plain might not be possible.

The third objective is the increase of ground water recharge. This objective concerns itself with losses of such a magnitude that reconstruction by those located in the flood plain might not be possible.

Downstream View—Rillito Cr. Flowing Wells Road Crossing at Right Center

Trailer Court Flowing Wells Road, December 1965

Adjacent to First Avenue Bridge—Northside, December 23, 1965



Downstream View—Rillito Cr. Swan Rd-Crossing in Foreground
December 31, 1965

The fourth objective is an increase of recreation and open space land uses in the urban area. This includes preservation of existing open space as well as the conversion of vacant and agricultural land to specific open space uses, in order to preclude future conversion of the vacant or agricultural land into residential uses.

The fifth objective is the reduction of erosion of the channel banks. Since the Rillito Creek is a meandering stream, erosion is a significant problem, especially from an environmental quality standpoint. The absence of stable banks has resulted in a landscape along the creek which is not esthetically pleasing.

The units of measurement associated with the above objectives were selected primarily on the basis of what seemed reasonable to constitute objective achievement. Secondly, measurements were chosen on the basis of the immediate availability of adequate data. Therefore, in several cases proxy variables had to be used in place of more natural measures of achievement. In an actual study, decision making could be improved by selecting better measures of achievement for some of the objectives. During the period of analysis, the measurement units were changed whenever it became apparent that they were not sufficiently sensitive to measure plan differences.

The following describes the basis for measurement of each objective and the methods used to obtain the specific values of objective achievement for each plan.

1) Net benefits are equal to the difference between annual average future dollar benefits and annual average future dollar costs. Average future value is equal to the average price level over the economic life of the project (50 years)

2) Reduction in catastrophic losses is based on the ratio of residual flood damages inflicted on commercial and residential property to the total value of residential and commercial property in the flood plain. The specific measure of objective achievement is equal to the following expression:

$$100 - \frac{RD}{PV} \times 100.$$

RD is the residual residential and commercial damages from an SPF. PV is the total value of residential and commercial property located in the flood plain.

Residual damages were obtained by:

a) Computing the discharge that could not be prevented by the channel improvement.

b) Computing the total damage associated with the given discharge.

c) Determining the amount of residential and commercial damages as a percentage of total damages.

d) Multiplying the computed percentage from c) by the value generated from b).

For example, the present and future residential and commercial damages that would occur in Reach 1 from an SPF given a 50-year channel would be equal to $1.54M:

- Q:60,000 - Q:21,000 = Q:39,000*
- Total damages for a Q of 39,000 = $1.9M
- Residential and commercial damages = 81% of total damages
- 81% times $1.9M = $1.54M

Property values used for calculations such as those above were obtained directly from the Corps data where available. For Reaches 1, 2, and 3, property values existed in a variety of forms, and it was necessary to convert all of this data into the proper format before the actual measurements of objective achievement could be made.

3) Ground water recharge is measured in terms of the average <u>increase</u> in the ground water table as a result of the project. This data was supplied directly by the Corps. No additional calculations were required.

4) Open space preservation is equal to the difference in acres specifically devoted to open space uses with and without the project. Vacant or agricultural land as such was not considered as open space unless it

*Q:60,000 indicates that the rate of overflow discharge is 60,000 cubic feet per second.

was specifically zoned for such use. This is because in the future such land could be converted to residential use under the existing zoning regulations.

5) Erosion reduction is measured in terms of the average annual number of acres eroded by flooding with and without the project. Data was obtained directly from the Corps. Erosion reduction was limited in this study to plans incorporating channel improvements.

Because of the emphasis on selecting measurement units on the basis of available data, the actual process of obtaining specific values of objective achievement for each plan was not a difficult task.

A summary of the objective measurements is tabulated below:

Objective Category	Objective	Unit of Measure
Economic efficiency	Increased net benefits (B-C)	Average future dollar value
Disaster prevention	Decreased risk of catastrophic losses from a single flood occurrence	Ratio of residual residential and commercial damages to residential and commercial property value in the flood plain
Local development	Increase ground water recharge	Average annual recharge in acrefeet
Environmental quality	Increase recreation and open space land uses within the urban area	Acres devoted to recreation and open space land uses
Environmental quality	Decrease erosion of channel banks	Acres prevented from eroding

DEVELOP ALTERNATIVE PLANS

A number of alternative flood control measures appeared to be appropriate, given the conditions in Tucson, and these measures were considered alone and in combinations. Each combination was considered as a new plan. These alternative plans are set forth below according to the procedures outlined in the methodology.

The first set of flood control measures to be generated was that of the traditional structural measures and the second was that of the standard non-structural flood control measures. These measures are listed below:

- Structural
  - Dam
  - Levees
  - Channel

- Non-structural (Flood Plain Related)
  - Flood plain regulations (includes zoning)
  - Flood proofing
  - Flood warning and evacuation systems
  - Flood insurance
  - Public acquisition for open space uses
  - Permanent evacuation (relocation)
  - Public information programs
  - Flood relief

A third set of flood control measures discussed in the methodology relate primarily to the diversion of development to areas outside the flood plain. Examples of these are:

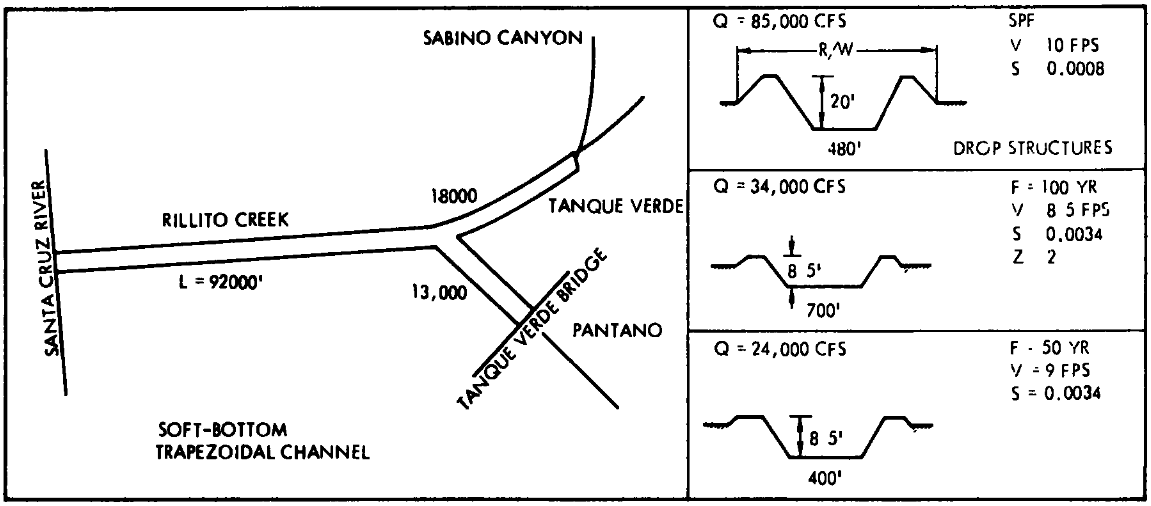
- Extension of public utilities
- Highway construction
- Tax incentives
- Development of alternative sites outside the flood plain

However, because of time and data consideration, only the first two sets of flood management plans were actually considered.

In establishing the initial set of plans, extensive use was made of previous Corps work. The Corps plans which were used as a basis for parts of this section include the structural plans presented in December 1967 and structural and flood proofing plans presented in January 1969. In addition to these plans, other types of flood plain management were considered, namely flood insurance, public acquisition, and zoning. Time constraints precluded consideration of other non-structural alternatives. Had Corps plans not been available, techniques similar to those now used by the Corps would have been employed to develop them. Six structural plans were considered and are presented below.

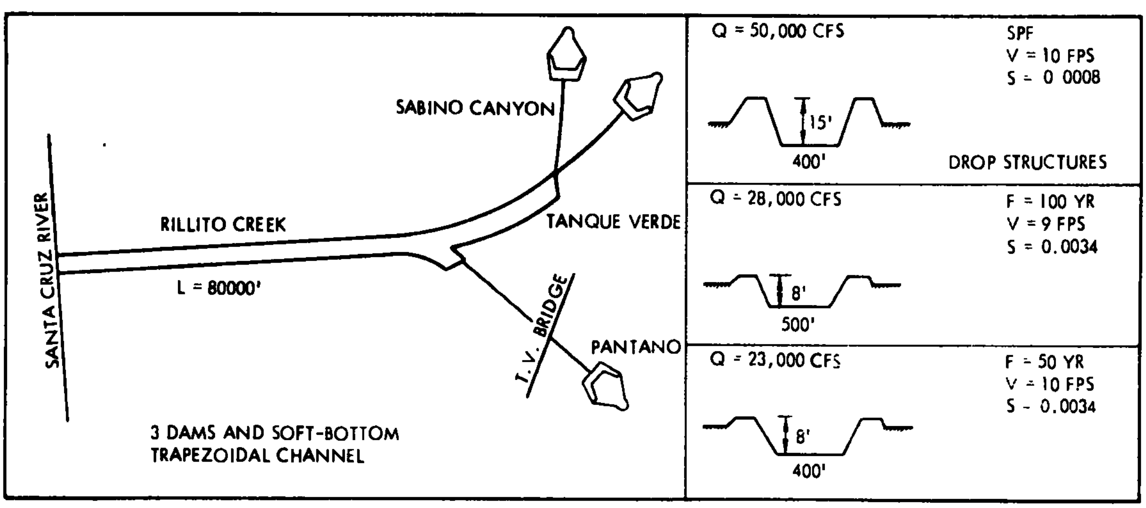
Plan A

A soft-bottom trapezoidal channel was considered first. Three designs were presented, the first for handling the SPF, the second for the 100-year flood, and the third for the 50-year flood.



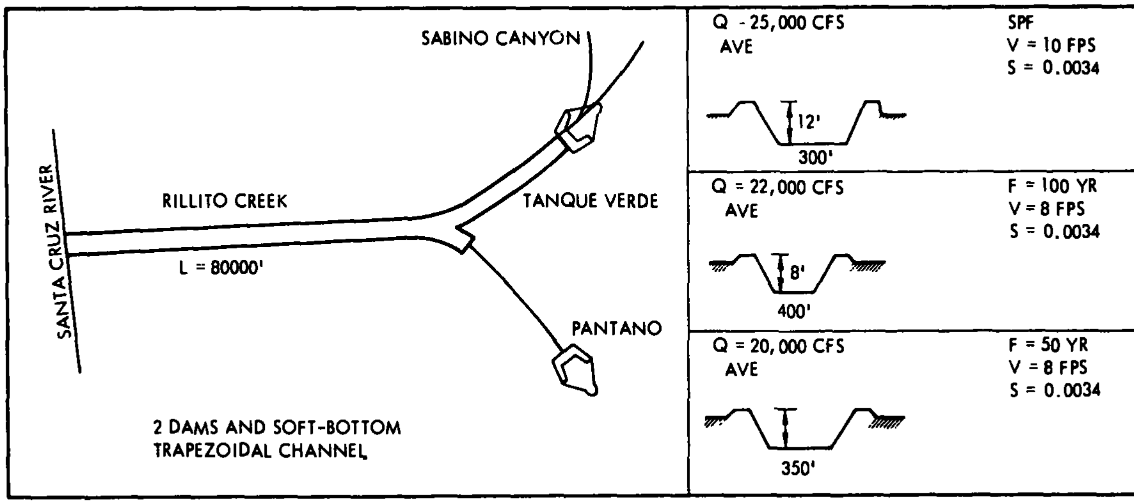
Plan B

The second plan consisted of 3 dams and a soft-bottom trapezoidal channel. Designs were presented for the SPF, the 100-year flood, and the 50-year flood.



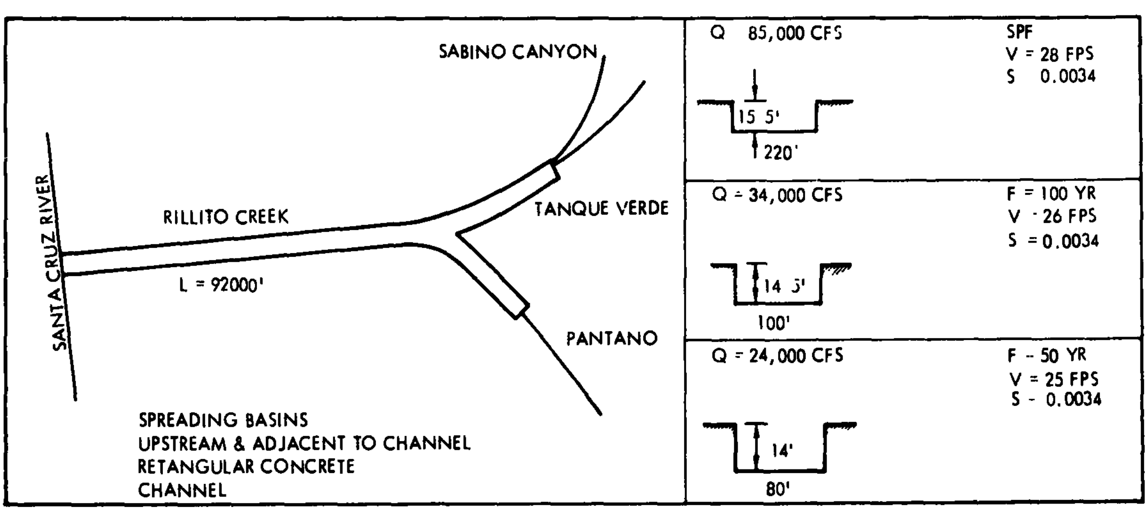
Plan C

The third plan considered consisted of two dams and a soft-bottom trapezoidal channel. Designs were presented for the SPF, the 100-year and 50-year floods.



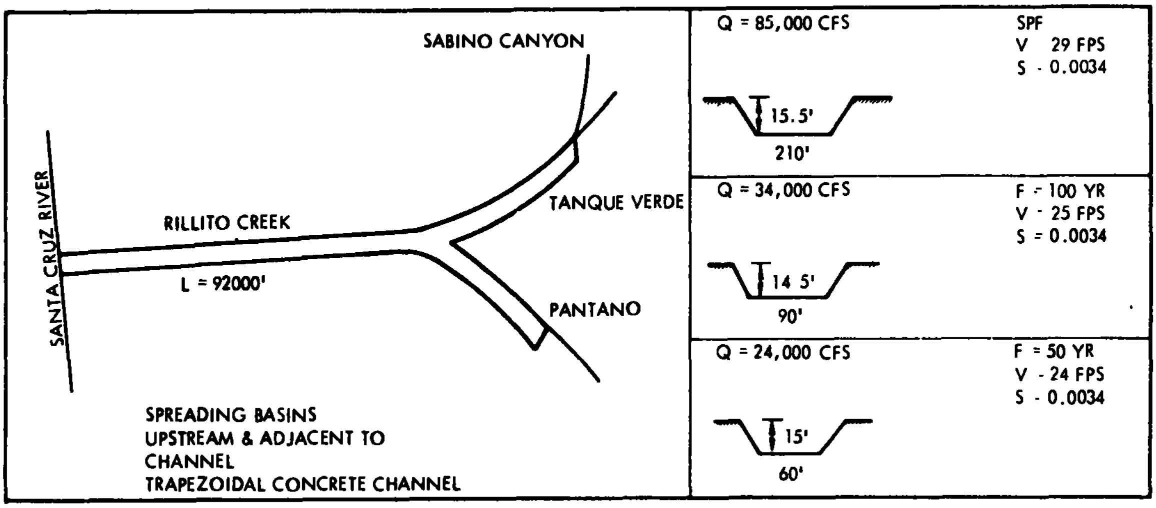
Plan D

The fourth plan considered consisted of a rectangular channel with spreading basins upstream and adjacent to the channel. Designs were presented for the SPF, the 100-year and 50-year floods.



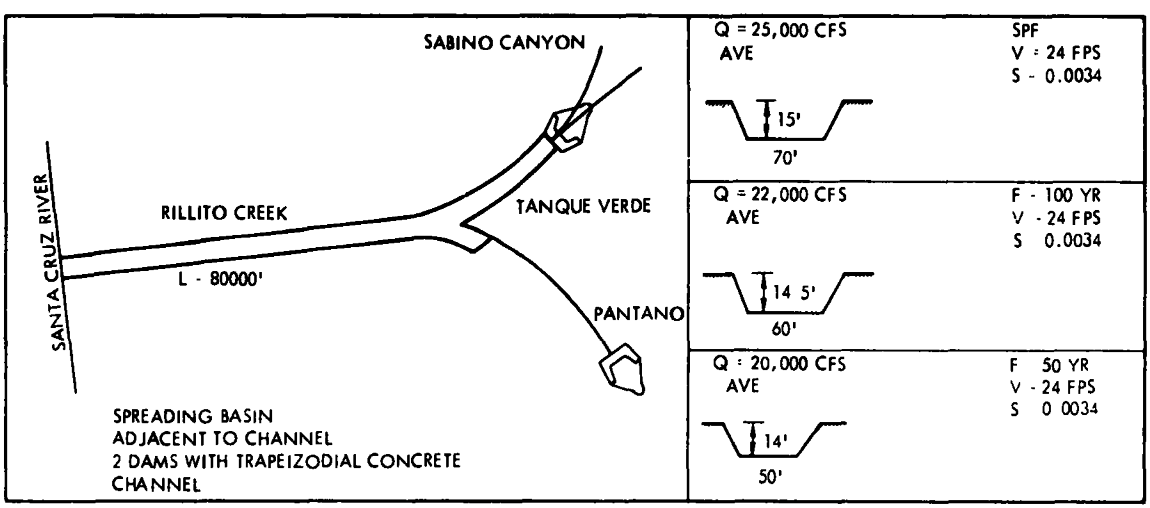
Plan E

The fifth plan considered consisted of a trapezoidal concrete channel. Designs were presented for the SPF, the 100-year and 50-year floods



Plan F

The sixth plan considered consisted of two dams with a trapezoidal concrete channel with a spreading basin adjacent to the channel. Designs were presented for the SPF, the 100-year and 50-year floods.



These six structural plans were based, to one degree or another, on meeting the objectives being considered. Providing protection against the SPF, 100-year and 50-year floods was aimed at both damage reduction and prevention of catastrophic losses. The dams in Plans B and C were primarily intended to provide increased ground water recharge. Purchase of the dry bed for the channel improvement right-of-way could provide a small green belt and erosion losses would be reduced by the channel improvement.

At this point the performance with respect to the various objectives must be evaluated. The following tables present the relevant information pertaining to the performance of various alternatives. Table 9 gives the benefit and cost values for the various structural alternatives. These values were based on Corps estimates. This was possible because the first step under the proposed methodology corresponds with present Corps practice. It is of interest to note that among the structural plans, A-3, a plan which provides for only 50-year protection, provides the highest level of net benefits. For each of the six basic structural measures the value of net benefits is highest for 50-year protection and lowest where protection is provided against the Standard Project Flood.

In addition to benefit-cost calculations, it was necessary to estimate levels of achievement of nondollar objectives for each plan. As has been previously discussed, a set of proxy measurement units was generated to permit quantification and comparison of the objectives. Table 10 gives the levels of achievement corresponding to each plan. Note also that a new plan Θ is presented in Table 10. This plan represents the status quo or the alternative of taking no action to affect the development of the flood plain.

Table 9

Plan	Level of Protection	Costs ($000)	Benefits ($000)	B-C ($000)
A-1	SPF	1135	1142	7
2	100 year	985	1030	45
3	50 year	700	937	237
B-1	SPF	2435	1202	-1233
2	100 year	1650	1090	- 560
3	50 year	1350	997	- 353
C-1	SPF	1420	1202	- 218
2	100 year	1180	1090	- 90
3	50 year	940	997	57
D-1	SPF	1455	1142	- 313
2	100 year	975	1030	55
3	50 year	835	937	102
E-1	SPF	1345	1142	- 203
2	100 year	855	1030	175
3	50 year	725	937	212
F-1	SPF	1860	1142	- 718
2	100 year	1360	1030	- 330
3	50 year	1190	937	- 253

The next step was to examine the structural plans presented in Table 10 and to set aside those plans which are dominated by some other plan. This procedure will often significantly reduce the number of plans under consideration. In this case the reduction is from eighteen plans to eight plans. As stated in the methodology, the dominated plans should simply be set aside since it may be desirable to reintroduce such a plan as a component of a new composite plan at a later point in the planning process. The reduction in the number of plans can significantly reduce the complexity of the analysis.

Table 10

Plan	0_1 Net Benefits (\$000)	0_2 Disaster Prevention (%)	0_3 Erosion Reduction (acres)	0_4 Open Space (acres)	0_5 Ground-Water Recharge (acrefeet)
⊖	0	65	0	0	0
A-1	7	99.9	95	531	0
-2	45	85	50	531	0
-3	237	80	46	531	0
B-1	-1233	99.9	95	531	4000
-2	- 560	85	50	531	4000
-3	- 353	90	46	531	4000
C-1	- 218	99.9	95	531	4000
-2	- 90	85	50	531	4000
-3	57	80	46	531	4000
D-1	- 313	99.9	95	0	0
-2	55	85	50	0	0
-3	102	80	46	0	0
E-1	- 203	99.9	95	0	0
-2	175	85	50	0	0
-3	212	80	46	0	0
F-1	- 718	99.9	95	0	0
-2	- 330	85	50	0	0
-3	- 253	80	46	0	0

Examination of Table 10 shows that Plans ⊖, D1, E1, F1, F2 and F3 can be set aside because they are dominated by Plan A1; Plans B1, and B2, and B3 and dominated by C1. The performance levels for the remaining set of nondominated plans are tabulated in Table 11. The plans are listed in descending order with respect to net benefits.

The next step was to introduce non-structural plans. Three non-structural alternatives were considered in this demonstration case: flood proofing, public acquisition and zoning, and flood insurance.

Table 11

Plan	0_1 Net Benefits ($000)	0_2 Disaster Prevention (%)	0_3 Erosion Reduction (acres)	0_4 Open Space (acres)	0_5 Ground-Water Recharge (acrefeet)
A-3	237	80	46	531	0
E-2	175	85	50	0	0
C-3	57	80	46	531	4000
D-2	55	85	50	0	0
A-2	45	85	50	531	0
A-1	7	99.9	95	531	0
C-2	- 90	85	50	531	4000
C-1	-218	99.9	95	531	4000

These three were selected because, along with flood warning and evacuation, they are considered principal FPM alternatives. Flood warning and evacuation were not considered as feasible alternatives because the majority of flooding results from flash floods, because development in the flood plain is primarily low density, and because it is unlikely that damage reduction would be greatly decreased through temporary evacuation. The three nonstructural plans are summarized below.

Plan G

This plan consists of flood proofing future building sites through the use of land fill. Designs are presented for protection against the SPF, the 100-year flood, and the 50-year flood. These plans will be denoted by G1, G2, and G3 respectively. No attempt is made to protect existing structures in this plan.

Plan H

This plan consists of a combination of public land acquisition and rezoning for recreational and open space uses. The first design includes purchase of all vacant and agricultural land within the SPF. The second design includes the additional purchase of all residential and commercial acres within the 50-year flood plain. These plans will be denoted by H1 and H2 respectively.

Plan I

This plan consists of making flood insurance available to residential development located in the flood plain. Flood insurance would be mandatory for future development and voluntary for existing development. The policy premium would equal the expected value of losses and the administration costs would be borne by the government.

The non-structural plans differ from the structural plans in that they provide much more limited physical protection to development, they are aimed more at damage prevention than damage reduction, and they tend to discourage rather than encourage development in the flood plain.

The next step involves estimating the benefits and costs of each nonstructural plan.

Flood proofing costs for Reaches 4 and 5 for protection against the SPF, 100-year flood, and 50-year flood were obtained directly from the Corps. Flood proofing costs for Reaches 1, 2, and 3 were obtained by determining the cost/acre to flood proof structures in Reaches 4 and 5 for various levels of protection and then multiplying these values by the number of acres to be flood proofed in the affected areas. Flood proofing benefits were obtained for Reaches 4 and 5 and found to be approximately equal to 80% of the average future damages prevented with a channel designed for similar levels of protection. The value of 80% was then used for Reaches 1, 2, and 3 to compute damage reduction benefits. Objective achievement values were obtained by the same methods as before.

Public acquisition and zoning costs and benefits had not been previously considered by the Corps and thus it was necessary to derive these values. Acquisition and zoning costs were based on procedures similar to those used by the Corps of Engineers in computing right-of-way costs. Total cost is equal to the sum of:

1) Annual acquisition charges
2) Annual loss of productivity

3) Annual operation and maintenance costs
4) Administration costs

Annual acquisition charges are equal to the value of property to be acquired, at today's prices, multiplied by 3-1/4% amortized over 100 years. Loss of productivity is equal to the value of property acquired multiplied by 2-3/4% (6% - 3-1/4%).* Operation and maintenance costs necessary to maintain the land as open space were estimated by the Corps to be equal to approximately $40/acre/year. Administration costs were set at 10% of the sum of annual acquisition and annual O and M costs. Benefits derived from the acquisitions and zoning program were limited to present and future damages prevented as a result of the program. This was based on the assumption that residential or commercial development was not justified unless physical protection could be provided in the form of structural or flood proofing measures. Public acquisition and zoning would eliminate future unrestricted development in the flood plain, thus preventing future damage. To the extent that present residential and commercial properties were acquired, reduction in present damage was considered as relevant.

Flood insurance costs and benefits were not considered by the Corps and, as such, had to be specifically derived for the case study.

Flood insurance costs were limited to the annual expenses of administrating an insurance program. The annual insurance premium would be equal to average annual residential damages. Benefits were of two types. The first included damages prevented as a result of the flood program which discourages uneconomic encroachment onto the flood plain. In this, flood insurance and zoning benefits are similar in nature. The second includes the risk premium that individuals would be willing to pay to prevent the uncertainty of expected losses. It is assumed that this additional benefit is just equal to the administrative costs of the insurance program.

*It is not assumed that land is non-productive when transferred from a private to a public use. There is a loss of productivity cost from the standpoint of the private sector which is, however, offset by objective achievement gained as a result of its use in the public sector.

The formulation of the six initial non-structural plans was based on what seemed to be feasible in light of comments by the Corps as well as by local officials. Lack of time and data limited formulation of additional non-structural alternatives. Table 12 lists the benefit-cost values for each on the initial non-structural plans.

Table 12

Plan	Areas Affected Within the Flood Plain	Costs ($000)	Benefits ($000)	B-C ($000)
G-1	Flood proofing residential and commercial acreage within the flood plain. SPF protection.	307	477	170
G-2	Flood proofing residential and commercial acreage within the flood plain. 100-year protection.	92	423	331
G-3	Flood proofing residential and commercial acreage within the flood plain. 50-year protection.	64	380	316
H-1	Acquisition of all vacant and agricultural acreage within the flood plain.	1231	603	- 628
H-2	Acquisition of all vacant and agricultural acreage within the flood plain and residential and commercial acreage within the 50-year overflow area. Zoning of the acquired land for open space uses.	2095	917	-1178
I-1	Insurance available to residential development within the flood plain.	90	383	293

In the case of both the structural as well as the non-structural alternative, the generation of specific values for each of the objectives was computed in the same manner. Table 13 lists the values of achievement for the objectives corresponding to each plan.

Table 13

Plan	0_1 Net Benefit ($000)	0_2 Disaster Prevention (%)	0_3 Erosion Reduction (acres)	0_4 Open Space (acres)	0_5 Ground-Water Recharge (acrefeet)
G-1	170	87	0	0	0
G-2	331	77	0	0	0
G-3	316	75	0	0	0
H-1	- 628	68	0	4977	0
H-2	-1178	70	0	5259	0
I-1	293	97	0	0	0

After the calculation of achievement levels, the inferior plans were set aside (using the same criteria employed in elimination of inferior structural plans), and the remaining plans were ranked according to their level of net benefits. Of the six non-structural plans only Plan G-3 and G-1 could be set aside at this stage (Plan G-2 dominates Plan G-3 and Plan I-1 dominates G-1). After the initial reduction, the non-structural plans are ranked according to achievement of net benefits. Table 6 combines the structural and non-structural plans, listing them in order of net benefits.

The methodology specifies that the next step in the formulation of a set of plans is the development of new plans by putting two or more previously developed plans in combination. The objective is to combine plans which are complementary in order to construct new plans which perform well with regard to a number of objectives. This often will involve the combination of structural and non-structural measures for different reaches of the river. There is no mechanical procedure nor general rule as to how plans should be combined. There is largely a consequence of the fact that the performance level of plans, when put in combination, is seldom the sum of the performance levels of the plans when considered separately. As pointed out in the methodology, many plans may be incompatible in the sense that they cannot be implemented simultaneously. Therefore, the knowledge and imagination of the planner are critical for the development of a promising set of plans. From the above remarks it is clear that in putting together new plans, one must understand the characteristics of the basic component plans and how these components will perform in combination.

Table 14

Plan	0_1 Net Benefit ($000)	0_2 Disaster Prevention (%)	0_3 Erosion Reduction (acres)	0_4 Open Space (acres)	0_5 Ground-Water Recharge (acrefeet)
G-2	331	77	0	0	
I-1	293	97	0	0	
A-3	237	80	46	531	
E-2	175	85	50	0	
C-3	57	80	46	531	4000
D-2	55	85	50	0	
A-2	45	85	50	531	
A-1	7	99.9	95	531	
C-2	- 90	85	50	531	4000
C-1	- 218	99.9	95	531	4000
H-1	- 628	68	0	4977	
H-2	-1178	70	0	5259	

For purposes of demonstration, twelve plans have been developed which are combinations of the previous plans. The new plans are mostly combinations of structural and non-structural measures or combinations of different structural measures for different reaches of the river. The combinations included here were chosen both because of their promise for performance and because of the relative availability of data. No claim is made that the plans which were developed include the most promising combinations. The purpose was to demonstrate that new, nondominated alternatives could be generated by considering combinations of structural and nonstructural measures.

The plans which were developed are presented in Table 15. A description of each plan is presented in the second column. Because this case is largely designed to demonstrate the use of data in the methodology, the rationale for combining different plans is omitted and the new plans are simply described and presented with their performance characteristics. The plans are labeled so that one of the basic components is identified. For example, A-1-1 is a combination of A1 restricted to Reaches 4 and 5 and flood proofing for Reaches 1, 2, and 3. The performance estimates were developed by the TRW personnel using the measurement procedures described for each objective and the available data.

The plans in Table 15 are now added to the previously developed plans and the dominated plans are once again set aside. The remaining nondominated plans are displayed in Table 16.

The next step outlined in the methodology is the development of substitute plans for flood control which involve activities outside the flood plain. The establishment of alternative sites for development is an example of such a plan. Again, because of time and budget constraints and because of data requirements, no plans of this type were generated for this demonstration. This in no way limits the usefulness of the demonstration which is intended primarily to demonstrate the use of data in the procedure to evaluate alternatives. The alternatives presented in Table 16 represent the nondominated alternatives for final consideration. Again, it should be pointed out that in actual Corps study there would be a larger set of plans for final consideration containing plans which have been omitted in this demonstration. Therefore, the results of the following section on the evaluation of alternatives must be interpreted as an instructive exercise as opposed to a definitive treatment of the choice of plans for the Tucson case.

SELECTION OF THE BEST PLAN

Selection of the best plan from among the alternatives considered requires two types of information. Required first are measures of the objective attainment levels which could be expected to result from the implementation of any alternative. This information has been derived and is summarized in Table 16.

Table 15

Plan	Components	Costs ($M)	Benefits ($M)	0_1 Net Benefits ($000)	0_2 Disaster Prevention (%)	0_3 Erosion Reduction (acres)	0_4 Open Space (acres)	0_5 Local Development (acres)	0_6 Ground-Water Recharge (acrefeet)
A-1-1	SPF channel protection for Reaches 4 and 5. Flood proofing for 100-year flood for Reaches 1, 2, and 3.	0.827	0.993	166	92	60	343		0
A-3-1	50-year channel protection for Reaches 4 and 5. No protection for Reaches 1, 2, and 3.	0.410	0.770	360	76	29	343		0
A-3-2	50-year channel protection for Reaches 4 and 5. Additional protection for 100-year flood with flood proofing. No protection for Reaches 1, 2, and 3.	0.440	0.800	360	78	29	343		0
A-3-3	50-year channel protection for Reaches 4 and 5. Additional protection for SPF with flood proofing. No protection for Reaches 1, 2, and 3.	0.580	0.840	260	90	29	343		0
A-3-4	50-year channel protection for Reaches 4 and 5. Additional protection for 100-year flood with flood proofing. Protection for Reaches 1, 2, and 3 for 100-year flood with flood proofing.	0.457	0.843	386	79	29	343		0
A-3-5	50-year channel protection for Reaches 4 and 5. Additional protection for 100-year flood with flood proofing. Acquisition of all vacant and agricultural land in Reaches 1, 2, and 3 for open space uses.	0.722	0.861	139	78	29	1483		0
A-3-6	50-year channel protection for Reaches 4 and 5. Additional protection for 100-year flood with flood proofing. Flood insurance available to occupants of Reaches 1, 2, and 3.	0.472	0.887	415	80	29	343		0
A-3-3-1	50-year channel for Reaches 4 and 5. Protection for SPF with flood proofing in Reaches 4 and 5. Flood proofing in Reaches 1, 2, and 3 for the SPF.	0.617	0.887	270	96	29	343		0
G-1-1	Flood proofing the 50-year overflow area for Reaches 1-5 incl. for the SPF.	0.128	0.352	224	78	0	0		0
G-1-2	Flood proofing the 50-year overflow area for Reaches 1-5 incl. for the SPF. Flood insurance available to present and future residential development in the area between the 50-year overflow and the outer limits of the SPF overflow. No protection for existing development in the 50-year overflow.	0.165	0.465	300	81	0	0		0
H-1-1	Acquisition of all vacant and agricultural land in the 50-year overflow area for Reaches 1-5 inclusive.	0.660	0.441	-219	72	0	2707		0
H-1-2	Acquisition of all vacant and agricultural land in the 50-year overflow area in Reaches 1-5 inclusive. Flood proofing for all future residential and commercial structures for SPF year flood in Reaches 1-5 inclusive.	0.838	0.571	-267	90	0	2707		0

Table 16

Plan	0_1 Net Benefits ($000)	0_2 Disaster Prevention (%)	0_3 Erosion Reduction (acres)	0_4 Open Space (acres)	0_5 Ground-Water Recharge (acrefeet)
A-3-6	415	80	29	343	0
I-1	301	97	0	0	0
A-3-3-1	270	96	29	343	0
A-3	237	80	46	531	0
A-1-1	166	92	60	343	0
A-3-5	139	78	29	1483	0
C-3	57	80	46	531	4000
A-2	45	85	50	531	0
A-1	7	99.9	95	531	0
C-2	- 90	85	50	531	4000
C-1	-216	99.9	95	531	4000
H-1-1	-219	72	0	2707	0
H-1-2	-267	90	0	2707	0
H-1	-726	68	0	4917	0
H-2	-852	72	0	5259	0

As stated in the methodology, the second imperative for the selection of the best plan is a set of value judgment describing the relative importance of each objective. Such data must give a measure of the marginal attainment level of one objective that society is willing to sacrifice in order to gain a marginal increase in the attainment level of another objective. Perhaps the most easily used expression of the required value judgments is a set of estimates of society's willingness to pay for marginal increases of any objective attainment level. The willingness to pay is defined as that increase in net benefits which would just compensate the members of society for a decrease in the level of attainment of the objective under consideration. An equivalent definition is that decrease in net benefits which when coupled with an increase in the objective under consideration would leave society just as well off after the change as before. Although the value statements have been introduced into the Tucson study in the form of willingness to pay figures, there is no reason that this form must be used. However, money value does provide a convenient numeraire because of the relative ease of translating the value of objective attainment to monetary units.

It is important to realize that without introduction of the value statements, either explicitly or implicitly, no rational decision can be made. Conversely, as is discussed in the methodology, any decision made without explicit introduction of value judgments involves such judgments implicitly.

In the methodology three procedures were set forth to introduce the necessary value statements. Two of these procedures, the critical value approach and the decision analysis approach, introduce value statements through willingness to pay values; the third uses direct tradeoffs which incorporate the values of the decision maker. These procedures are demonstrated in this section. It will be noted that they are complementary since several may be employed in arriving at a decision as to the best plan.

CRITICAL VALUE APPROACH

In this procedure limits were derived for the possible range of each willingness to pay value. By the use of these limits, every plan which could be shown to be inferior to another plan for all willingness to pay values between the limits was eliminated from further consideration. The remaining set of plans could be used subsequently as a basis to decide which willingness to pay values should be more precisely determined. As the limits are subsequently tightened, more plans are eliminated. This procedure could be followed either until only one plan remains or until the probable gains from a more precise specification of the limits would be outweighed by the probable cost of the research required to gather the additional information.

This procedure was applied to the Tucson data. Table 16 summarizes the alternatives which have been generated and the expected level of objective attainment associated with each one. Any alternative which was dominated by another has been eliminated from the table.

The first step of the procedure is to derive limits on society's willingness to pay for increases in attainment of each objective. In the Tucson study, limits were arrived at by means of discussions with Corps and local officials. In order to determine preference, the following question was asked: "Are those affected willing to pay an amount greater than x for specific levels of objective achievement?" Various values of x were used in order to obtain limits on the willingness to pay for each objective. Willingness to pay values in the study were not based directly on values supplied by either local officials or the Corps of Engineers. If time had permitted, methods similar to those used by the Corps in measuring recreational benefits would have been employed. In discussion with Tucson planning officials, the study team attempted to assess the factors upon which willingness to pay values would be based. Of interest were such questions as: How much had the community spent for erosion reduction in the past? Was there adequate open space to serve the needs of the Community? How much will water cost when the Central Arizona Project is completed? Based on an analysis of the answers to these and similar types of questions, the study team generated a set of willingness to pay values which it felt could be defended. The limits so derived are displayed in Table 17. Note that the willingness to pay for net benefits is by definition equal to one.

Table 17

Objective	Range of Objective Achievement	Willingness to Pay Value
0_1	entire range	1 $/$
0_2	entire range	8450 - 14,800 $/%
0_3	entire range	0 - 180 $/acre
0_4	0 - 1000 acres	25 - 500 $/acre
0_4	1000 - 6000 acres	10 - 200 $/acre
0_5	entire range	0 - 35 $/acrefeet

figures, there is no reason that this form must be used. However, money value does provide a convenient numeraire because of the relative ease of translating the value of objective attainment to monetary units.

It is important to realize that without introduction of the value statements, either explicitly or implicitly, no rational decision can be made. Conversely, as is discussed in the methodology, any decision made without explicit introduction of value judgments involves such judgments implicitly.

In the methodology three procedures were set forth to introduce the necessary value statements. Two of these procedures, the critical value approach and the decision analysis approach, introduce value statements through willingness to pay values; the third uses direct tradeoffs which incorporate the values of the decision maker. These procedures are demonstrated in this section. It will be noted that they are complementary since several may be employed in arriving at a decision as to the best plan.

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0_4	0 - 1000 acres	25 - 500 \$/acre
0_4	1000 - 6000 acres	10 - 200 \$/acre
0_5	entire range	0 - 35 \$/acrefeet

Further note that the willingness to pay values for open spaces are lower for acres above one thousand than for the first one thousand acres. This reflects the feeling that there is a diminishing return after a certain level of open space. It is important that this kind of consideration be incorporated into the analysis. It should be pointed out that setting different willingness to pay values for different ranges of objective achievement will increase the computation required in comparing alternatives. This, however, should not present significant difficulties if the computations are done on the computer.

The second step of the procedure is to compare every alternative with every other one in a pairwise manner in order to ascertain the actual gains and losses of objective attainment resulting from a choice of one alternative over the other. For example, a selection of alternative I-1 over alternative A-3-5 would result in the following changes: 1) a gain in net benefits of $162,000 ($301,000 - $139,000), 2) a gain in disaster prevention of 19% (97% - 78%), 3) a loss in erosion reduction of 29 acres (29 acres - 0 acres), and 4) a loss of open space of 1483 acres (1483 acres -0 acres). This comparison must be made for every possible pair of alternatives.

The third step of the procedure uses the limits discussed above in order to eliminate every plan which can be shown to be inferior to another plan. Basically, the method compares the two plans of every pair under the assumptions of willingness to pay which are most favorable to one of the plans. If this plan is shown to be inferior under the most favorable assumptions, it is eliminated from consideration. If not, the plan is evaluated under the most unfavorable assumptions. If the plan is shown to be superior under the most unfavorable assumptions, the other plan from the pair is eliminated. This process continues until every pair of plans has been compared. At this point, the remaining alternatives include all of the plans which are optimal under some set of willingness to pay values within the limits chosen.

There are several computational methods to perform the analysis described above. Perhaps the easiest and the most economical method when there is a large number of alternatives is to program the analysis on a computer. The analysis can be performed manually, although such a procedure is extremely time consuming even when only a modest number of alternatives is available. Appendix A of the methodology includes the mathematical expression necessary for the evaluation and also a flow diagram for the computer program to make the necessary calculations.

Conceptually, the various computational schemes are identical. When comparing alternative n to alternative i, the upper limit of willingness to pay is used to evaluate all objective attainment levels better met by alternative n than by alternative i. The lower limit is used to evaluate objective attainment levels better met by alternative i than by alternative n. If under these assumptions, which are most favorable to alternative n, alternative i is shown to be superior, alternative n is eliminated as a candidate for the best plan. Next, the plans are evaluated under the circumstances most favorable to alternative i. If n is shown to be superior to i under these conditions, alternative i is eliminated as a candidate. This procedure is followed for all pairs of alternatives for which n does not equal i. That is, no plan is compared to itself.

The procedure is illustrated below for two comparisons, one which results in no eliminations, the other which results in the elimination of an alternative. The limits on willingness to pay are those summarized in Table 17 and repeated in Table 18. Since all of the values for 0_4 lie in the range 0-1000 only one set of willingness to pay values is given for 0_4 in Table 19. First, Plans A-3 and A-3-3-1 are compared; neither can be eliminated. Second, A-3 and A-3-3-1 are compared; alternative A-3 is eliminated.

The levels of objective achievement resulting from the plans are rewritten in Table 18 for convenience. Also for convenience the plans are each given new identifying numbers in addition to their old identification.

Table 18. Objective Achievement Levels

Plan	Number	0_1 $(000)	0_2 %	0_3 acres	0_4 acres	0_5 acrefeet
A-1	1	7	99.9	95	531	0
A-3-3-1	2	270	96	29	343	0
A-3	3	237	80	46	531	0

Table 19. Limits on Willingness to Pay

		0_1 $/$	0_2 $/%	0_3 $/acre	0_4 $/acre	0_5 $/acrefeet
High	WH	1	14,800	180	500	35
Low	WL	1	8,450	0	25	0

The change from Plan 1 to Plan 3 involves the following changes in levels of objective achievement:

$$0_{13} - 0_{11} = \$237K - \$7K = \$230,000$$

$$0_{23} - 0_{21} = 80 - 99.9 = -19.9$$

$$0_{33} - 0_{31} = 46 - 95 = -49$$

$$0_{43} - 0_{41} = 531 - 531 = 0$$

$$0_{53} - 0_{51} = 0 - 0 = 0$$

where O_{ij} is the level of achievement of plan; with x to objective i.

Hence in achievement of 0_1, Plan 3 is better than Plan 1. In achievement of 0_2 and 0_3, Plan 1 is better than Plan 3. First, the plans will be analyzed under the assumptions most favorable to Plan 3. The variable S_{31} represents the difference in total willingness to pay between Plan 3 and Plan 1, under the values of willingness to pay which are most favorable to Plan 3. Therefore, if S_{31} is greater than zero, Plan 3 is better than Plan 1 under the assumptions most favorable to Plan 3. No information would be gained from such a comparison. If, however, S_{31} were smaller than zero, it could be concluded that Plan 3 is inferior to Plan 1 under all assumptions of willingness to pay between the limits. Therefore, Plan 3 could be eliminated from further consideration.

$$S_{31} = (0_{13} - 0_{11})WH_1 + (0_{23} - 0_{21})WL_2 + (0_{33} - 0_{31})WL_3$$

$$= \$230,000\ (1) + (-19.9)\ (\$8,450) + (-49)\ (\$0)$$

$$= \$230,000 - \$168,155$$

$$S_{31} = \$61,845$$

Since S_{31} is greater than zero, we can conclude that Plan 3 is favorable to Plan 1 under the assumptions most favorable to Plan 3. Hence, this calculation will not allow either plan to be eliminated.

Second, the plans will be analyzed under the assumptions most favorable to Plan 1.

$$S_{13} = (0_{11}-0_{13})WL_1 + (0_{21}-0_{23})WH_2 + (0_{31}-0_{33})WH_3$$
$$= -\$230,000 + (19.9)(\$14,800) + (49)(\$180)$$
$$= -\$230,000 + \$294,520 + \$8,820$$
$$S_{13} = \$72,340$$

Thus since $S_{13} > 0$, we can conclude that Plan 1 is superior to Plan 3 under the assumptions most favorable to Plan 1. Therefore, the foregoing analysis does not allow either Plan 1 or Plan 3 to be eliminated.

As a second example, Plan 2 and Plan 3 will be analyzed. Consider the changes incurred in going from Plan 3 to Plan 2.

$$0_{12} - 0_{13} = \$33,000$$
$$0_{22} - 0_{23} = 16$$
$$0_{32} - 0_{33} = -17$$
$$0_{42} - 0_{43} = -188$$
$$0_{52} - 0_{53} = 0$$

Now consider S_{23}

$$S_{23} = \$33,000 + 16(\$14,800) - 17(\$0) - 188(\$25)$$
$$= \$33,000 + \$236,800 - \$0 - \$4,700$$
$$S_{23} = \$265,100$$

Hence, under the assumptions most favorable to Plan 2, Plan 2 is shown superior. This will not allow either plan to be eliminated. Now consider S_{32}.

$$S_{32} = -\$33,000 + 16(\$8,450) - 17(\$180) - 188(\$500)$$
$$= -\$33,000 + \$135,200 - \$3,060 - \$94,000$$
$$S_{32} = \$71,140$$

In this case, under the assumptions most favorable to Plan 3, Plan 2 is still superior to Plan 3. Therefore, we can conclude that under <u>all</u> assumptions as to willingness to pay values, within the limits given, Plan 2 is superior to Plan 3. Thus Plan 3 can be eliminated from further consideration.

In the Tucson study, the analysis outlined above was completed for the alternatives in Table 16, using the limits on willingness to pay displayed in Table 17. All but four of the alternatives were thus eliminated from further consideration. The remaining alternatives are displayed in Table 20.

Table 20. Alternatives Not Eliminated by Use of Willingness to Pay Limits

Plan	0_1 ($000)	0_2 (%)	0_3 (acres)	0_4 (acres)	0_5 (acrefeet)
I-1	301	97	0	0	0
A-3-3-1	290	96	29	343	0
A-3-5	139	78	29	1483	0
H-1-2	-267	90	0	2707	0

As previously stated, the set of plans displayed in Table 12 was derived by making pairwise comparisons between plans to eliminate inefficient plans. For the reader interested in checking the list, one way of arriving at this final set is to use A-3-3-1 to eliminate A-3-6, A-1-1, A-3, C-3, A-1, A-2, C-1, and C-2, to use A-3-5 to eliminate H-1-1, and to use H-1-2 to eliminate H-1 and H-2. It is interesting to note that among the plans eliminated was A-3-6 which produces the highest level of net measurable benefits, but which does not perform particularly well with regard to other objectives. On the other hand plan H-1-2 which has negative net benefits, but which provides for a large amount of open space is one of the four plans not eliminated.

In addition, of the four remaining plans, all involve non-structural components and two of these plans I-1 and H-1-2 do not involve either a dam or channel improvements. The point here is that, even under very broad limits on willingness to pay values, plans with significant non-structural components are shown to be superior to the purely structural alternatives in the case of Tucson. In this case, at least, broadening the scope of flood plain planning can lead to significant improvements.

From this point of the analysis, no further reduction in the set of remaining alternatives is possible without more information as to the correct willingness to pay values. By the derivation of Table 20, it is obvious that every alternative can be shown to be better than each other alternative for some set of willingness to pay values within the limits chosen. Therefore, no alternative from Table 20 can be eliminated without the use of tighter limits on the willingness to pay values. Conversely, any choice of one alternative over another explicitly or implicityly uses more information concerning willingness to pay values than is displayed in Table 17.

Since no further elimination of alternatives can be accomplished without additional information, there are two general procedures which can be used in order to reach an ultimate choice of the best alternative. Each requires a more precise statement of value judgments than is contained in Table 17. The first procedure is to use a decision analysis approach and to derive the subjective probability distribution on the possible willingness to pay values for each objective. This procedure is described more fully in the following section of the Tucson study. The second procedure involves further research on the proper willingness to pay values, in order to eliminate more alternatives from consideration.

Research into the willingness to pay values can be facilitated by use of the computer program to eliminate alternatives. The program can be used to establish which values are critical for the elimination of additional alternatives. Merely by changing the limits of willingness to pay values, one at a time or in groups, the planner can see how far each limit must be tightened in order to eliminate more alternatives. This sensitivity analysis can be used in order to decide which willingness to pay values should be researched further. It should be noted that when the program is run to test the sensitivity of the solution to limit changes, one need only analyze those alternatives not eliminated in earlier tests. Using all of the alternatives would take more computational time and would add no new information. In using the elimination procedure, the planner may continue research on the willingness to pay values until all alternatives but one have been eliminated. The remaining alternative will unequivocally be the optimal of all those considered. It may also happen that a point is reached whereby the set of noneliminated plans is difficult to reduce.

In the Tucson case it is possible to eliminate H-1-2 if the upper limit on willingness to pay for acres of open space above 1,000 acres is reduced from $200 per acre to $175 per acre. Also, varying the willingness to pay values for erosion reduction shows that the results are not sensitive to changes in these limits. Assuming that we can restrict the upper boundary on open space above 1,000 acres to $175 per acre, the plans for final consideration are given in Table 21.

Table 21

Plan	0_1 (\$000)	0_2 %	0_3 acres	0_4 acres	0_5 acrefeet
I-1	301	97	0	0	0
A-3-3-1	290	96	29	343	0
A-3-5	159	78	29	1483	0

At this point final selection requires that either direct tradeoffs be made or that the decision analysis approach be used.

Direct Tradeoffs

In this case consider the tradeoff to be made in comparing I-1 and A-3-3-1. If A-3-3-1 is selected, an average annual benefit of $11,000 is given up along with a one percent in disaster protection to achieve 29 acres of erosion reduction and 343 acres of open space. If the planner chooses plan A-3-3-1, this implies that

$$-\$11,000 - W_2 + 29\ W_3 + 343\ W_4 > 0$$

where W_2, W_3, W_4 are the per unit willingness to pay values for 0_2, 0_3, and 0_4 respectively.

Similarly, if A-3-3-1 is chosen over A-3-5, it implies that

$$\$131,000 + 18X_2 + 0X_3 - 1540X_4 > 0$$

Therefore the choice of A-3-3-1 implies that the planner's willingness to pay values satisfy two inequalities. These values are not uniquely determined, but are limited by the inequalities. In this case the tradeoffs are easy to see because we have reduced a large problem to one of considering just three alternatives with respect to four objectives. Thus, the critical value procedure made it possible to use the method of direct tradeoffs in making the final choice. The actual choice and the consideration of the appropriate tradeoffs would have to be made by the Corps.

Selection by Decision Analysis

Decision analysis provides an approach to the selection of the best alternative whenever the willingness to pay values are not known with certainty. In such a case the willingness to pay values can be treated as random variables. The subjective probability distribution of willingness to pay is generated for each objective. The planner then selects that alternative having the greatest expected value of total willingness to pay.

The first step is to generate the subjective probability distribution of willingness to pay values. This distribution is nothing more than a mathematical statement of the planner's uncertain knowledge as to the value of willingness to pay for any objective. Even though there may be one correct value of willingness to pay, the planner may not know this value. Hence, he is forced to treat the value as a random variable, even though a planner with perfect knowledge could unequivocally state that value. In this sense the subjective probabilty distribution is a statement of the uncertainty of the planner's knowledge; it is not a statement of the variability or lack of precision of the objective world.

A completely general formulation of this procedure is presented in the methodology. For the purpose of this demonstration the decision rule was to maximize expected willingness to pay,

$$\sum_{j=1}^{5} 0_j \, E(W_j),$$

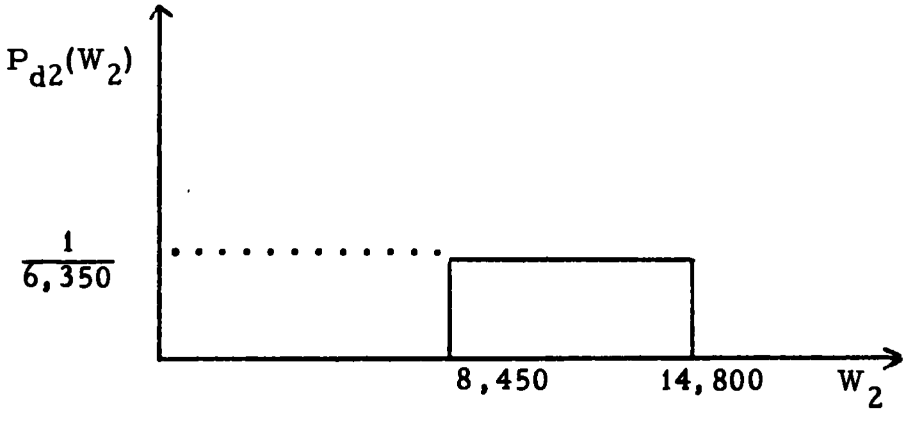
and the probability distribution on each W_j was assumed to be uniform over the range between the limits set in Table 9.

For the Tucson study, it was assumed that all values of willingness to pay between the limits given were equally probable. In general this would be a bad assumption. However, because of our complete uncertainty as to the probable values of the Wj's, and because only the mean of the distribution was important, the equiprobability distribution was accepted as a convenient function. The expected values of the Wj's would be calculated as follows:

$$E(W_j) = \int W_j P_{dj}(W_j) dW_j,$$

Where $P_{dj}(W_j)$ is constant between the limits on W_j, and equals zero outside of the limits.

In particular, consider W_2. The limits on W_2 are \$8,540/% and \$14,800/%. The equiprobability assumption implies that the probability distribution on W_2 is as graphed below:



Therefore, the expected value of W_2 is as follows:

$$E(W_2) = \int_{8,450}^{14,800} W_2 P_{d2}(W_2) dW_2$$

$$= \frac{1}{2} (14,.800 + 8.450)$$

$$= \$11,625 \ \$/\%$$

A similar calculation was performed for each of the willingness to pay values. The results are tabulated in Table 22.

In Table 23 the total expected willingness to pay has been computed for all of the plans in Table 16. The procedure to calculate expected willingness to pay is, with one exception, to multiply the level of achievement for each objective by the expected value of willingness to pay for that objective and to take the sum over all objectives. The exception is that in

Table 22

Objective	Range of Objective Achievement	Expected Willingness to Pay Values
0_1	Entire Range	1 \$/\$
0_2	Entire Range	11,625 \$/\$
0_3	Entire Range	90
0_4	0-1000 acres 1000 -	262.50 \$/acre 105 \$/acre
0_5	Entire Range	\$17.5 \$/acrefoot

computing expected willingness to pay for disaster prevention 65 must be subtracted from the level of achievement produced by each plan. This is because disaster prevention, the ratio of residential and commercial damages to residential and commercial property, with the status quo level of protection is 65%. Willingness to pay will thus be zero for any level of objective achievement under 65%. For this reason it is only reasonable to multiply this increase by the expected willingness to pay for a one percent increase in disaster prevention.

It is interesting to note that given the values for expected willingness to pay per unit of objective achievement, plan A-3-3-1 was the best. It should be noted that the plan judged best by means of the decision analysis approach was among the set of plans not eliminated by means of the previous analysis. This observation must be true in general. Both the decision analysis approach and the critical value approach will lead to the same results when properly executed. Thus, the two approaches can be viewed as being complementary to one another. At the same time it should be noted that there will in general be plans, such as A-3-6, which will be eliminated on the basis of the critical value analysis, but which, for some set of willingness to pay values within the established ranges, will be superior to plans which are not eliminated in the critical value analysis. This, however, is not a cause for concern because, as previously mentioned, the best plan, given the range of willingness to pay values, will always be among those plans not eliminated.

Table 23.*

Plan	$0_1E(W_1)$ ($000)	$0_2E(W_2)$ ($000)	$0_3E(W_3)$ ($000)	$0_4E(W_4)$ ($000)	$0_5E(W_5)$ ($000)	$0_5E(W_5) \sum_{j=1}^{5} 0_jE(W_j)$ ($000)
A-3-6	415	174	3	90	0	682
I-1	301	372	0	0	0	673
A-3-3-1	270	360	3	90	0	723
A-3	237	174	4	139	0	554
A-1-1	166	314	5	90	0	575
A-3-5	139	151	3	314	0	607
C-3	57	174	4	139	70	444
A-2	45	233	5	139	0	422
A-1	7	407	9	139	0	462
C-2	- 90	233	5	139	70	357
C-1	-216	407	9	139	70	409
H-1-1	-219	81	0	442	0	304
H-1-2	-267	291	0	442	0	466
H-1	-726	35	0	674	0	- 17
H-2	-852	81	0	710	0	- 61

*Some numbers have been rounded.

This concludes the evaluation procedure. The result could have been changed if different ranges of willingness to pay values had been used or if we had assumed different subjective distributions over these values. As has been stated, the purpose was not to prove that plan A-3-3-1 is best for Tucson, but to demonstrate how to use the proposed methodology to evaluate plans.

In this case the methodology performed effectively in that it was possible with very imprecise specifications of willingness to pay to reduce the problem to a choice among three plans which could be evaluated by the decision analysis approach or by making direct tradeoffs. Furthermore, non-structural measures proved to be effective in this case and, finally, the objectives other than measureable benefits were critical in the selection of the best plan.

APPENDIX A

COMPUTERIZED IMPLEMENTATION OF THE METHODOLOGY

It has been pointed out that one of the obstacles to implementation of the methodology is that generation and evaluation of a large number of plans may be both costly and time consuming. A possibility for mitigating this problem is to employ computers in both the generation and evaluation of plans. Promising computer applications are discussed in this appendix to the methodology. However such possible applications are only discussed; they have not been developed here. Therefore full development will have to await further work.

The first area of computer application is the computer generation of alternatives. According to the procedure outlined in the methodology, once the basic structural and nonstructural plans have been formulated, many new plans can be generated by creating combinations of basic plans. The number of combinations, using basic components such as reservoirs, channels, flood proofing, flood zoning, etc. at various levels of protection, can become quite large. However, the process of generating a large number of combinations is costly in terms of both time and money. Therefore use of computers to form the combinations appears promising. Some work along these lines has already been completed by Professor L. Douglas James at the University of Kentucky. The flood control measures put into combinations in the work by James were flood proofing, channel improvement, land use adjustment, and reservoir storage.

The first section of this appendix discusses the possible use of computers in generating alternatives and analyzes some of the difficulties to be encountered. It further includes a discussion of approaches implementing the use of computers to formulate plans.

In addition to the task of generating large numbers of plans, there is the task of evaluating these plans. The larger the number of plans and objectives, the more difficult the mechanics of evaluation become. This is particularly true for the process of making direct tradeoffs among plans and for the critical value approach, which requires two-way, pairwise comparisons among alternatives. These two cases are discussed in the second and third sections of this appendix, respectively. In the case of performing the critical value analysis, an actual flow chart is presented for making the comparisons on the computer.

COMPUTER GENERATION OF PLANS

One promising use of the computer for planning flood plain development is in the generation of plans. More precisely, when the planner has selected a set of basic flood control measures which can be varied independently, then the computer can be used to put these measures into combinations. Where a criterion has been selected for choosing the optimum plan, a computer routine can be used not only to generate plans, but also to select the best combination from among them. The computer program developed by James performs both functions, using the criterion of maximization of net benefits.

The first step in such a procedure is to develop a set of measures which can be implemented in combination and where the level of each component can be varied. Several considerations are important in selecting the set of measures to be used. First, one should select only those measures which he can analytically model vis-a-vis their effects on the levels of objective attainment. Similarly, unless the joint effects on the objectives of any combination of the measures can be analytically modeled, it will be impossible to use this methodology correctly.

The second step is to model the impact of any combination of the measures. One procedure would be to directly model the effects on the levels of objective attainment. A more indirect procedure would be to first model the effects of the measures on any of the physical variables of the system. The second step would be to model the relationship between the physical variables and the levels of objective attainment. For example, one might first analyze the probability distribution of flood severity as a function of the degree of implementation of each of the measures. Next, one would model the level of objective attainment (flood damage reduction, lives saved, etc.) as a function of the probability distribution of flood severity. As an example of the more direct approach, one may model the recreational opportunity created as a function of the size and type of storage reservoir constructed.

One difficulty that must be overcome in the modeling is the observation that in general the effects of any two measures are not additive. Thus, the flood loss reduction attributable to a storage reservoir cannot be added to the loss reduction attributable to non-flood plain land development in order to estimate the loss reduction which would obtain when a combination of the two measures is used. Although it is unlikely that such an error would be made when considering two measures explicitly modeled, the chance of error is increased when one of the measures is not explicitly considered in the computer program but is subsequently combined with the computer generated plan. Hence, whenever there is a set of measures which may be combined with the computer generated plan, it is necessary that there be a provision to change some parameters of the computer model, depending on whether those measures will in fact be added to the computer generated plan. In the above cited example, suppose that the measure of development outside of the flood plain may be added to the computer generated plan. In this case, the functional dependence of flood losses on flood severity will depend on the extent of outside development. Hence, the computer program must provide a means of incorporating this change.

A second problem is uncertainty as to the relationship between the measures implemented and the resulting levels of objective attainment. This problem can be handled in two ways. First, provision can be made for the planner to run the program several times, each time using a different value for any of the questionable parameters. Such a sensitivity analysis will tell the planner how sensitive the results are to changes in any of the questionable parameters. In the fortunate circumstance that the solution is fairly insensitive to any parameter, such a parameter can be left at its most probable value. However, when the solution is found to depend critically on a parameter, two approaches are possible. First, more research can be focused on a better estimation of the questionable parameter. Although uncertainty may be effectively eliminated with such an approach, it may be too costly for the planner to go deeply into such research himself. The second approach is to treat the parameter in question as a random variable to which the planner must assign a subjective probability distribution. Then, using this distribution, the probability distribution of objective attainment can be calculated, as can the expected values of the levels of objective attainment. This expected value can then be treated as if it were known with certainty to be result which would be obtained.

The third step of model development is to construct an appropriate objective function to be maximized by the computer. (Actually one may or may not want to combine plan generation with optimization.) This may merely be a linear function of the objectives whose coefficients can be adjusted as parameters of the model. It is important that the coefficients can be adjusted because, in general, the planner will not be able to determine with certainty what the appropriate tradeoff is (social willingness to pay) between any two objectives. For example, if there is uncertainty as to the proper tradeoff between environmental quality and economic efficiency, one would want a means of adjusting the ratio between the economic efficiency coefficient and the environmental quality coefficient.

The fourth step involves the development of a computer program to maximize the value of the objective function over the set of feasible combinations of measures. The method used by L. Douglas James is basically an exhaustive comparison of the values of the objective function generated by each possible combination of the measures. Other methods are possible, but since the choice of algorithms depends basically on the form of the models used, no specific algorithm will be discussed here.

The computer program, once completed, will provide a convenient tool for the generation of alternatives for further consideration. The planner will feed in the data on questionable parameters, on coefficients of the objective function, and on functional changes arising from the additional measures to be combined with the plan generated. The computer will then select the optimum combination of measures and will read out that combination along with the levels of objective attainment to be expected from the chosen combination. To this combination the planner will add those measures not explicitly considered by the program and will calculate the resulting levels of objective attainment. This entire package of measures will hence be saved as an alternative for further consideration.

Once all sets of alternatives have been generated in the manner described above, each should be carefully reviewed by the planner. In particular, the resulting levels of objective attainment must be checked. This is because the planner can usually better estimate the levels of objective attainment than can the computer program. The planner can individually consider each combination; the computer program must be general enough to approximate any combination. The required generality is usually gained at the cost of ignoring the unique details of any individual combination. Once the final check is completed, the planner can then move into the final optimization procedure which is described elsewhere in this report.

The development of an effective computer routine for the generation of plans covering broad range presented in the methodology is a major undertaking. However, it should be possible to develop a routine that would generate plans composed of those components most common to flood management problems. This would reduce significantly the number of plans which would have to be developed in the traditional manner, and thus greatly simplify the implementation of the proposed methodology.

COMPUTER AIDS IN PERFORMING THE TRADEOFF ANALYSIS

The first procedure presented in the methodology to perform the evaluation of alternative plans involves consideration of the various tradeoffs associated with a move from one plan to another. In the process of performing these tradeoffs, it is possible for the decision maker to see the implications of any particular decision and to take this information into account in making the final decision. Conversely, given any decision, the implications of this decision for the underlying values of the decision maker can be specified. This procedure, however, is very difficult to implement when there are a large number of plans which perform with respect to a number of objectives. The problem is that these alternatives have to be presented in a very large performance matrix, and the relevant tradeoffs are more difficult to perceive.

The process of performing the tradeoff analysis is essentially the process of performing a multidimensional surface search among discrete points in the objective space. At the present time there is no very useful computer technique to help the decision maker perform this analysis. This is an area of research which should be explored, although preliminary attempts to make progress in this direction have proved very unsatisfactory.

This is, however, an approach which appears promising. If one is willing to assume a linear objective function, that is, to assume constant social willingness to pay values, then it is possible to develop a computer technique which will show the implications of any choice for the value structure which must underlie that choice. Put differently, for any alternative, one can show that the range of the willingness to pay values (for which that alternative is optimal) must fit. This can be exceedingly useful for the planner, because the implications of every choice with regard to willingness to pay are clearly spelled out. This was one of the major virtues of the method of performing direct tradeoffs. In addition to performing this analysis with regard to different willingness to pay values, one can, at the same time, incorporate into the analysis the implications of a particular choice with regard to the rate of discount which is applicable if that choice is to be optimal. Work along these lines is in progress; however, further work is required before it will be in operational form.

COMPUTER IMPLEMENTATION OF THE CRITICAL VALUE APPROACH

The procedure for performing the critical value analysis involves a large number of arithmetic operations which can be performed rapidly on a computer. Since this procedure for performing the computations was outlined in the methodology, the development of the appropriate computer routine is a simple problem in programming. This routine is described below and a program can easily be written. It was roughly estimated that, given 1000 plans and 10 alternatives, the upper limit on the time required to run such a program would be two minutes. It could be much less with fewer alternatives -- as little as only a few seconds. As a result it is feasible to perform extensive sensitivity tests on the limiting values for willingness to pay.

PROCEDURE FOR ELIMINATING ALTERNATIVES BY USING LIMITS ON WILLINGNESS TO PAY VALUES

Let

W_{Lj} = the lower limit of willingness to pay for the jth objective

W_{Hj} = the upper limit of willingness to pay for the jth objective

O_{nj} = the expected level of attainment of the jth objective by the nth plan

S_{ni} = the difference in total willingness to pay between the nth plan and the ith plan, evaluated under the limits most favorable to n

j = vary from 1 to M if there are M objectives

Then

$$S_{ni} = \sum_{j \in A_{ni}} (O_{nj} - O_{ij}) W_{Hj} + \sum_{j \in B_{ni}} (O_{nj} - O_{ij}) W_{Lj}$$

A_{ni} is the set of j for which $(O_{nj} - O_{ij}) > 0$.

B_{ni} is the set of j for which $(O_{nj} - O_{ij}) < 0$.

Therefore, if $S_{ni} < 0$, Plan n is inferior to Plan i and must be eliminated.

S_{ni} is calculated for all n and i such that $i \neq n$.

Data for elimination of alternatives:

$W_{H1}, W_{H2}, \ldots, W_{HM}$	High values of willingness to pay
$W_{L1}, W_{L2}, \ldots, W_{LM}$	Low values of willingness to pay
$O_{11}, O_{12}, \ldots, O_{1M}$	Plan 1 objective level attainment
$\vdots$	$\vdots$
$O_{N1}, O_{N2}, \ldots, O_{NM}$	Plan N objective level attainment
M	Number of objectives
N	Number of alternatives

Print Output:

j	P_j
1	0
2	1
.	.
.	.
.	.
N	0

$P_j = 0$: P_j is eliminated

$P_j = 1$: P_j is not eliminated

APPENDIX B

GLOSSARY OF TERMS

Objective	A final result or outcome which is deemed to be desirable.
Economic Efficiency	An objective whose level of achievement is measured in terms of net benefits.
Regional Development	A class of objectives whose level of achievement is only measurable in terms of the level of employment, the level of income earned in a region, to the number of new industries entering the area, and so forth.
Environmental Quality	A class of objectives which relate to the enhancement and preservation of environmental quality and whose level of achievement is only measurable in terms of open space acres, level of pollution, availability of recreational facilities, and so forth.
Consequences	An outcome resulting from the implementation of a project. Consequences measurable in monetary terms are called benefits or costs.
Benefits	An outcome for which it is possible to determine the amount individuals are willing to pay in monetary terms.
Costs	The amount in monetary terms required to compensate individuals who forego the use of resources required by the project.
Intangible Benefits	Those consequences for which individuals are willing to pay but for which there are no generally acceptable techniques for measuring willingness to pay.
Intangible Costs	Costs which cannot be measured in monetary terms.
Opportunity Costs	The monetary value of goods and services which would be foregone in order to obtain a specific level of an objective.
Shadow Price	The implicit price in terms of foregone benefits which must be paid to achieve a specific level of an objective in question.
Intermediate Goal	A term used to specify the various effects which produce the desired objective.
Willingness to Pay	Willingness to forego dollars to obtain an objective.

Flood Plain Management	An ongoing program which is intended to lessen the damaging effects of floods and make effective use of related water and land resources within the flood plain.
Structural Measures	A flood control project designed to lower flood heights or provide barriers against flood waters.
Nonstructural Measures	Flood plain management measures, other than structural measures, designed to reduce flood damage and damage potential. These measures are aimed at providing selective protection depending on the specific flood risk, land use, and potential damages for a given location in the flood plain.
Measures Involving Development Outside the Flood Plain	Development projects designed to avoid flood damages by diverting development to locations outside the flood plain.