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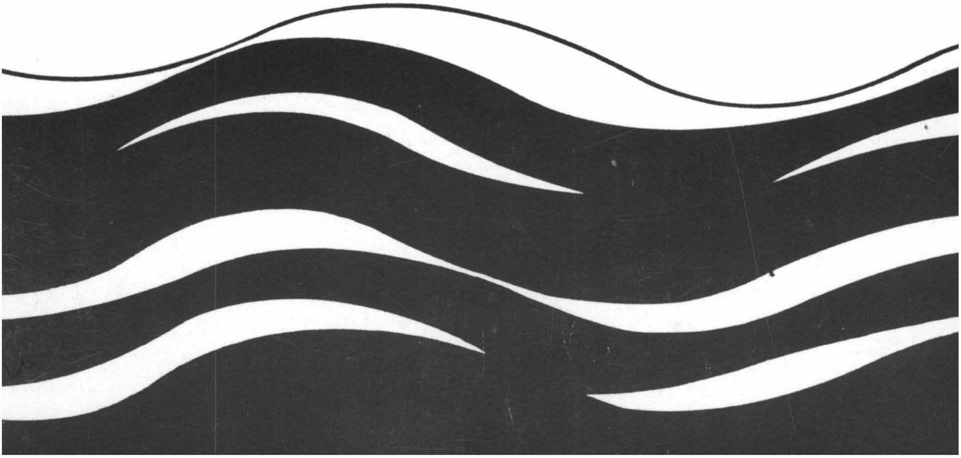
Gary F. Martel & Robert T. Lackey



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PREFACE

Since implementation of the National Environmental Policy Act (NEPA) of 1969, there has been a sharp increase in the emphasis placed on studying environmental changes caused by proposed and existing dam construction projects. According to former Secretary of Interior Rogers C. B. Morton [1971], "For the Environmental Policy Act to be effective we must develop some system for relating large numbers of actions and environmental factors and for quantifying environmental elements that are impossible to measure in discrete units." In part due to lack of understanding of environmental interactions, and because assessment methods presently available are inadequate, the federal government has required an environmental impact statement (EIS) be filed that analyzes potential anticipated environmental change for all major federally supported developments.

The National Environmental Policy Act is based on a six-point requirement system: (1) description of primary and secondary environmental impact, including aesthetics; (2) description of probable environmental impact; (3) study, development, and description of alternative uses of the resource; (4) assessment of the short-term versus long-term environmental effects; (5) description of any irreversible results; (6) discussion of problems and objections by local parties (only used when applicable).

Several methods have been advanced to evaluate environmental impact and/or costs of alterations caused by proposed projects. Modes of evaluation range from specific methodologies, such as water quality rating systems, to broad matrix systems covering large arrays of environmental impact caused by all types of projects. All methods have shortcomings. Among the shortcomings are the requirement of large volumes of data collected over a long time period, limited accuracy due to a lack of rigorous measurement, and omission of results based on resource value concepts. Existing methods address some, but not all of the six points of NEPA.

This research sought to devise a method of creating an environmental impact abstract based on information contained in a completed environmental impact statement, specifically for a dam project. Use of such a procedure would allow a preliminary evaluation of impact in a very short time. In addition, it would permit more complete analysis and evaluation over a longer period, since the data would be organized for easier accessibility and handling.

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Gary F. Martel
Robert T. Lackey

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Various methods of evaluating the effects on the environment of different construction projects have been proposed in the past ten years. All previously developed methods had significant shortcomings when applied to dam projects.

The Dam Impact Evaluation System (DES) reported in this study was developed specifically for evaluating and comparing impacts from dam projects and project alternatives. DES operates on the creation of a distribution based on "low," "most likely," and "high" inputs by project evaluators on both impact and importance of factors and actions. Computer output includes comparisons between projects in both tabular and graphic form. Information is available on the estimated impact, variance of the estimator's inputs, and the probabilities of differences between projects.

The Dam Impact Evaluation System contains features lacking in many previous methodologies. DES is easily implemented in practice because all that is required is the environmental impact statement for the project under consideration. Thus, the problems of economics and of allocating personnel to collect large quantities of data are avoided.

DES provides a method by which the value judgments and estimates of evaluators may be dealt with statistically. Both impact and weighting factors are considered based on the probability distributions of evaluator input. Weighting factors are combined with impact to form weighted values that may be utilized in comparing dam projects and alternatives.

System flexibility or generality is a necessary feature of any assessment method which is to be used over a large geographic area. DES is extremely flexible because the hierarchical system may be expanded or contracted to fit particular dam project specification.

A valuable feature of DES is that it utilizes the input for maximum information. The high, low, and most likely values for each evaluator are used to create variance and mean values which may be utilized in project comparisons and/or evaluation. The estimation of variances is valuable because it indicates areas of uncertainty. Thus, factors with large variances may need additional data information to insure more accurate prediction. These factors are also easily recognized. Further, the distributions and

numeric output indicate areas where the dam project may cause significant change or alteration.

Finally, DES creates understandable, usable output graphically and numerically that may be utilized in project evaluation and comparison. Graphs based on an α of 0.1 may be used to assess proposed dam projects.

Key Words: Environmental Impact Statement, Environmental Analysis, Environmental Assessment, Simulation, Reservoirs and Impoundments, Dams, Probability and Statistics.

INTRODUCTION

The history of formal environmental assessment in the United States has been relatively short, but dynamic. Once man became aware that he was a part of the environment and not separate from it, many individuals became deeply involved in the cause to "save the environment." Political campaigns were launched using environmental issues as a central theme. Environmental laws were passed, some of which lacked effective enforcement powers, or were simply impossible to realize. Agreements were made between and within states to control pollution and limit environmental degradation.

Such environmental activities found ultimate realization in the move to "save the environment." Currently, the energy crisis, a distressed national economy, and a high level of inflation have turned people's minds from environmental problems, and decreased the emphasis placed on environmental considerations. The question arises as to whether American society will return to a tolerance for altering the environment for economic and political gain, or maintain environmental considerations together with political, social, and economic issues.

The maintenance of environmental values in the planning framework requires some method of environmental assessment. Ideally, the assessment method must be easily applied and conform to environmental as well as economic constraints.

Environmental assessment is a complex and difficult process. Environmental specialists in various fields often have opposing views as to what constitutes significant environmental change and what should be considered in the asssessment of environments. Resolving opposing views within an institutional framework is not easily accomplished. However, one possible resolution lies in utilizing computer-implemented assessment methodologies for such projects as dam construction and operation, which significantly alter environments.

I. Study Background

Need exists for an evaluation system able to predict likely environmental impact prior to project construction. Ideally, a methodology for environmental assessment of dam construction should be generally applicable to many different project studies, but still specific enough to retain predictive capability.

Several methods have been advanced for evaluation of impact and/or costs of alterations caused by proposed projects. Modes of evaluation range from specific methodologies, such as water-quality rating systems [Horton, 1965], to the broad matrix systems covering large arrays of environmental impact [Leopold et al., 1971]. All methods have shortcomings; among these are voluminous data requirements, limited accuracy due to an inability to make quantitative evaluations, and absence of results based on social values. Proposed methods of evaluating environmental impact address themselves to answering all or part of the following six points of the National Environmental Policy Act (NEPA) of 1969, which require:

1. Description of the primary and secondary environmenal impact, including aesthetics;

2. Description of probable environmental impact;

3. Study, analyzation, and description of alternative uses of the resource;

4. Assessment of the short-term versus long-term environmental effects;

5. Description of any irreversible results; and

6. Discussion of problems and objections raised by local interested parties.

II. Study Objective

Since the passage of NEPA in 1969, there has been increased emphasis on studying the environmental alterations caused by proposed and existing construction projects. According to former Secretary of Interior Rogers C. C. Morton [1971], "for the Environmental Policy Act to be effective we must develop some system for quantifying environmental elements that are impossible to measure in discrete units."

The objective of this study is development of a computer-based methodology that will allow environmental impact analysis by utilizing input from environmental impact statements. This methodology will:

1. Provide a means of abstracting environmental impact statements in order to facilitate comparisons between project alternatives, and

2. Illustrate environmental impact through use of existing data from environmental impact statements and the input of expert opinion.

STATE OF THE ART

It is surprising that more work has not been done in the area of developing environmental impact assessment methodologies, considering the value of assessment prior to initiation of construction. Techniques have been developed for evaluating such factors as water quality [Horton, 1965], outdoor recreation [Craighead and Craighead, 1962], and environmental aesthetics [Schafer and Mietz, 1970]. However, methods are lacking to assess adequately the all-encompassing impact of such projects as dam construction. Many assessment systems have useful features that might aid in evaluating proposed reservoir projects. These features should be considered in developing any new assessment system.

Probably the best known and most often utilized method of environmental evaluation is the matrix method developed by Leopold et al. [1971]. This method involves creation of a double-axis matrix (see *Figure 1*). One axis represents proposed construction actions, while the other represents environmental factors that may be affected. In each matrix box representing a point of interaction between a proposed action and an environmental factor, two numbers are placed—one representing the *importance,* the other the *magnitude* of the impact on the environmental factor. The numbers are selected on a scale of 1 to 10, with 1 representing the least impact and 10 representing the most severe impact. For instance, in evaluating a proposed road-construction project, the *magnitude* of siltation would likely be assigned a larger number such as 8 or 9. If that effect continues only for a limited time and over a limited area, however, the *importance* rating for the matrix might be only 3 or 4. Leopold et al. [1971] suggested that plusses may be used to show expected beneficial effects derived from the project.

Leopold's system proves quite useful when used as a general preevaluation tool for projects involving environmental change. One of the most valuable aspects of Leopold's method is that it may be utilized to identify areas in which acquisition of data is needed. Also, areas of obvious environmental disturbance may be easily identified, and thus gross comparisons made between projects. One of the major problems with Leopold's method is that it is lacking in the ability to predict change caused by development. There are two major reasons for the lack of predictive value: (1) the matrix method requires value judgments, not measurements by the individuals completing the matrix, and (2) no method of limiting personal biases is provided.

Leopold [1969a, 1969b] also has developed two other matrices which are more specific in potential application. These matrices are aimed at quantifying aesthetics of rivers and river valleys. Quantification of river aesthetics is achieved through a ranking system based on "uniqueness" of areas where dams are proposed. The matrix is based on 46 factors divided into three categories—physical, biological, and human interest. The total sum of the ranks is used to rank the uniqueness of proposed construction sites.

Leopold's "uniqueness" system was one of the first attempts at classification through use of specific categories associated with particular values. Each of the 46 factors is divided into five groups or levels. For example, the factor of river width would be classified as follows: (1) less than 3 feet, (2) 3-10 feet, (3) 10-30 feet, (4) 30-100 feet, and (5) greater than 100 feet. Thus, a rating of 4 would be assigned to a river 50 feet wide. Group numbers do not reflect values but are used on a comparative basis.

In Leopold's study, 12 alternate construction sites were compared. A group number ranging from 1 to 5 was determined for each of the 46 factors at each construction site. After categorization was complete, each site was evaluated for uniqueness. If only one of the 12 sites had a value of 5 for river width, this site received a 1 rating, as its ratio was 1:1; if two sites had the same value they received a 0.5, or 1:2, and so on. Finally, the totals were determined for the 46 parameters under each proposed construction site, and the one with the highest total was the "most unique."

A problem exists in implementing Leopold's uniqueness system. This system scores highest not value or desirability, but the site which is "most different." This problem is evident in Leopold's test study in which one site scored well above the others, not as a result of desirable environmental aspects, but primarily because of difference from other sites. This was the only site with floating vegetation, poor water quality, large algae concentrations, infestation levels of rooted plants, presence of elodea and duckweek, low fauna diversity, and high pollutant levels. The second-place site identified in this study was the Hells Canyon area of the Snake River, weighted as highly valuable due to desirable unique aspects.

Evaluation of "uniqueness" is not necessarily the way to site selection.

The possible construction sites must be limited to similar areas in order to allow valid comparisons in Leopold's uniqueness system. Another major problem is that Leopold's methodology does not give a final quantitative value for environmental evaluation, but yields a comparative index under which sites may be selected.

In a more specialized study, Carlson [1973] evaluated the effects of a proposed ski area on fish and fish habitat using a matrix approach similar to Leopold's. Twenty-eight environmental factors were considered under four different development schemes. A rating system ranging from –3 to 3 was used to assign values to the factors in the matrix (*Table 1*), and a "strength-of-relationship) matrix" based on a rating of 1-4 was developed to show the significance of each of the 28 factors to fish populations (*Table 2*). Carlson's methodology incorporates a weighting factor, and thus could be more quantitative than methods previously described. However, his method does not integrate weighting and evaluation matrices into usable form, and the final results are stated in qualitative, non-tabular conclusions.

Calvert and Heilman [1971] show the need for specific assessment methodologies for different types of construction projects. Their study deals with early stages of analysis in power plant siting. Alternate sites are rated for different factors on a scale of 1 to 4—4 being excellent and 1 being poor. Three broad areas are considered—development costs, environmental effects, and public acceptance. The sum of the products of weighting factors, multiplied by ratings, yields a total upon which the sites are ranked. The higher the value, the better the site for power plant location.

Using a method like that proposed by Calvert and Heilman for environmental assessment may mask likely events. High weighting factors or favorable economic considerations may serve to indicate a favorable siting area where considerable environmental losses would result. The same problem exists within the environmental section of the siting approach. The three assessed factors are air, water, and land, with values of 1 to 4 assigned to each, and an average value taken. No importance-weighting factors are applied to air, water, or land, and, again, the average may hide substantial environmental impact. Ideally, in any method the impact on each aspect of the environment will be examined separately, and the final value based on the constituent parts. Economic considerations must not be incorporated before reviewing each independent environmental section.

In a study published by Commonwealth Associates, Inc. [1972] under the direction of J. D. Calvert, a more comprehensive system was developed for evaluating alternative power plant sites. The three basic groups of the earlier study (air, water, and land) are expanded and subheadings are added for aquatic, terrestrial, and wetlands factors. Forty-five elements were identified within these groups and evaluated on a magnitude and importance rating for each proposed site. Magnitude is determined on a comparative basis. The alternative exhibiting the greatest effect is given a value of 10 and the other alternatives scaled down from there. Importance ratings are determined in a variety of ways for each element. Some ratings are based on value judgments, while others may have specified values. The interpretation of the input is accomplished through use of a computer program which combines environmental impact information and project cost to determine best alternatives.

Many of the problems which existed in Calvert's earlier study also exist in the one published by Commonwealth Associates. Initially economic and environmental factors are shown separately, but a subsequent combination indicates total impact on air, water, and land without showing distinct areas of disruption. This is of little value in reviewing environmental impact. Use of a necessary magnitude factor of 10 is not realistic, since any of the alternatives may have limited magnitude in a particular area and therefore would merit a ranking only at the low end of the scale. In addition, importance values do not function on a comparative basis in the system. Some are always set at 10, some are related to human use, and others are scaled to environmental disturbance. Thus a particular importance value may have little overall meaning in the total program, since a value of 10 for one element is not necessarily comparable to a 10 value for another element.

Historically, decisions on most construction projects have been based on predominant economic and social considerations. Many attempts have been made to apply benefit/cost analysis to environmental analysis. Comber and Biswas [1973] support the economic evaluation of environmental factors while pointing out many of the inherent shortcomings of other assessment methodologies. Because most public decisions are, at least in part, economically oriented, some monetary method is necessary to evaluate absolute values of construction projects. However, economic assessment may yield little in terms of indicating actual environmental change, and a non-economic method of environmental assessment still may be necessary.

Few evaluation systems have been developed exclusively for water-related resource development. However, one such system developed by Dee et al. [1973] for Batelle Laboratories, called the Environmental Evaluation System (EES), may represent the furthest advancement to date in water resource assessment. EES is based on a hierarchical arrangement beginning with four major categories (ecology, environmental pollution, aesthetics, and human interest) which are divided into 18 components, and finally into 78 parameters. Parameters are assessed on a scale of 0 to 1 where 0 is the lowest possible quality and 1 is the highest possible. Parameter weighting also is developed utilizing a total 1,000 points distributed over the 78 parameters. Delphi techniques, or the consensus approach, were used to minimize the qualitativeness of subject weighting factors. The final project evaluation is based on a comparison of an area without a project versus the "predicted area" with the project.

The basic principles underlying the EES are sound; however, there are drawbacks which make it almost impossible to apply on a general basis. The weighting factors created in the program using the Delphi technique ares set up identically for all projects. Therefore planners utilizing the system do not have the flexibility of changing importance values for specific projects. However, the importance of individual factors does change from project to project depending on the type of environments involved. The Delphi technique, although a distinct advantage over previous methods, does not yield a range or variance of impacts that reflects probability or reliability of estimates. The technique does yield a single average number. Individuals who are strongly biased in their evaluation are likely to have an even greater effect through the Delphi technique than with averaging techniques because they will change the opinions of others. Also the EES requires very specific information such as food-web indices, species diversity, biochemical oxygen demand, pH, and similar factors. The accumulation of these data on existing environments is a time-consuming and expensive process, and determining such factors for a project that is not in existence is almost impossible, or is at least prohibitively expensive, particularly when a variety of proposed alternatives is available. A system of a more general nature is needed to assess large numbers of water resource project alternatives.

One process not found in other environmental assessment systems but present in EES is the use of "flags" or indicators of severe environmental change. The flag system acts to designate areas where the proposed water resource project may cause a high level of environmental disturbance. Such a technique is important because it identifies areas that may be particularly sensitive and require additional investigation.

An earlier system developed by Horton [1965] to assess water quality might be used in general environmental assessment where sufficient data are available. Weighting factors are assigned on a basis of 1 to 4 with wieght determined by the importance of a particular variable (i.e., dissolved oxygen, coliforms, and alkalinity). The rating is based on measurements of parameters of water quality, and a value is determined, based on the products (parameter weighting value times rating).

A system developed by the United States Water Resources Council [1973], aims at providing guidelines for planning and evaluation of water projects [Warner and Bromley, 1974]. The Water Resource Council approach identifies four classes of environmental effects: (1) effects resulting in changes in natural beauty (i.e., wilderness areas, rivers, and mountains); (2) effects of changes to valuable archeological, historical, biological, geological, and ecological systems; (3) effects of changes in quality of water, land, and air due to pollution, and (4) effect on the future resource in terms of irreversible or irretrievable effects. These four classes are then subdivided into smaller factor groups to be evaluated for impact.

One of the major flaws of the Water Resource Council approach is that it does not include a method of predicting or measuring impacts. In addition, no weighting between factor groups is provided.

Warner and Bromley [1974] reviewed three environmental impact assessment methodologies [Dee et al., 1973; Leopold et al., 1971, and U.S. Water Resources Council, 1973] based on ecological content, applicability, and political viability. The approach by Dee et al. [1973] appears most suitable while the Leopold and Water Resource Council approaches seem less desirable. The Leopold technique seems somewhat more promising for the sole purpose of reviewing ecological content. Dees's approach seems less applicable than the methods of Leopold and the Water Resource Council. Major problems with Dee's method were listed as limited data availability, and high commitments of time, personnel, and technological expertise by those conducting the study. Political viability may favor Dee's method because it is more quantitative and lends itself to a defendable political position.

A two-part study performed by Dearinger [1968] and Dearinger et al.

[1973] describes a methodology for assessing the value of small watersheds on a comparative basis. This study attempted to list all the significant aesthetic- and recreational-related parameters, then listed the categories into which each parameter fell, and finally gave each category a value from 1 to 10. For example, 65° F may be the optimum average temperature (as perceived by the evaluators), so it is given a 10 rating. Averages deviating to either side are given lesser ratings (i.e., 60° and 70° = 9; 55° and 75° = 8, and so forth). Weighting factors are similarly assigned for each category and subcategory.

Lack of flexibility is one of the major problems with Dearinger's methodology. Most of the rating and weight options must be changed with each major location shift. Desirability of factors depends largely on regional preference and availability; thus a large quantity of work must be done for each new location or site to which the methodology would be applied. Preset weighting or importance factors make the system unusable in a comparative study. Weighting factors must be flexible since the importance of specific factors and actions will change from project to project even in the same area.

Another method of environmental assessment which appears promising is objective ranking. Objective ranking has long been used in the decision-making process in industrial and military operations [Dunsford, 1974], but is just beginning to become apparent in natural resource fields. Dunford's method involves a matrix with product evaluators at the top, and alternate products along the side. A scale of 1 to 10 is used, 10 being the most favorable. A weighting factor ranging between 1 and 10 is also utilized. A final rank for each product is obtained by multiplying the evaluator number by the weighting factor and adding the products for each alternate good. The product with the highest sum is then ranked first, with the other products ranked second, third, etc., in decreasing order. Dunford's method, although lacking in direct applicability for environmental assessment, is more quantitative than the other matrix methods reviewed, and coupled with such environmental assessment methodologies as Leopold's, may prove the answer to rapid, inexpensive assessment and comparison.

Churchman et al. [1957] presented the objective ranking technique as a method to evaluate decisions with respect to project objectives. The ranking method has also been applied to a general environmental assessment method by Martel and Lackey [1975]. The first step in this rating system is to create a group of environmental factors common to all proposed study projects or alternatives. These broad environmental factor groups would include possible alterations that a particular project might make on the environment. A board of evaluators is then selected, and each member ranks the different factor groups as to their importance to environmental quality *(Figure 2).* The average importance rank is then used as the factor importance in the evaluation.

The second step in the ranking method is to place all possible alternatives on one axis with the same factor groups as in the importance chart on the other. The judges would then evaluate numerically the significance of each broad group to each alternative project development plan *(Figure 3).* The evaluation indices in the evaluation chart must be negative and positive signs because all project alterations do not lead to environmental degradation.

The third and final step in this ranking procedure is to combine importance ranks and alternative ranks *(Figure 4).* The horizontal sum of the alternatives indicates the total environmental impact.

The objective ranking method [Martel and Lackey, 1975] has many advantages over other methods because it allows a basis of comparison between proposed project alternatives, yields a final impact value, and contains a weighting factor between project blocks or factors.

None of the available methods of environmental assessment is able to predict or adequately compare the impact of proposed project alternatives. Other areas of weakness in existing environmental assessment methods are the length of time required to accomplish them (as is the case with biological evaluation systems), and the inability of the analyst to compare results with the other studies done by the same method. A rapid method for evaluating environmental impact statements would allow decisionmaking to occur in a shorter time period than currently possible.

METHODOLOGY

For this study, a system was developed for comparing and evaluating dam projects and alternatives, and their impact. This system specifically addresses point two (description of environmental impact) of the six-point requirement system of the National Environmental Policy Act. Environmental impact statements from three projects—Gathright Lake, Back Creek, and Burnsville, Leading Creek, and West Fork Lakes—were reviewed for content. An Environmental Protection Agency publication [1973] containing environmental impact statement guidelines then was used to establish an environmental assessment methodology that can be implemented through the use of environmental impact statements. The Dam impact Evaluation System (DES) was developed to utilize available information in the assessment of dam projects and alternatives.

I. Hierarchical System of Evaluating

Environmental impact statements typically contain a series of statements concerning different environmental parameters and an explanation of how the proposed project will likely affect these parameters. In order for any type of environmental assessment methodology to be meaningful, the parameters must be organized into some type of system. A hierarchical method *(Figure 5)* of grouping the individual parameters is used in this study to facilitate comparisons and locate specific areas of potential environmental alteration caused by the proposed project. Three factor groups (sociological, terrestrial, and aquatic) are utilized in categorizing the parameters. These groups are then subdivided further into more specific divisions under which the parameters are listed *(Figure 5)*. The advantage of categorization is that it will permit comparisons of parameters and groups of parameters which have basic similarities. In addition, broader comparisons may be made by moving up in the hierarchy.

Parameters described in environmental impact statements of dam projects may be grouped into three basic factor areas (for the example used in this study): sociologic, terrestrial, and aquatic. Each factor area may further be broken down until the related parameters have been listed *(Figure 5)*. The sociologic factor group includes environmental aspects directly related to human activity and well-being. Changes within the sociologic parameters are associated with effects on economic and/or societal benefits.

A. Sociologic Factors

The sociologic group is divided into two subareas: recreation factors and a broad group of "other factors." The latter group encompasses parameters typically addressed in environmental impact statements that are directly related to human values, but not similar enough in any other respects to be further subdivided into separate groups.

Recreation Factors: The topic of recreationally based activities is an area always addressed in environmental impact statements developed for proposed dam projects. The evaluation of changes in recreation usage and the recreational potential of an area is of significance in determining societal value of a proposed project.

Recreational fishing, for example, is affected by nearly any dam project, and the evaluation of gains and losses is important in project evaluation. Most impact statements describe fishing potential in terms of man-days of recreational use presently being realized in the river-system, and the anticipated number of fishing man-days likely to be realized with the resulting impoundment and tailwater.

The estimated effect of a proposed dam project on hunting is usually expressed in changes in man-days of hunting per year. Hunting is almost always adversely affected by a dam project because almost all man-days are lost. Potential does exist, however, for the development of shallow areas for waterfowl habitat in some dam projects. In addition, projects may include habitat improvement and increased access.

Along with fishing, a variety of other water-based recreational activities may be affected by dam projects. Preimpoundment sites may have substantial recreational potential and use for activities such as canoeing and boating. Water-based recreational factors must be evaluated in terms of what is created as well as lost. Factors to consider as potential developmental benefits might include such activities as boating, swimming, and water-skiing. When dealing with any aspect of water-based recreation, the relative value and importance of various types of recreational experience to those who will use the area must be evaluated. Potential for crowding and displacement of users from other recreational areas also may be significant in some projects.

As with water-based recreation, land-based recreation is considered in environmental assessment. Factors other than hunting, such as hiking, camping, and nature walking, are often altered or destroyed in the creation of reservoirs and must be considered with other recreational losses.

The potential for loss of unique recreational activities exists when any area is impounded. Unique scenic areas such as gorges, special historical sites, and facilities may cause an area to have a higher recreational value than indicated by a measure of numbers of man-days of use, as the value of the individual experience may increase.

Other Factors of Sociologic Importance: The potential exists for substantial changes in a variety of areas other than recreation which are directly related to man's activities and desires. Although social factors are not grouped under a common heading (such as recreation), they may be individually or collectively important in the evaluation of dam projects.

The production of food is an important societal factor. Because of basin requirements, dam projects are frequently located in areas of varying topography with a relatively high degree of slope. However, under many circumstances agricultural lands of substantial social and economic value may be lost. Large river valleys are among the most productive and fertile regions of the world because annual flooding often provides necessary soil nutrients. Loss of land from inundation, decline in soil fertility, and any other effects on food production must be evaluated for proposed dam projects and alternatives.

The potential for dam failure is not generally great. However, this factor must be considered along with the resultant environmental and sociologic impact in areas of seismic activity and uncertain geologic stability.

Areas of aesthetic or scenic value are evaluated to determine their importance to the area. Scenic vistas, gorges, and waterfalls have high levels of aesthetic desirability and may be of importance in different projects and areas. Aside from value derived from usage of recreational areas and historical sites, the existence and maintenance of such areas has sociologic value. Although such factors are not easily quantifiable, projects proposed for sites containing historical areas should be reviewed as to their historical significance and value.

Project sites may include definite potential for archeological discovery and study. Review of the potential for significant discovery and information in these areas is needed.

Dam projects may directly and indirectly affect human health. Habitat for aquatic disease-carrying organisms may be either created or destroyed. Indirect effects on health may be caused by aggregations of people living or working in the project area, and changes in septic systems.

Atmospheric conditions are not generally affected to any high degree by dam projects. However, in specific projects, changes in velocity and direction of wind along with increased humidity may have an effect on people in the surrounding area.

Almost all project areas have some potential for utilization and development of renewable and nonrenewable natural resources. The proposed project itself represents one method of utilizing available potential. In exercising the option of impounding an area, natural resource alternatives may be lost or gained. Potential for timber production, mining operations, and developmental areas must be considered as part of the evaluation of "sociologic factors."

B. Terrestrial Factors

The parameters and actions addressed under the section on "terrestrial factors" *(Figure 5)* relate predominantly to loss of the terrestrial environment due to inundation. However, other important considerations include actions and parameters affecting the area around the project both during and after construction.

Biota: In evaluating environmental impact it is advantageous to look at biological and physical effects separately. Such an approach allows a better understanding of where impact is greatest. One of the potentially impacted elements is the biota of an area. Biota is made up of the flora and fauna of the affected area; any alterations will, either directly or indirectly, affect the existing biota.

The predominant effect of dam projects on flora is caused by inundation. Evaluation should concentrate on the importance of the vegetation to the surrounding area (i.e., erosion control and wind breaks), and its significance to such other factors as wildlife. In addition, changes in ground water and atmospheric conditions may alter the vegetation of the surrounding areas. In such an evaluation, the entire flora system must be reviewed from the simple mosses to the largest trees.

While terrestrial vegetation is destroyed through inundation, many of the native fauna species of the area are capable of moving out as the impoundment fills, so primary effects are found in habitat reduction, productivity, and fauna displacement. Inundation and the subsequent habitat loss usually result in reductions of wildlife abundance, changes in density, diversity, and elimination of animal species from an area. Other potential areas of faunal impact may include changes in waterfowl resting, breeding, and feeding habitat, and the blockage of migration of terrestrial wildlife due to the created impoundment.

With man's ever-increasing influence on the environment, a large number of plant and animal species are in danger of extinction, or are rare and found only in restricted areas. These species must be identified and considered in the evaluation of areas for dam projects.

Physical Environment: Along with a proposed dam project's effects on biologic portions of the terrestrial environment, the potential exists for a variety of changes in physical make-up and stability of the surrounding area. Dam projects result in the impoundment of waters sometimes to levels several hundred feet above the original water table. Impounded waters will form a significant input to the water table and may affect the quality and temperature of available ground water.

Impounding a large area of water will create a flat surface area of higher elevation and different topographic structure than the previous river valley. The effect of the project on local weather patterns should be considered and may be of significance. Wind velocity, wind direction, and precipitation may also be affected by the proposed project. Generally, the air quality of the area surrounding dam projects is not severely affected. However, in special cases, increases in dust and moisture levels in the atmosphere of the surrounding areas are of significance.

The potential for disruption of surface and subsurface formations exists, even when ground cover is carefully protected. Water tables will rise to levels not previously encountered. Increased water table levels could result in slumps and slides in the project area. In addition, evaluation of subsurface formations of porous rock and caves must be undertaken to identify potential areas of leakage. The possibility of geologic instability must be evaluated for each individual project.

C. Aquatic Factors

Dam projects also change the aquatic ecosystem. Evaluation of the impact of change from a lotic to lentic environment must be conducted in impoundment evaluation. Also, affected areas (downstream and upstream from the project site) must be evaluated. As was the case with terrestrial evaluation, the aquatic system can be divided into two groups—"biota" and "physical environment"—and subsequently into the respective factor groups. This division allows better analysis and understanding of impacts on the aquatic system. The division also allows independent evaluation of the separate groups.

Biota: The biologic components of the river system are greatly affected by the impoundment of waters. In addition, the changes that will occur in flow below the dam will affect the river downstream from the project. Changes in the species composition of the river system may be expected throughout the affected watershed.

Shifts in the species composition of the river system occur because some organisms previously adapted to the river life are not as well adapted to the reservoir. However, species formerly existing in ponds and marshes in the impoundment area may flourish in the new reservoir environment. Such changes are considered part of the project impact and should be evaluated accordingly. In addition, dams may affect sections of the river system by inhibiting fish movements, and spreading other plant and animal species to areas where they did not previously exist.

In certain areas and drainage systems, aquatic plants and animals exist that are unique to the system or have been reduced in their range so as to be found only in specific limited areas. Elimination of a plant or animal species is an irretrievable loss of genetic information. Such organisms must be given special consideration when they occur in a project area.

Marsh areas exist in many river systems and may be important in aquatic as well as terrestrial productivity. Often marshes act as nursery areas for fish, and may have beneficial effects outside the project area.

As the normal flow of a river is accumulated into one area, so are the nutrients which it carries. The normal river flow acts to flush these nutrients through the system and ultimately to the ocean. Thus, biomass is not accumulated in the river system. Development of reservoirs creates a nutrient sink. Eutrophication, or the natural aging of lentic environments, is a process which may occur quite rapidly in reservoirs. The development of large populations of algae (blooms) in the reservoir should be evaluated in preimpoundment studies. The potential for growth of rooted aquatic vegetation should also be addressed.

Physical Environment: Just as the biological system is altered by impoundment, the parameters that make up the physical environment of the system are also greatly changed. The significance and importance of these physical changes in the aquatic system are important in the review of proposed projects.

In certain projects the actual drainage system or natural flow will be changed by diversion or inundation. In these cases the effects on the other drainage systems must also be evaluated and incorporated into project impact.

A factor which exists in all impoundment projects is the change of river flow below the dam. Seasonal change in river depth and velocity is a naturally-occuring event, and river valleys and ecosystems have developed under this influence. It is important to determine the effects of river flow changes as brought about by the project. Projects may act to affect flow in a variety of ways depending on design and use of the facility. River flow may be regulated so as to lessen seasonal peaks of flow, or release of water may be sporadic and fluctuate greatly.

When water is held up in its natural flow or passage to the ocean, evaporation is increased. Utilization of water as a basic resource is of primary importance to many ecosystems. Water loss from reservoir projects is highly variable and depends on surface area and climatic factors. Evaporation may be an important consideration in regions where water supply is an important factor in downstream areas.

When waters are impounded, the natural temperature regime of the river is changed. Waters within a reservoir may stratify with warm surface temperatures grading into cooler temperature levels in deeper water during the summer months. Downstream communities may be greatly affected depending upon the level from which the water is discharged. The potential exists for high levels of impact in both the reservoir and downstream areas.

The development of dam projects creates a potential for change in water quality both in the impounded section and below the dam. Factors such as floating debris and water clarity may also prove to be of significance. Water quality factors are examined in view of their environmental effect and the objectives of the proposed project.

D. Additional Factors

Just as all environments differ, so do the potentials for impact on impoundments. Different construction techniques and environmental situations may create a need for categories not listed in the sample DES hierarchical system, or for the expansion of existing factors into smaller, more specific groups. Additional factors should not be ignored, but should be added to the existing hierarchical system. The addition of factors to the methodology is not difficult and is discussed in the user's guide *(Appendix I).*

II. Evaluation of Activities Associated with Dam Projects

While the individual factor affected by dam projects may be evaluated to yield valuable information about project impact, there are many activities that are conducted in conjunction with dam project development that also yield valuable information about project impact. A list of major activities often associated with dam projects is provided in *Figure 6.* As was the case in the factor categorization system, these activities may not represent all of the activities that may be associated with dam projects. Activities may be added or deleted from those presented, and existing activities may be divided or expanded.

A. Identification of Specific Activities

Road construction is conducted in conjunction with most dam projects. Road construction and the activities associated with it may have an effect on many factors—both environmental and sociologic. Under certain conditions the dust and exhaust fumes from heavy equipment may cause short-term damage during construction to nearby residential areas or sensitive environmental communities.

Projects often involve the relocation of vast quantities of earth. Filling and digging activities may affect both the area of development and surrounding areas, particularly when fill is being brought in from outside the project area.

Blasting is another action which may have a substantial effect on the physical as well as biologic segments of the environment during construction. Blasting may result in high levels of dust in the project area and in destruction of surrounding vegetation. In areas of steep slope, the result may be slides, and thus further environmental damage.

With any project, some level of disturbance to the surrounding area will occur. In dam projects, large amounts of heavy equipment and materials must be moved about in the project area. The potential for erosion accompanies the disturbance of surface vegetation, road construction, and excavation. If areas are allowed to substantially erode during or after construction, topsoil will be lost, making revegetation of the area very difficult. Erosion may also block roads and drains and create gullies. Gullies can impede utilization of the area for recreation and further construction. Dredging and channel modification are usually conducted below the impoundment and act to create uni-directional, even flow in conjunction with dam discharge. The effects of such activity may be of significant importance to downstream systems.

Although generally a temporary measure, river diversion is another activity that is often undertaken during construction of dam projects. Included in the evaluation of river diversion should be consideration of river flow below the dam during reservoir filling. Diversion activities may have significant impact on aquatic systems, particularly in the short term.

Flood control may have both beneficial and detrimental effects on downstream aquatic systems. Severe flooding may act to destroy important aquatic habitat and do damage to social as well as environmental factors. Flooding of rivers is, however, a natural process. This process provides nutrients to downstream agricultural areas and silt loads necessary for delta stabilization. Also, annual high flows often coincide with high fish productivity in estuaries. The production of these estuaries provides a large portion of sport and commercial marine harvest. Potential impacts of flood control need to be evaluated as to their importance in the specific proposed project.

Siltation is one of the greatest natural destructive agents of reservoirs [Heinemann et al., 1966]. The impoundment of rivers causes settling of silt carried by the river, and thus the gradual filling of the impoundment. In addition, siltation rates below the dam are changed and imbalance in the physical system may result. Thus, siltation rate may be an important factor in the review of project sites and alternatives.

Water level within the reservoir may also fluctuate. Fluctuations in water level may affect many environmental parameters. Large fluctuations are undesirable for short development and recreation. Areas of unsightly mud may be exposed and reefs and shallows created. Such areas form impediments to boating. Large fluctuations may act to limit fish productivity by decreasing reproduction and food production in the littoral area. Depending on project objectives, these events could have significant effects on the physical environment of the reservoir system.

III. Dealing with Subjective Input

In any predictive study of proposed projects, uncertainty exists about potential impact. Environmental systems are of such a nature that often the best available data for project evaluation are estimates by experts based on their previous experience. Economic, personnel, and time factors may make needed studies impossible. The conclusions drawn may in some cases be biased by personal feelings or preference.

Considering the inadequacies and constraints of data and evaluation techniques, some method of treating available input must be developed in order to make reasonably accurate predictions. Many methods and strategies have been tried in the effort to limit the detrimental effect of qualitative input. Averaging techniques have proved inadequate since bias and wide ranges of input are not indicated in the final product [Martel and Lackey, 1975].

Methods have been developed to limit the effects of biased or erroneous information; some of the methods are better than averaging techniques. The modal value gives the most popular opinion on the subject. Large numbers of qualified individuals, however, are required to create the necessary distribution.

Perhaps a better method of limiting bias than averaging is the Delphi technique. The Delphi technique is the method by which evaluators are brought to a consensus on a subject through feedback of information based on the opinions of the group [Meier and Thornton, 1973]. For example, a group of people may be given a questionnaire which, after completion, is analyzed. The group is then informed what the result of the group analysis was via a median or other measure of central tendency. The group members then are permitted to reevaluate their original decisions based on the new information. Iterations of the reevaluation are continued until minimal change is observed in decisions.

If all individuals had the same personal makeup, the end result of the Delphi technique would be a consensus based on best estimates. However, the actual situation is that some individuals are more inclined to compromise than others, and personal bias may act to shift the final result more than would occur in an averaging method. The range and standard deviations of the initial inputs are not utilized in the Delphi technique. Range and standard deviation values indicate the uncertainty range or potential impact of proposed actions.

A. Utilization of Distributions on Subjective Input

The major problem with single-estimate or agreement methods for project evaluation is lack of information about their reliability or variance. A more desirable evaluation method of estimates than central tendencies is creation of a probability distribution of the potential impact or importance of a proposed project on a particular factor or parameter. Interval estimates of evaluator input such as variance could then be determined from the probability distribution. Variance would indicate a range in impact based on the certitude of the project evaluator. Point estimates such as the mean and mode could then be utilized for more specific comparisons.

One possible method of creating distributions for dam projects is through use of the beta distribution. The beta distribution requires input of three values on a scale of zero to one [Taha, 1968]. The three values are the lowest feasible, most likely, and highest feasible value of some factor. An α of 0.1 or 0.05 may be used to select the low and high values because 100 percent confidence would naturally be the entire scale or 0 - 1.

A modified formula for constructing a beta distribution is:

$$\overline{D} = \frac{(a+b)/2 + 2m}{3} = \frac{a+b+4m}{6} \qquad [1]$$

where:

$\overline{D}$ = distribution mean,
a = low value,
b = high value, and
m = most likely value.

A weighting value of 4 is placed on the most likely or modal value. The variance of the distribution, V, is:

$$V = [(b-a)/6]^2 \qquad [2]$$

It is assumed that 90 percent of all observations fall within three standard deviations [Taha, 1968].

The beta distribution is of use when using one judge's estimates or decisions; however, the distribution created is uncertain based on the six standard deviations used. Another problem arises in adapting to multiple judge inputs with the beta distribution. Averaging techniques tend to create biased results as they decrease the range of the distribution. The utilization of six standard deviations causes an information loss, because the actual variance of the distribution is not utilized.

I. J. Good [personal communication, 1975] suggests that the transformation:

$$x = \log [p/(1-p)] \qquad 0 \leqslant p \leqslant 1 \qquad [3]$$

where:

p = disruption or importance value,
x = transformation factor

might be utilized where p equals the degree of disruption or importance of the factor under consideration and x runs from minus to plus infinity. Judges are selected to evaluate the impact and importance of dam projects on factors. The judges are asked to choose the low and high values that they feel will encompass 90 percent of the possible impact or importance, and to choose the value they feel will most likely result from the proposed project.

The mean μ and standard deviation σ are estimated by a least-squares method, or minimization of the expression:

$$W_j = [(L_j - \mu + 2\sigma)^2 \ 4(M_j - \mu)^2 \ (H_j - \mu - 2)^2]$$

where:

W_j = weighting value for each judge (all judges are assumed equal here or $W_j = 1$),
L_j = low value of judge j,
M_j = most likely value of judge j,
H_j = high value of judge j, and
J = number of judges.

Thus leading to the formulae:

$$\mu = \frac{W_j (L_j + 4M_j + H_j)}{6W_j}$$

$$\sigma = \frac{W_j (H_j - L_j)}{4W_j}$$

or:

$$\mu = (1/6J)\ (L_j + M_j + H_j) \qquad [4]$$

$$\sigma = (1/4J)\ (H_j - L_j) \qquad [5]$$

where:

W_j = 1
J = number of judges

The transformation of the standard deviation and mean may now be made back to the original impact or importance scale using:

$$p = 1/(1 + e - x)$$

Use of these formulae in creating distributions for impact evaluation allows maximum utilization of available data input, and leads to a more accurate method of assessment than available methods.

B. Dam Evaluation System (DES)

Computer Program: The DES program *(Appendix II)* is based on the analysis of the high, most likely, and low values for the magnitude (impact) and weighting (importance) values designated by dam project evaluators for each parameter. The program is written in FORTRAN and was implemented on an IBM 370 computer. A user's guide *(Appendix I)* was written to aid in implementing the system.

DES is flexible in that it allows the addition of parameters, and/or the expansion or contraction of the number of levels in the hierarchical system. Any number of lowest level factors may be added to the hierarchical system, which may be expanded to seven levels. In addition, up to 99 evaluators may be used for data input on any one factor, with the total number of evaluators for each factor remaining open from 1-99, thus permitting utilization of available expertise in specific areas.

In many cases it is desirable to compare more than one project, or to compare project alternatives as to their impact. The dam evaluation system (DES) permits comparisons between projects based on the created probability distributions. As many as 10 projects or alternatives may be compared at one time. Comparisons may be made at any level for any factor with as many as 15 factors compared between the projects, or a total of up to 150 comparisons.

Visual comparisons of weighted impact distributions are useful in general analysis and in determining factors which will be greatly affected by proposed dam projects.

After creating the project distributions, DES makes comparisons between the alternative projects and prints these in tabular form *(Figure 7)*. It is important to develop some method of quantitative comparison between dam project alternatives so that conclusions and decisions may be made on the analysis of the data input. Available assessment methods do not permit comparisons to be made between individual project parameters or levels.

Results of the dam evaluation system are reported in three ways on the comparison table *(Figure 7)*. In the lower left-hand corner of the table is printed the expected impact difference between project J and project K when $J>K$. The expected impact value of the ith impact when $J=K$

is printed on the diagonal. In the upper right-hand corner is printed the probability that J is more desirable than K when $J<K$. Thus, both expected values for dam project factors and probabilities between project alternatives are displayed in the table.

Qualitative information of the variability of the project impact may be obtained from the overall project distribution while specific comparisons are made in the table. The available graphic and tabular analysis allows for evaluation of each element both alone and in conjunction with other projects.

Plotting the Distributions: Utilizing Equations 3 through 6, a probability distribution based on an expert's best estimates of the impact of dam projects (or alternate dam sites) may be created. The distribution is made up of potential impact on the x axis and probability on the y axis *(Figure 8).* Because weighting or importance values are also estimates, a distribution is also created for the importance value on each factor evaluated. The user of DES has the option of having these distributions displayed. Specific factor distribution graphs may be individually displayed without generating all other factor graphs at the same time.

The importance and magnitude probability distributions are then multiplied with the resultant product or weighted distribution created for each affected factor. Any level of the hierarchical system may be plotted to make comparisons or analyze impact. Individual factor distributions are combined additively at the next level of the hierarchical system and so forth until the top level or total project distribution has been created. The option for display or output of the distribution exists at every level. In addition, a separate countermand option is available for each factor at any level. Thus, if only one element (such as water quality) of a hierarchical level is needed for display, the level may be set so that none of its elements will be displayed, and the countermand option utilized on the one desired element.

RESULTS AND DISCUSSION

I. Hypothetical Application of DES

The utilization of DES will be illustrated through a hypothetical application to a small flood control project. The proposed project will be compared to one project alternative. The categorization developed in *Figures 5* and *6* will be utilized for the evaluation of the proposed project and alternative.

The proposed flood control project is located in a rural area and is designed to control the maximum flooding of a small stream on a 1,000-year flood cycle. Approximately 60 acres of land will be covered by the impoundment, 40 of which is marginal forest land, and 20 acres of which is being utilized for beef cattle production. The stream to be impounded supports a low quality smallmouth bass fishery that generates 100 man-days of use per year. The forested area to be inundated had been clear-cut ten years earlier, and is part of an area that supports a good deer herd that is heavily utilized by hunters.

One of the major objections raised to the project is that a renovated house once belonging to a local Civil War hero is located on the area to be impounded, and the nearest suitable area for relocation is five miles away. The natural resources of the area primarily include the potential for timber production, which is viewed as marginal. The vegetation of the area is considered by wildlife managers to be significant to a number of animals, including mice, rabbits, and deer. A major concern is the poor stability of the hillsides in the project area. Impoundment of the stream may lead to minor slides and slumps in the area. Two major effects on the stream biota are expected. One is a shift in the impounded waters from the warmwater stream system of fauna and flora to a lake-type system. Secondly, it is expected that algal blooms may develop in the impoundment.

The proposed impoundment is also expected to create a decrease in the average stream temperature below the dam, and create a more even flow of water during the year. The project proponents cite flood control and an increase in angler use of 2,000 man-days per year as major project benefits.

Activities associated with the proposed project include building a road through adjacent farmland for access, excavating a large amount of soil from an adjacent hill, and channelizing about a quarter mile of stream directly above the impoundment. Project operation involves large fluctuations in water levels.

The project alternative under consideration is the development of a smaller dam engineered to control flood waters of the 100-year flood. The major differences are that the alternative will cover a total of 40 acres, 20 of which will be the acreage utilized for beef cattle, and the other 20 for forest land. The historical site of Civil War time may be moved to a location 100 feet away. The alternative is not viewed to be as effective in flood control, and the smaller impoundment would be expected to generate 500 man-days in warmwater fishing. Other differences are viewed as proportionate changes in the factors and activities associated with the development and operation.

Four experts were chosen for the evaluation. The data input on the affected factors is shown in *Tables 3* through *6.* The evaluators desire to have graphic output for the first and second hierarchical levels, and the following factors: fishing, hunting, historical landmarks, fauna, geologic stability, and water quality. In addition, graphic output is desired for all activities except road construction. A scale of 0 to 10 will be used for importance estimates. The graphic and tabular results of the analysis by DES are as follows in *Tables 3* through *8* and *Figures 9* through *24.*

II. DES Results and Output

Inspection of *Tables 7* and *8* indicate project Alternative Two to be less harmful to the surrounding area for both factors and activities. However, the probability of significant difference is small (0.8 for factors and .33 for activities).

Other areas may be evaluated while considering both the tabular output of *Tables 7* and *8* and *Figures 9* through *24.* For example, the effect on fishing may be compared for Alternative One in *Figure 9* and Alternative Two in *Figure 14* where the mean value is five for Alternative One and zero for Alternative Two. In addition, the variance and skewness of each distribution may be compared for each factor or activity shown in the graphic output.

III. Relation to Other Assessment Methodologies

Numerous studies have been performed in the area of environmental assessment. In the development of DES many of the good points of earlier systems have been included.

One of the most valuable aspects of the approach developed by Leopold et al. [1971] is that a list of factors is provided from which environmental impact statements may be reviewed and formalized. The hierarchical system *(Figure 5)* presented with DES develops and presents potential impacts of dam construction, and may be used as a preevaluation guide in the development of environmental impact statements.

Utilization of some method of weighting importance between individual factors is necessary in project evaluation, and has been developed in other assessment methodologies [Leopold et al., 1971; Carlson, 1973; Calvert and Heilman, 1971; Commonwealth Associates, Inc., 1972; Dee et al., 1973; Horton, 1976; Dearinger and Dearinger et al., 1968 and 1973, and Martel and Lackey, 1975]. The weighting or importance concept has also been developed in DES. Because weighting values are by definition estimates of importance, distributions were created based on evaluator input. Development of importance distributions yields additional information about the certainty and range of evaluators in reference to the factors' importance.

A valuable factor in the utilization of distributions to analyze impact is that areas of needed data acquisition may be identified. Large variances in impact distributions may indicate the need for additional information on specific factors. This will allow for a narrower range of estimates by project evaluators.

DES also computes the mean estimates of impact along with probability of impact for each factor and level in the hierarchy. Utilizing this information, factors having a high potential of being severely impacted may be identified as in the environmental evaluation system developed by Dee et al. [1973].

IV. Unique Features of DES

The implementation of DES on a particular project or group of project alternatives may be achieved in a short period of time. Evaluators must estimate the impact and importance of each factor under consideration for a proposed project. The total amount of time needed for evaluation will depend upon the number of projects, and the number of factors affected by each project.

One of the unique features of DES is the utilization of distributions. Weighted impact distributions are created by multiplying the impact distributions by the importance distributions. These distributions are accumulated additively to form distributions at the higher levels. The distributions allow comparisons and evaluation to be made between projects and alternatives that were not possible with earlier methods.

DES allows for and utilizes the input of up to 99 evaluators and makes comparisons between projects and alternatives based on probability as well as estimated difference. The utilization of the probability of differences actually present between specific projects is a valuable feature in the assessment methodology in that project evaluators are able to see—based on the impact and importance data—how significant the differences actually are.

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Utilizing the environmental impact statement(s) for the project alternative to be evaluated, construct a hierarchical system of the impacts, or utilize the one provided here *(Figures 5* and *6).*

On the first card (Card 1), the levels of the hierarchy at which the impacts are to be displayed should be designated. Utilize a *0* for the 'no display' option and a *1* if the impact graph for that level is desired. Place one space between each option level. For example, in the system provided, there are four levels; therefore, if a display is desired for the overall project, the three factor areas, and the six sub-factor areas, but not for individual parameters, the input would be: *1* in Column 1, *1* in Column 3, *1* in Column 5, and *0* in Column 7.

Card 2 is for the establishment of the importance scale or weighting factor scale of the system. It is suggested that a scale of 0 to 10 be utilized for most projects, a *0* signifying no importance to the system, and a *10* signifying the highest possible importance. In Columns 1 and 2, the minimum possible value of the importance scale should be placed (in this case *0*), and in Columns 4 and 5, the maximum possible value of the scale (in this case *10*). In Columns 7 and 8, the desired increment level for importance decisions should be placed. These are the increments that will be shown on the graph of importance—for example *1, .5, .25,* etc.

Card 3—or the "Parameter Card"—contains the information on the factor or level under consideration. The following are the necessary inputs on each parameter card:

—Column 1—Place the number corresponding to the level of the hierarchical system being considered. The highest level for the first parameter card will be *0,* the next level of consideration (the first sub-groups of the system) will be number *1,* through *9,* or a possibility of 10 levels of evaluation.

—Column 3-4—Place the number of people estimating the impact values.

—Column 6-7—Place the number of people estimating the importance or weighting values.

—Columns 9-10—Place an identification number here if you are evaluating more than one project, and wish comparisons to be made between the projects at this level. A *0* indicates no comparisons to be made. This same identification number should be placed in Columns 9 and 10 for the same factor in the other project to be compared. The same identification number may not be used for two factors in the same project.

In Columns 12-18, the impact scale is determined. The total possible range is fixed at *11*, however, minus values and plus values may be utilized to indicate adverse versus beneficial effects. If the outcome is unknown a scale of —5 to +5 may be utilized.

—Columns 12-14—These columns are to be utilized in setting the low value for the impact scale. If the factor under consideration is known to have a detrimental outcome, a *—10* may be utilized; if the factor is known to be positive, a *0* may be utilized.

—Columns 16-18—These columns are to be utilized in setting the high value for the impact scale. Considering a factor known to be degraded by the project, this would be *0*, and a factor that is known to improve would have a *10* value.

—Columns 20-21—This option allows for decision on the increments shown on the axis of the factor graph or output. For example, whole numbers would call for a *1* decision, halves, *.5*, etc.

—Column 23—This is the option to countermand the plotting directive on Card 1. For instance, in the sample system on Card 1 it was decided that the first three levels would be plotted. If one desires to forego this option in Level 2 for sociologic factors, one merely inserts the value *1*. If one wishes the directive to proceed as planned, a *0* is inserted.

—Columns 30-57—Put in the name of the factor group for this card. For example, the first card would be "Total Reservoir Development."

Unless working on the lowest level or individual factors, the following card will be a replicate of Card 3 for the next level down and to the left in the hierarchical system that has not been covered.

When the first base level card (smallest division) is reached, the data

When the first base level card (smallest division) is reached, the data cards for that factor should be placed directly after it with the impact data proceeding the importance data.

Evaluation is based on the expected impact of the project on the factor under consideration. The input should be in the form of a "low," "most likely," and "high" value of impact of the proposed project on the factor. The range between the low and high value should reflect an alpha level of 0.10 as estimated by the evaluator using DES. All values must be followed by a decimal point. The card structure is as follows:

—Columns 1-5—Insert the lowest potential impact or importance.

—Columns 7-11—Insert the modal or most likely project impact or importance.

—Columns 13-17—Insert the highest possible impact or importance.

Each evaluator should utilize two data cards for the factor under consideration, one for impact and one for importance. All the impact cards should be placed together followed by the importance cards in the same order.

After the data cards, the parameter card for the next factor may be placed and the process continued until all factors and levels have been evaluated.

I. Sociologic Factors for Parameter Identification

A. Recreation

Fishing: Relate fishing opportunities prior to impoundment to opportunities created by the reservoir project.

Hunting: Utilizing wildlife recreation potential, estimate the magnitude of loss or gain to the area.

Other Water Recreation: Compare water-based recreation (other than fishing) prior to project development to water-based recreation after impoundment (i.e. boating and swimming).

Other Land Recreation: Compare land-based recreation in the project area such as hiking, picnicking, and camping to land-based recreation after impoundment.

Unique Recreation: Compare special or unique recreational potential in the project area (i.e., high quality white water canoe area or unique cave system) to any recreational aspects created by the impoundment.

B. Other Factors

Food Production: Based on losses versus gains to agriculture, estimate total impact considering agricultural losses due to inundation, water made available for irrigation, changes in erosion and sedimentation, and any other factors affecting food production.

Dam Failure: Utilizing the engineering section of the impact statement, determine the potential for project failure due to leaks or project destruction from geologic activity, and impact of such an event.

Aesthetics: Consider the project area as to its aesthetic value compared to the value when a reservoir occupies the river valley.

Historical Landmarks: If historical landmarks exist in the area, consider the sociologic impact of the relocation or loss of those historical areas.

Archeological Areas: If sites of archeologic value exist in the project area, determine the impact of the project on these sites.

Health: In some areas health considerations may be a factor. Considering aggregation of people and change in local water conditions, determine the potential for change in human health in the project area.

Atmospheric Conditions: Considering the activities and results of the construction activities such as noise and dust, determine the impact of these actions on society.

Natural Resources: Considering the natural resource base of the project area (such as timber, minerals, and oil), determine the impact on these resources.

II. Terrestrial Factors for Parameter Identification

A. Biota

Vegetation: In view of the type and size of the proposed project, determine the impact on the area's vegetation due to inundation and changes in ground water and other local factors.

Fauna: Considering the animal populations of the area, estimate the overall effect on fauna considering loss of habitat and nesting or breeding areas, obstruction to migrations, and any other pertinent factors.

Endangered Flora: Reviewing the EIS for endangered and rare terrestrial plant species, determine magnitude of the project's effect on these species.

Endangered Fauna: Reviewing the EIS for animal species present that represent rare or endangered species, determine the project impact on any groups that exist in this area.

B. Physical Environment

Ground Water: Taking into consideration the impact statement's input on this section and the soil and geologic structure of the area, determine the project's effect on ground water level and quality.

Atmospheric Conditions: If the local climate is to be affected, determine the extent. Changes that may occur primarily are due to changes in wind patterns and humidity on a local basis.

Geologic Stability: Considering the project impact on ground water supplies and the geologic and soil structure of the area, determine potential for earth movement (i.e., slumps and slides) and leakage.

III. Aquatic Factors for Parameter Identification

A. Biota

Fauna and Flora Shifts: Consider the shifts in aquatic plant and animal species, diversity, and abundance due to project development.

Endangered Fauna: Reviewing species lists of the watershed, determine if any rare or endangered aquatic animals exist in the project area and, if so, determine the project's effect on them.

Endangered Flora: Utilizing the available data determine what (if any) endangered or rare aquatic plants exist and the project's impact on them.

Marsh Areas: Identify marsh areas that exist in the project area and determine the potential effect of impoundment.

Eutrophication: Estimate the potential for reservoir enrichment due to accumulation of nutrients, and the potential effect of algae blooms in the reservoir.

B. Physical Environment

Drainage: If the project involves change in drainage patterns (i.e., pump storage or diversion of river), determine the impact of this action.

River Flow: Determine the impact or change to the aquatic environment caused by controlled discharge from the impoundment.

Evaporation: If loss of water is of significance in the project area, estimate the magnitude of water loss for the area.

Temperature: Evaluate changes in the temperature regime in both the reservoir and the river system.

Water Quality: Consider changes in water quality factors such as clarity and floating debris.

Other Factors: Consider other factors such as aggregation of pollutants and floating debris. If other factors are diverse or important enough, new groups may be added to the hierarchical system at any level.

IV. Activity Identification

Road Construction: Evaluate the impact on the surrounding area caused by project road construction.

Dust and Exhaust Fumes: If harmful dust and exhaust fumes are present, evaluate conditions.

Filling and Digging: Considering filling and digging activities for the dam abutments and body of the dam, determine adverse impact on the terrestrial environment.

Blasting: This should be considered in terms of temporary effect on flora and fauna as well as permanent impact on geologic structure.

Channel Modification: If channelization and/or dredging is to be carried on in conjunction with the project, estimate the impact of such changes on the aquatic environment.

Road Diversion: If the natural direction or flow of the river is to be shifted or stopped during construction, determine the effect on the river system.

Flood Control: If flood control is one of the project's objectives, weigh the value of flood control against the detriment in terms of the aquatic environment.

Siltation: Considering construction as well as operational activites, estimate the effect of siltation in both the reservoir and the downstream area.

Erosion: In view of disturbance caused by project development in the area, estimate the potential impact of erosion in the area.

Water Level Fluctuations: Consider the fluctuations in water level of the proposed reservoir, and the impact of such changes on the aquatic environment.

V. Sample Evaluation for Assessment Methodology

All card inputs begin in Column 1 of the card. A slash (/) equals one space. Skip one space for each /.

Card 1: 1/1/1/0

Result: Graphs will be plotted for total project impact, the three first-level factor groups, and the six second-level groups. Graphs will not be produced for individual factors.

Card 2: /0/10//1

Result: The importance scale will be based on a range of 0-10, and only whole numbers will be allowed.

Card 3: 0//3//3//0///0///0//1/0//////total project

Result: The highest level (0 or total project) is being assessed by three persons, and three people are setting importance values. Only one project is being examined at this time, so no comparisons are made. Because we are at the upper level, no scale values are required, so zeroes are put in the columns. The increments shown on the X-axis of the plot will be whole units or 1,2,3, etc. The graph will be plotted as specified on Card 1. The factor name is 'total project.'

Since there is no data input at this level, the next card will be the parameter card for Sociologic Factors.

Card 4: 1//3//3//0///0///0//1/0//////sociologic factors

Result: The first sub-level has now been reached with all other values remaining the same.

There is no data input at this level so the next card will be the parameter card for Recreation, as follows.

Card 5: 2//3//3//0///0///0//1/0//////recreation

Result: This card is for Recreation at the second sub-level with all other factors remaining the same.

There is still no data input, so Card 6 will be the parameter card for the next level.

Card 6: 3//3//3//0///0//10//1/1//////fishing

Result: This is the third sublevel or the first factor to be analyzed under recreation. This factor is known to be beneficially affected by the project, so a positive scale of 0 to 10 is utilized. It has been decided that a distribution of this parameter would be desirable; however, Card 1 indicates that plots of the third sublevel not be shown, so the countermand option is utilized.

Data card input is required immediately following the factor card at the lowest sublevel. The impact data should proceed the importance data, with each "low," "most likely," and "high" value on one card. The following is one possible data input for the three evaluators.

Data Cards

1: ///3.////5.////7.
2: ///2.////3.////4.
3: ///2.////5.////8.
4: ///5.////3.////9.
5: ///6.////7.////9.
6: ///4.////8.////9.

Result: The first three cards are the inputs of the three evaluators on the impact of the project on recreational fishing. The first evaluator judged the least possible impact to be 2, while the most likely was 5, and the greatest possible impact would be 7. The second evaluator selected a narrower range indicating greater confidence (2, 3, 4), and the third a wide range (4, 8, 9). The last three cards 4-6 indicate the importance or weighting value fishing should have in relation to this particular project as estimated by the three evaluators.

The evaluation should be continued with parameter cards being followed by data cards for the rest of the recreation factors. Following the data cards for unique recreation, the next parameter card will be "Other Factors," followed directly by the parameter card for food production, the related data cards, and the rest of the parameter cards and data cards for this level. This procedure should be continued until all levels and factors have received parameter cards and data cards where applicable.

After completing the evaluation of the factors affected by the project, the procedure is repeated for the activities, thus making two separate computer runs for each evaluation.

COMPUTER PROGRAM FOR DAM IMPACT EVALUATION SYSTEM

```
      INTEGER END,ENDING,SSCRPT,TITLEN(7),TITLE(7),SIDE1(5)
      INTEGER SIDE2(6),TITLES(10,7),TCOMP(15,10,7)
      REAL MINPCT,MAXPCT,INCPCT,LOW1,LOW2,LOW, INCREM, IMPACT(10,106)
      REAL IMPORT(10,106),NET(106),PLOTS(10)
      DIMENSION X(106),X1(106),Y(106),Y1(106),W(106),W1(106),Z(106)
      DIMENSION Z1(106),HOLD(106),KCOMP(15),OUT(10,10),COMP(15,10,106)
      DATA TITLEN,TITLE,TITLES,TCOMP/1134*'    '/,IBLANK/'    '/
      DATA SIDE1/'IMPA','CT P','ROBA','BILI','TY  '/
      DATA SIDE2/'IMPO','RTAN','CE P','ROBA','BILI','TY  '/
      DATA END,ENDING,SSCRPT,KCOMP/18*0/
      DATA MINPCT,MAXPCT,INCPCT,LOW1,LOW2,LOW, INCREM/7*0.0/
      DATA IMPACT,IMPORT,NET,X,X1,Y,Y1,Z,Z1,W,W1,HOLD,OUT/3280*0.0/
      DATA COMP/15900*0.0/
 1000 FORMAT(10(F1.0,1X))
 2000 FORMAT(F2.0,1X,F2.0,1X,F2.0)
 3000 FORMAT(I1,3(1X,I2),1X,F3.0,1X,F3.0,1X,F2.0,1X,F1.0,6X,7A4)
 4000 FORMAT(1H1,1X,'TABLE ',I2,'. COMPARISON OF IMPACT DISTRIBUTION ',
     1  'GROUP ',I2,'. IMPACT NUMBERS AND TITLES ARE SHOWN AT LEFT. THE'
     2  ,' (J,K)TH',/,1X,'ELEMENT OF THE TABLE IS THE EXPECTED DIFFERE',
     3  'NCE IN IMPACTS J AND K (E(IMPACT(J)-IMPACT(K))) WHEN J>K (LOW'
     4  ,'ER LEFT),',/,1X,'THE EXPECTED VALUE OF THE JTH IMPACT WHEN'
     5  ,' J=K (ON DIAGONAL), AND THE PROBABILITY THAT IMPACT J IS MOR',
     6  'E DESIRABLE',/,1X,'(LESS OBJECTIONABLE) THAN IMPACT K'
     7  ,' (P(IMPACT(J)>IMPACT(K))) WHEN J<K (UPPER RIGHT).',//,5X,
     8  'IMPACT',22X,2X,10(3X,I2,3X))
 5000 FORMAT(1X,114('-'))
 6000 FORMAT(1X,/,1X,I2,2X,7A4,2X,10(1X,F6.2,1X))
      READ(5,1000) PLOTS
      READ(5,2000) LOW,HIGH,INCREM
   10 READ(5,3000,END=20,ERR=999) LEVEL,NMPACT,NMPORT,NCOMPR,MINPCT,
     1  MAXPCT,INCPCT,CKPLOT,TITLEN
      GO TO 30
```

```
20 LEVEL = 0
   NMPACT = 0
   NMPORT = 0
   ENDING = 1
30 LEVEL = LEVEL + 1
   END = 11 - LEVEL
   DO 210 K=1,END
   K1 = 11 - K
   IF(IMPACT(K1,106).EQ.0.0) GO TO 210
   SUM1 = 0.0
   SUM2 = 0.0
   RANGE1 = IMPACT(K1,102) - IMPACT(K1,101)
   LOW1 = IMPACT(K1,101)
   STEP = RANGE1*0.01
   DO 40 J=1,100
   SUM1 = SUM1 + IMPACT(K1,J)*STEP
40 SUM2 = SUM2 + IMPORT(K1,J)*0.01
   IF(SUM1.EQ.0.0) GO TO 95
   DO 50 J=1,100
   X(J) = (J-1) * RANGE1/100.0 + LOW1
   X1(J) = X(J)
   IF(IMPACT(K1,J).LE.0.0) GO TO 50
   IF((ALOG10(IMPACT(K1,J))-ALOG10(SUM1)).LT.(-72)) GO TO 50
45 Y(J) = IMPACT(K1,J)/SUM1
50 Y1(J) = Y(J)
   X1(101) = LOW1
   X1(102) = LOW1 + RANGE1
   Y1(101) = 0.0
   Y1(102) = 1.0
   IF((PLOTS(K1)+IMPACT(K1,104)).NE.1.0) GO TO 75
   CALL SCALE(X1,102,6.0,XMIN,DX,1)
   CALL SCALE(Y1,102,6.0,YMIN,DY,1)
```

```
      DO 60 I=1,7
   60 TITLE(I) = TITLES(K1,I)
      YSTEP = IFIX(5.0*DY+1.0)/10.0
      XINC = IMPACT(K1,103)/DX
      YINC = YSTEP/DY
      DX = 1.0
      DY = 1.0
      CALL  SAXIS(DX,DY,TITLE,-28,6.1,0.0,XMIN,IMPACT(K1,103),XINC,0.0)
      CALL  SAXIS(DX,DY,SIDE1,18,6.1,90.0,YMIN,YSTEP,YINC,0.0)
      DO 70 J=1,100
      X1(J) = X1(J) + DX
   70 Y1(J) = Y1(J) + DY
      CALL  PLOT(DX,DY,3)
      CALL  LINE(X1,Y1,100,-1)
      CALL  PLOT(7.0,0.0,-3)
   75 CONTINUE
      IF(SUM2.EQ.0.0) GO TO 95
      DO 80 J=1,100
      W(J) = (J-1)/100.0
      W1(J) = W(J)
      IF(IMPORT(K1,J).LE.0.0) GO TO 80
      IF((ALOG10(IMPORT(K1,J))-ALOG10(SUM2)).LT.(-72)) GO TO 80
      Z(J) = IMPORT(K1,J)/SUM2
   80 Z1(J) = Z(J)
      W1(101) = 0.0
      W1(102) = 1.0
      Z1(101) = 0.0
      Z1(102) = 1.0
      IF((PLOTS(K1)+IMPACT(K1,104)).NE.1.0) GO TO 95
      CALL  SCALE(W1,102,6.0,WMIN,DW,1)
      CALL  SCALE(Z1,102,6.0,ZMIN,DZ,1)
      ZSTEP = IFIX(5.0*DZ+1.0)/10.0
```

```
      WINC = 0.1/DW
      ZINC = ZSTEP/DZ
      CALL SAXIS(OX,OY,TITLE,-28,6.1,0.0,WMIN,0.1,WINC,0.0)
      CALL SAXIS(OX,OY,SIDE2,22,6.1,90.0,ZMIN,ZSTEP,ZINC,0.0)
      DO 90 J=1,100
      W1(J) = W1(J) + OX
   90 Z1(J) = Z1(J) + OY
      CALL PLOT(OX,OY,3)
      CALL LINE(W1,Z1,100,-1)
      CALL PLOT(7.0,0.0,-3)
   95 CONTINUE
      IF(K1.EQ.1) GO TO 165
      IF(SUM2.GT.0.0) GO TO 105
      DO 100 J=1,100
  100 NET(J) = Y(J)
      GO TO 135
  105 TOTAL = 0.0
      DO 120 I=1,100
      RY = Y(I)
      IF(RY.EQ.0.0)GO TO 120
      DO 110 J=1,100
      RZ = Z(J)
      IF(RZ.EQ.0.0) GO TO 110
      SSCRPT = (X(I)*W(J) - LOW1) * 100.0/RANGE1 + 1.0
      PROD = 10**(-72)
      IF((ALOG10(RY)+ALOG10(RZ)).LT.(-72)) GO TO 115
      PROD = RY*RZ
  115 NET(SSCRPT) = NET(SSCRPT) + PROD
      TOTAL = TOTAL + NET(SSCRPT)
  110 CONTINUE
  120 CONTINUE
      IF(TOTAL.EQ.0.0) GO TO 135
```

```
      DO 130 J=1,100
  130 NET(J) = NET(J)/TOTAL
  135 RANGE2 = IMPACT(K1-1,102) - IMPACT(K1-1,101)
      LOW2 = IMPACT(K1-1,101)
      DO 140 J=1,100
  140 W(J) =((J-1)/100.0)*RANGE2 + LOW2
      IF(IMPACT(K1-1,106).EQ.1.0) GO TO 143
      DO 142 J=1,100
  142 HOLD(J) = NET(J)
      GO TO 155
  143 DO 150 I=1,100
      RZ = NET(I)
      DO 150 J=1,100
      IF(RZ.EQ.0.0) GO TO 145
      SSCRPT = (X(I) + W(J) -LOW1 - LOW2) * 100.0/(RANGE1+RANGE2) + 1.0
      RY = IMPACT(K1-1,J)
      IF(RY.EQ.0.0) GO TO 145
      PROD = 10**(-72)
      IF((ALOG10(RY)+ALOG10(RZ)).LT.(-72)) GO TO 150
  145 PROD = RY*RZ
  150 HOLD(SSCRPT) = HOLD(SSCRPT) + PROD
  155 IMPACT(K1-1,101) = IMPACT(K1-1,101) + IMPACT(K1,101)
      IMPACT(K1-1,102) = IMPACT(K1-1,102) + IMPACT(K1,102)
      IMPACT(K1-1,103) = IFIX((RANGE1+RANGE2)/10.0)
      IMPACT(K1-1,106) = 1.0
      DO 160 J=1,100
  160 IMPACT(K1-1,J) = HOLD(J)
  165 CONTINUE
      IF(IMPACT(K1,105).EQ.0.0) GO TO 185
      TOTAL = 0.0
      DO 167 J=1,100
  167 TOTAL = TOTAL + IMPACT(K1,J)
```

```
      LCOMP = IMPACT(K1,105)
      KCOMP(LCOMP) = KCOMP(LCOMP) + 1
      KC = KCOMP(LCOMP)
      IF(KC.GT.10) GO TO 185
      IF(TOTAL.EQ.0.0) GO TO 175
      DO 170 J=1,104
      IF(J.GT.100) GO TO 170
      IF(IMPACT(K1,J).EQ.0.0) GO TO 170
      IF((ALOG10(IMPACT(K1,J))-ALOG10(TOTAL)).LT.(-72)) GO TO 170
      IMPACT(K1,J) = IMPACT(K1,J)/TOTAL
  170 COMP(LCOMP,KC,J) = IMPACT(K1,J)
  175 DO 180 J=1,7
  180 TCOMP(LCOMP,KC,J) = TITLES(K1,J)
  185 CONTINUE
      DO 190 J=1,106
      IMPACT(K1,J) = 0.0
      IMPORT(K1,J) = 0.0
      X(J) = 0.0
      X1(J) = 0.0
      Y(J) = 0.0
      Y1(J) = 0.0
      W(J) = 0.0
      W1(J) = 0.0
      Z(J) = 0.0
      Z1(J) = 0.0
      NET(J) = 0.0
  190 HOLD(J) = 0.0
      DO 200 J=1,7
      TITLES(K1,J) = IBLANK
  200 TITLE(J) = IBLANK
  210 CONTINUE
      DO 220 J=1,7
```

```
220 TITLES(LEVEL,J) = TITLEN(J)
    HOLD(101) = MINPCT
    HOLD(102) = MAXPCT
    HOLD(103) = INCPCT
    HOLD(104) = CKPLOT
    HOLD(105) = NCOMPR
    IF(INCPCT.LT.((MAXPCT-MINPCT)/10.0)) HOLD(103) =
   1  IFIX((MAXPCT-MINPCT)/10.0)
    IF(NMPACT.EQ.0) GO TO 225
    HOLD(106) = 1.0
    CALL DSTRIB(HOLD,NMPACT)
225 DO 230 J=1,106
    IMPACT(LEVEL,J) = HOLD(J)
230 HOLD(J) = 0.0
    HOLD(101) = LOW
    HOLD(102) = HIGH
    HOLD(103) = INCREM
    IF(NMPORT.EQ.0) GO TO 245
    CALL DSTRIB(HOLD,NMPORT)
    DO 240 J=1,100
240 IMPORT(LEVEL,J) = HOLD(J)
245 CONTINUE
    DO 250 J=1,106
250 HOLD(J) = 0.0
    IF(ENDING.NE.1) GO TO 10
    DO 340 I=1,15
    KC = KCOMP(I)
    IF(KC.GT.10) KC =10
    IF(KC.EQ.0) GO TO 340
    WRITE(6,4000) I,I,(J,J=1,KC)
    WRITE(6,5000)
    DO 320 J=1,KC
```

```
      RANGE1 = COMP(I,J,102) - COMP(I,J,101)
      LOW1 = COMP(I,J,101)
      DO 320 K=1,KC
      SUM1 = 0.0
      RANGE2 = COMP(I,K,102) - COMP(I,K,101)
      LOW2 = COMP(I,K,101)
      IF(RANGE1*RANGE2.EQ.0.0) GO TO 320
      IF(J-K) 260,280,300
  260 DO 270 L=1,100
      RV1 = (L-1)*RANGE1/100.0 + LOW1
      RY = COMP(I,J,L)
      IF(RY.EQ.0.0) GO TO 270
      DO 268 M=1,100
      RV2 = (M-1)*RANGE2/100.0 + LOW2
      RZ = COMP(I,K,M)
      IF(RZ.EQ.0.0) GO TO 268
      IF(RV1.LT.RV2) GO TO 270
      PROD = 10**(-72)
      IF((ALOG10(RY)+ALOG10(RZ)).LT.(-72)) GO TO 265
      PROD = RY*RZ
  265 SUM1 = SUM1 + PROD
  268 CONTINUE
  270 CONTINUE
      OUT(J,K) = SUM1
      GO TO 320
  280 DO 290 L=1,100
  290 SUM1 = SUM1 + ((L-1)*RANGE1/100.0 + LOW1)*COMP(I,J,L)
      OUT(J,K) = SUM1
      GO TO 320
  300 DO 310 L=1,100
      DO 310 M=1,100
      VAL = (((L-1)*RANGE1/100.0+LOW1) - ((M-1)*RANGE2/100.0+LOW2))
```

```
      RY = COMP(I,J,L)
      RZ = COMP(I,K,M)
      IF(VAL.EQ.0.0) GO TO 310
      IF(RY.EQ.0.0) GO TO 310
      IF(RZ.EQ.0.0) GO TO 310
      PROD = 10**(-72)*(VAL/ABS(VAL))
      IF((ALOG10(ABS(VAL))+ALOG10(RY)+ALOG10(RZ)).LT.(-72)) GO TO 305
      PROD = VAL*RY*RZ
  305 SUM1 = SUM1 + PROD
  310 CONTINUE
      OUT(J,K) = SUM1
  320 CONTINUE
      DO 330 J=1,KC
  330 WRITE(6,6000) J,(TCOMP(I,J,K),K=1,7),(OUT(J,K),K=1,KC)
  340 CONTINUE
  999 CONTINUE
      CALL PLOT(0.0,0.0,-4)
      RETURN
      DEBUG SUBCHK
      END
```

```
      SUBROUTINE DSTRIB(PROB,JUDGES)
      REAL LOW
      DIMENSION PROB(106)
 1000 FORMAT(F5.0,1X,F5.0,1X,F5.0)
      TOTAL = 0.0
      DIFF = 0.0
      LOW = PROB(101)
      HIGH = PROB(102)
      RANGE = HIGH - LOW
      IF(JUDGES.EQ.0) GO TO 25
      DO 10 J=1,JUDGES
      READ(5,1000) X,Y,Z
      IF(RANGE.EQ.0.0) GO TO 10
      X = (X-LOW)/RANGE
      IF(X.GE.1.0) X=0.9999984
      Y = (Y-LOW)/RANGE
      IF(Y.GE.1.0) Y=0.9999984
      Z = (Z-LOW)/RANGE
      IF(Z.GE.1.0) Z=0.9999984
      X1 = ALOG(X/(1.0-X))
      Y1 = ALOG(Y/(1.0-Y))
      Z1 = ALOG(Z/(1.0-Z))
      TOTAL = TOTAL + X1 + 4.0*Y1 + Z1
      DIFF = DIFF + Z1 -Y1
   10 CONTINUE
      MEAN = TOTAL/(6.0*JUDGES)
      SIGMA = DIFF/(4.0*JUDGES)
      IF(SIGMA.EQ.0.0) GO TO 35
      DO 20 J=1,100
      X = (J-1)*RANGE/100.0 + LOW
      X = (X-LOW)/RANGE
      IF(X.EQ.0.0) X = 0.000001
```

```
      X1 = ALOG(X/(1.0-X))
      ARG = -0.5*((X1-MEAN)/SIGMA)**2
      IF(ABS(ARG).GT.170) GO TO 45
      PROB(J) = EXP(ARG)/(SQRT(6.283184)*SIGMA)
      GO TO 20
   45 PROB(J) = 10**(-72)
   20 CONTINUF
      GO TO 25
   35 ISCRPT = (MEAN - LOW) * 100.0/RANGE + 1
      PROB(ISCRPT) = 1.0
   25 CONTINUE
      RETURN
      END
```

TABLES

TABLE 1

Definitions of Terms and Ratings Used in Carlson's [1973] Impact Matrix for Evaluating the Effect of a Ski Area on Fish and Fish Habitat

Terminology	Rating	Term-Rating Definition
High Positive	3	Fish habitat increased significantly. Growth and reproduction of existing populations increased. Fishery created where none existed previously. (Any new species introduced to the area must not reduce growth, reproduction, or survival of existing species.)
Moderate Positive	2	Fish habitat increased. Fishery created where none existed previously. (New fishes introduced to the area, as in ponds, must not reduce the growth, reproduction, or survival of species now in the area.)
Low Positive	1	Fishery created where none existed previously.
No Change	0	Present fish populations and habitat remain relatively unchanged.
Low Negative	–1	Some fish habitat and food destroyed. Habitat may be destroyed by increasing turbidity or temperature (or otherwise impairing water quality), by modifying stream channels or bottom substrates.
Moderate Negative	–2	Fish habitat, growth, and reproduction reduced significantly.
High Negative	–3	Fish habitat, growth, and reproduction reduced significantly and fish species diversity reduced.

TABLE 2

Definitions of Terms and Ratings Used in Carlson's [1973] Strength-of-Relationship Matrix for Evaluating the Effect of a Ski Area on Fish and Fish Habitat

Term	Rating	Term-Rating Definition
High	4	Factor constitute part of the immediate environment (habitat) of fishes in Beaver Creek and is essential for their success (for respiration, food, reproduction, etc.)
Medium	3	Factor constitutes part of the immediate environment of fishes in Beaver Creek but is not essential for their success (though evidence of adverse effects on the factor may be cause for concern about fish), or factor, though outside the immediate environment of the fishes of Beaver Creek, directly influences them or their habitat.
Low	2	Factor, outside the immediate environment of fishes in Beaver Creek, influences the stream environment (and the success of fishes) only indirectly.
None	1	Factor is apparently unrelated to success of fish populations or to maintenance of fish habitat in Beaver Creek.

TABLE 3

Factor Data for Impact Analysis on Alternatives as Used in Test Sample

Factors:	Evaluator 1			Evaluator 2			Evaluator 3			Evaluator 4		
Alternative 1	L	M	H	L	M	H	L	M	H	L	M	H
Fishing	3	4	6	5	7	8	—	—	—	4	6	7
Hunting	—	—	—	–4	–3	–2	–7	–6	–3	–6	–5	–2
Food production	—	—	—	—	—	—	–3	–2	–1	–5	–2	–1
Historical landmarks	—	—	—	—	—	—	–8	–6	–5	—	—	—
Natural resources	–6	–4	–2	–3	–2	–1	—	—	—	—	—	—
Vegetation	–4	–3	–2	–3	–2	–1	–5	–3	–2	–4	–2	–1
Fauna	–6	–3	–1	–3	–2	–1	–7	–3	–2	–4	–2	–1
Geologic stability	–7	–4	–2	—	—	—	–8	–5	–2	–5	–4	–2
Fauna and flora shifts	–1	0	1	1	2	3	–2	0	1	–3	–1	0
Eutrophication	–6	–4	–2	–5	–4	–3	—	—	—	–5	–3	–2
Water temperature	–3	–2	–1	–3	–2	–1	–5	–4	–2	–4	–3	–2
Water quality	–5	–2	–1	–6	–5	–4	–4	–3	–1	—	—	—
Alternative 2												
Fishing	–1	0	2	0	1	2	—	—	—	0	1	3
Hunting	—	—	—	–3	–2	–1	–2	–1	0	–4	–3	–2
Food production	—	—	—	—	—	—	–2	–1	0	–3	–2	0
Historical landmarks	—	—	—	—	—	—	–4	–2	–1	—	—	—
Natural resources	–3	–2	–1	–4	–3	–2	—	—	—	—	—	—
Vegetation	–3	–2	–1	–3	–2	–1	–2	–1	0	–2	–1	0
Fauna	–3	–2	–1	–2	–1	—	–4	–3	–1	–3	–2	0
Geologic stability	–5	–3	–1	—	—	—	–4	–2	–1	–3	–2	–1
Fauna and flora shifts	–1	0	1	1	2	3	–2	0	1	–3	–1	0
Eutrophication	–3	–2	—	–4	–2	–1	—	—	—	–4	–2	–1
Water temperature	–2	–1	—	–2	–1	—	–3	–2	–1	–4	–2	–1
Water quality	–5	–2	–1	–5	–4	–2	–3	–2	–1	—	—	—

TABLE 4

Data for Factor Importance Analysis on Alternatives as Used in Test Samples

Factors:	Evaluator 1			Evaluator 2			Evaluator 3			Evaluator 4		
Alternatives 1 & 2	L	M	H	L	M	H	L	M	H	L	M	H
Fishing	5	6	7	4	5	7	–	–	–	6	7	8
Hunting	–	–	–	4	6	7	7	8	10	6	7	9
Food production	–	–	–	–	–	–	1	2	3	3	5	6
Historical landmarks	–	–	–	7	8	9	–	–	–	–	–	–
Natural resources	1	2	3	2	4	5	–	–	–	–	–	–
Vegetation	3	4	6	2	5	5	5	6	7	4	5	8
Fauna	3	4	6	2	5	6	5	6	7	4	5	8
Geologic stability	4	6	7	–	–	–	3	4	5	4	6	8
Fauna and flora shifts	1	2	3	1	2	3	1	3	4	2	3	4
Eutrophication	5	6	7	1	2	3	–	–	–	8	9	10
Water temperature	1	2	3	1	3	4	2	3	4	1	3	5
Water quality	3	4	5	2	4	6	3	5	7	–	–	–

TABLE 5

Activity Data for Impact Analysis on Alternatives as Used in Test Samples

Factors:	Evaluator 1			Evaluator 2			Evaluator 3			Evaluator 4		
Alternative 1	L	M	H	L	M	H	L	M	H	L	M	H
Road construction	–5	–3	–1	–6	–2	–1	–4	–3	–2	–7	–2	–1
Filling and digging	–5	–4	–2	–4	–3	–2	–6	–4	–2	5	–3	–2
Erosion	–8	–7	–6	–10	–9	–7	–8	–6	–5	–9	–7	–6
Channel modification	–8	–6	–5	–9	–7	–6	–10	–8	–7	–9	–8	–6
Flood control	4	5	6	6	7	8	4	7	9	6	7	9
Water level fluctuations	–5	–4	–2	–6	–3	–2	–5	–4	–3	–6	–4	–3
Alternative 2												
Road Construction	–5	–3	–1	–6	–2	–1	–4	–3	–2	–7	–2	–1
Filling and digging	–4	–3	–1	–4	–3	–2	–5	–4	–1	–5	–2	–1
Erosion	–6	–5	–4	–8	–6	–5	–8	–6	–5	–7	–5	–4
Channel modification	–8	–6	–5	–9	–7	–6	–10	–8	–7	–9	–8	–6
Flood control	2	4	5	3	5	6	6	7	8	5	6	7
Water level fluctuation	–3	–2	–1	–4	–2	–1	–4	–3	–2	–4	–2	–1

TABLE 6

Data for Activity Importance Analysis on Alternatives as Used in Test Samples

Activities:	Evaluator 1			Evaluator 2			Evaluator 3			Evaluator 4		
Alternatives 1 & 2	L	M	H	L	M	H	L	M	H	L	M	H
Road construction	4	5	6	4	6	8	2	4	5	6	7	9
Filling and digging	3	4	6	4	5	7	2	4	8	5	7	8
Erosion	7	8	9	6	8	9	8	9	10	5	7	9
Channel modification	8	9	10	2	3	5	4	6	8	6	7	9
Flood control	5	7	8	4	5	6	7	8	9	3	6	8
Water level fluctuations	6	8	7	6	7	8	5	7	8	5	7	9

TABLE 7

Numerical Analysis of Factors for Test Sample

Impact numbers and titles are shown at left. The *J, K*th element of the table is the expected difference in Impacts *J* and *K* (*E* [Impact *J*] – [Impact *K*]) when $J > K$ (lower left), the expected value of the *J*th impact when $J = K$ (on diagonal), and the probability that Impact *J* is more desirable (less objectionable) than Impact *K* (*P* [Impact *J*] > [Impact *K*]) when $J < K$ (upper right).

	Impact	1	2								
1	Alternative 1	–22.70	0.08								
2	Alternative 2	4.70	–18.00								
1	Sociologic factors			–9.20	0.26						
2	Sociologic factors			1.51	–7.69						
1	Fishing					5.00	1.00				
2	Fishing					–5.00	0.00				
1	Hunting							–5.00	0.07		
2	Hunting							2.71	–2.29		
1	Historical landmarks									–5.00	0.00
2	Historical landmarks									2.26	–2.74
1	Terrestrial factors	–5.74	0.31								
2	Terrestrial factors	0.84	–4.90								
1	Fauna			–2.75	0.50						
2	Fauna			–0.31	–3.07						
1	Geologic stability					–5.00	0.00				
2	Geologic stability					2.23	–2.77				
1	Aquatic factors							–6.53	0.08		
2	Aquatic factors							2.35	–4.18		
1	Water quality									–5.00	0.00
2	Water quality									2.25	–2.75

TABLE 8

Comparison of Impact Distribution Group

Impact numbers and titles are shown at left. The *J, K*th element of the table is the expected difference in Impacts *J* and *K* (*E* [Impact *J*] – [Impact *K*]) when $J > K$ (lower left), the expected value of the *J*th impact when $J = K$ (on diagonal), and the probability that Impact *J* is more desirable (less objectionable) than Impact *K* (*P* [Impact *J*] > [Impact *K*]) when $J < K$ (upper right).

	Impact	1	2
1	Alternative 1	–11.99	0.33
2	Alternative 2	1.12	–10.87
1	Filling and digging	–5.00	0.52
2	Filling and digging	0.00	–5.00
1	Erosion	–5.00	0.54
2	Erosion	0.00	–5.00
1	Water level fluctuation	–5.00	0.00
2	Water level fluctuation	2.26	–2.74
1	Channel modification	–5.00	0.54
2	Channel modification	0.00	–5.00
1	Flood control	5.00	0.53
2	Flood control	0.00	5.00

FIGURES

FIGURE 1
Sample Matrix for Leopold et al. [1971] Matrix Method of Environmental Evaluation

I. EXISTING CHARACTERISTICS AND CONDITIONS OF THE ENVIRONMENT

II. PROPOSED ACTIONS		A. PHYSICAL AND CHEMICAL CHARACTERISTICS — 1. EARTH: a. MINERAL RESOURCES	b. SOILS	c. LAND FORM	2. WATER: a. SURFACE	b. QUALITY	c. TEMPERATURE	3. PROCESSES: a. FLOODS	b. EROSION	c. COMPACTION AND SETTLING	d. STABILITY (SLIDES, SLUMPS)	4. ATMOSPHERE: a. QUALITY (GASES, PARTICULATES)	b. CLIMATE (MICRO, MACRO)	B. BIOLOGICAL CONDITIONS	
A. MODIFICATION OF REGIME	a. BIOLOGICAL CONTROLS				3/5					7/6			7/5		
	b. MODIFICATION OF HABITAT														
	c. ALTERATION OF DRAINAGE	3/5								6/3			8/9		
	d. CANALIZATION														
	e. IRRIGATION	2/1					3/3			2/5			3/7		
	f. BURNING				5/2										
	g. SURFACE OR PAVING											6/2			
B. LAND TRANSFORMATION AND CONSTRUCTION	a. URBANIZATION														
	b. AIRPORTS						6/5					8/3	6/1		
	c. HIGHWAYS AND BRIDGES														
	d. RAILROADS		6/6		2/6					5/2			4/2		
	e. CABLES AND LIFTS														
	f. CANALS						2/7					3/5			
	g. OFFSHORE STRUCTURES														
	h. CUT AND FILL														
C. RESOURCE EXTRACTION	a. BLASTING AND DRILLING														
	b. SURFACE EXCAVATION	8/7			9/5		8/4			3/1					

FIGURE 2

Hypothetical Importance Ranking Matrix for a Proposed Impoundment Project, With Factors of Environmental Assessment Estimated as to Importance by Evaluators 1-N

	FACTORS OF ENVIRONMENTAL ASSESSMENT					
			CONSTRUCTION IMPACT			
EVALUATOR	TERRESTRIAL FACTORS	RECREATION	TEMPORARY	PERMANENT	WATER QUALITY	OTHER GROUPS →
1	1	4	1	3	3	
2	2	2	1	4	2	
3	3	3	1	5	4	
• • • N						
$\bar{R}_k$	2	3	1	4	3	

FIGURE 3

Evaluation of a Proposed Hypothetical Project's Impact on Environmental Factors, Utilizing a Modified Matrix Approach. Impact of Project Alternatives are Estimated for Each of the Factors of Environmental Assessment

FACTORS OF ENVIRONMENTAL ASSESSMENT

PROJECT	TERRESTRIAL FACTORS	RECREATION	CONSTRUCTION IMPACT TEMPORARY	CONSTRUCTION IMPACT PERMANENT	WATER QUALITY	OTHER GROUPS →
PROPOSED PROJECT	-3	4	-2	-3	-2	
ALTERNATIVE I	-3	3	-3	-3	-I	
ALTERNATIVE 2	-I	I	-2	-2	-I	
ALTERNATIVE N						

FIGURE 4

Decision Matrix for Objective Ranking Method of Environmental Assessment for Determining Best Alternatives for a Proposed Impoundment Project. Estimated Impact Values are Multiplied by the Average Importance Value for Each Factor, and the Factors Summed for each Project.

FACTORS OF ENVIRONMENTAL ASSESSMENT x $\overline{R}_k$

PROJECT	TERRESTRIAL FACTORS	RECREATION	CONSTRUCTION IMPACT TEMPORARY	CONSTRUCTION IMPACT PERMANENT	WATER QUALITY	TOTAL
PROPOSED PROJECT	-2x3 -6	4x3 12	-2x1 -2	-3x4 -12	-2x3 -6	-14
ALTERNATIVE 1	-3x2 -6	3x3 9	-3x1 -3	-3x4 -12	-1x3 -3	-15
ALTERNATIVE 2	-1x2 -2	1x3 3	-2x1 -2	-2x4 -8	-1x3 -3	-12
ALTERNATIVE N						

FIGURE 5

Major Factors to be Considered in Evaluating Environmental Impact Statements for Proposed Dam Projects

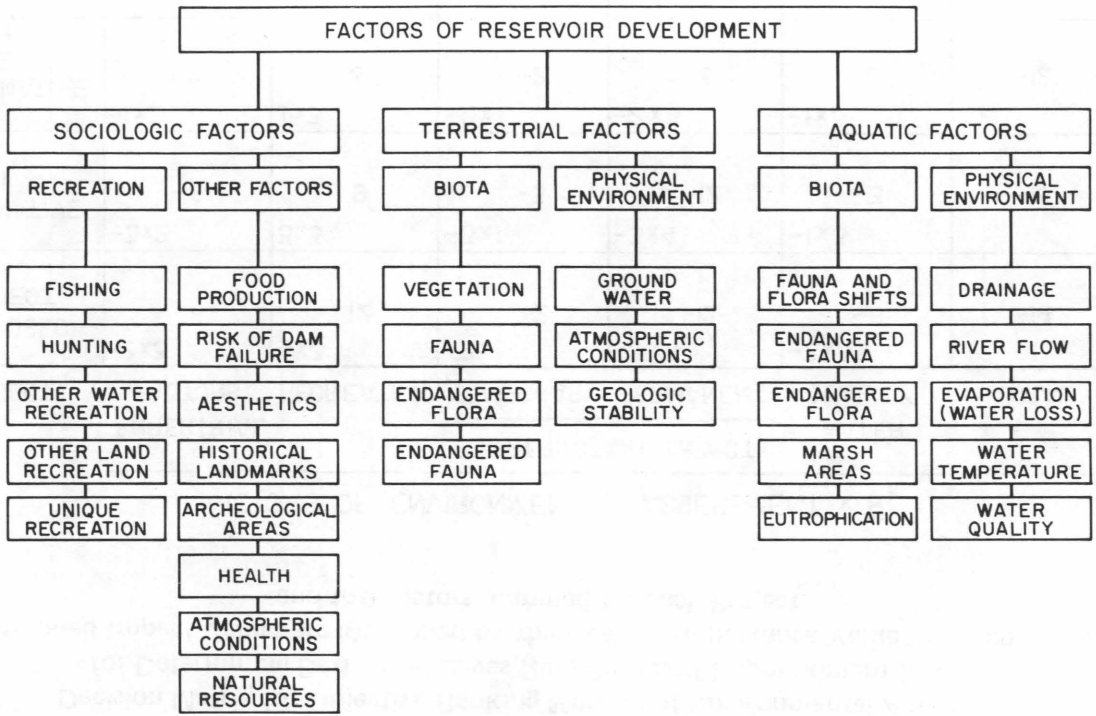


FIGURE 6

Major Activities of Reservoir Construction and Operation To Be Considered in Environmental Evaluation For Proposed Dam Projects

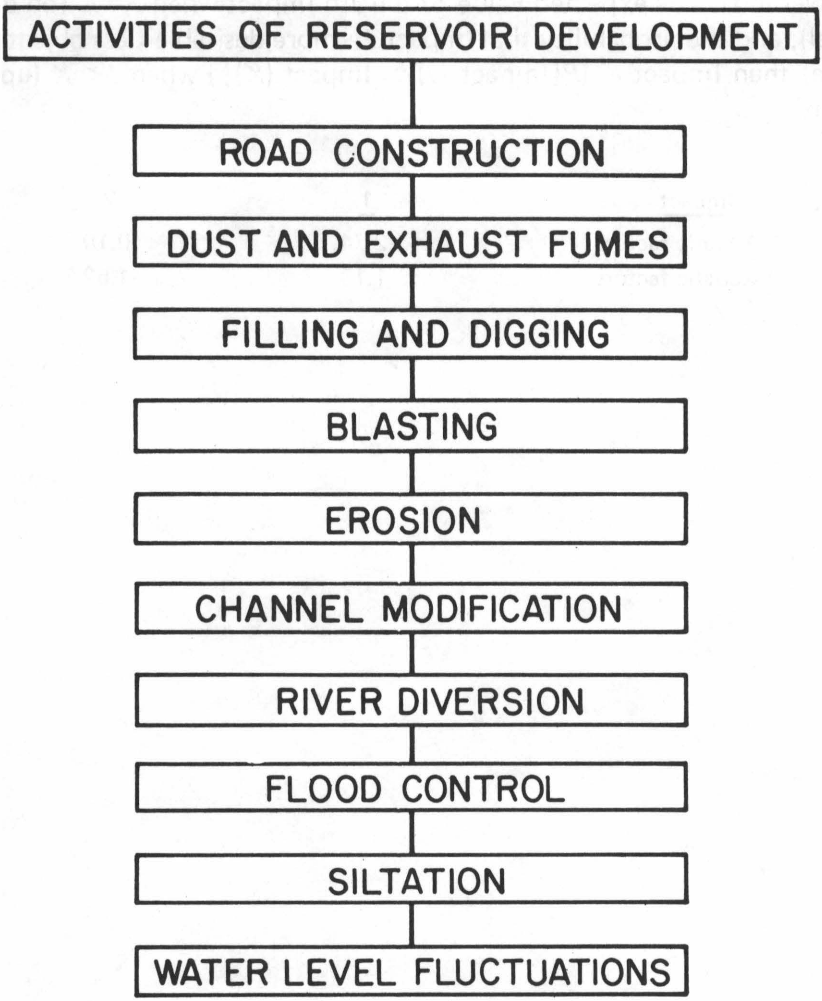


FIGURE 7

Sample Computer Output Comparing Project Alternatives Produced by Dam Evaluation System

Comparison of Impact distribution, group number, Impact numbers and titles are shown at left. The *(J,K)*th element of the table is the expected difference in Impacts *J* and *K* (*E* [Impact *(J)* – Impact *(K)*]) when *J* > *K* (lower left). The expected value of the *J*th Impact when *J* = *K* (on diagonal), and the probability that Impact *J* is more desirable (less objectionable) than Impact *K* (*P*[Impact *(J)* > Impact *(K)*]) when *J* < *K* (upper right).

Impact	1	2
1 Aquatic factors	-2.74	0.10
2 Aquatic factors	1.13	-1.62

FIGURE 8

Sample Graphic Output of Distribution for Dam Evaluation System. Project Factor = *X* Axis with Impact Probability = *Y* Axis.

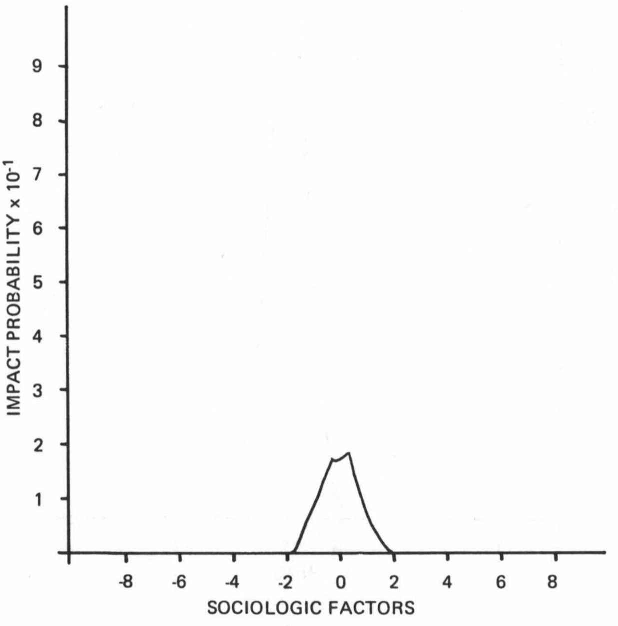
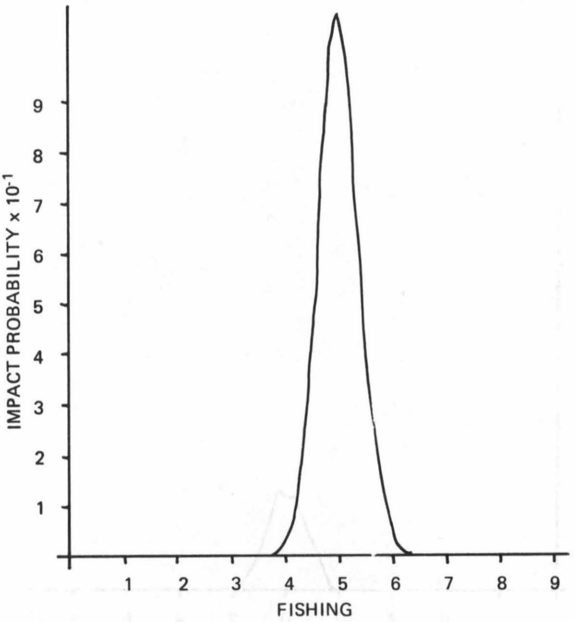


FIGURE 9
Graphic Analysis of Fishing and Hunting for Alternative One



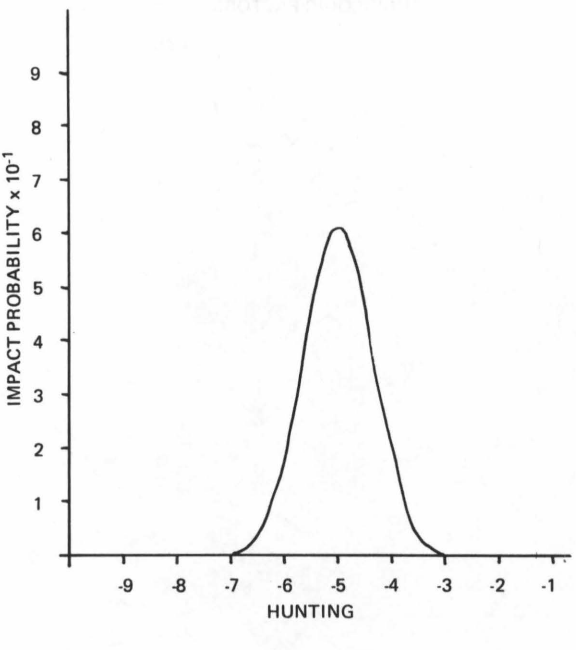
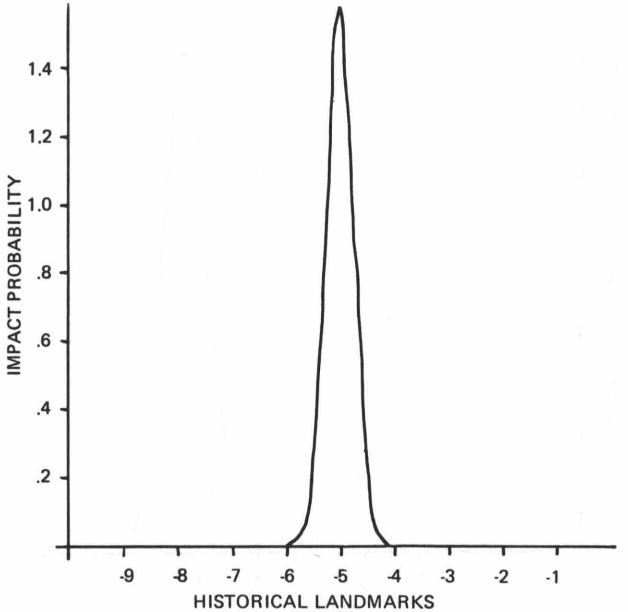


FIGURE 10

Graphic Analysis of Historical Landmarks and Sociologic Factors for Alternative One



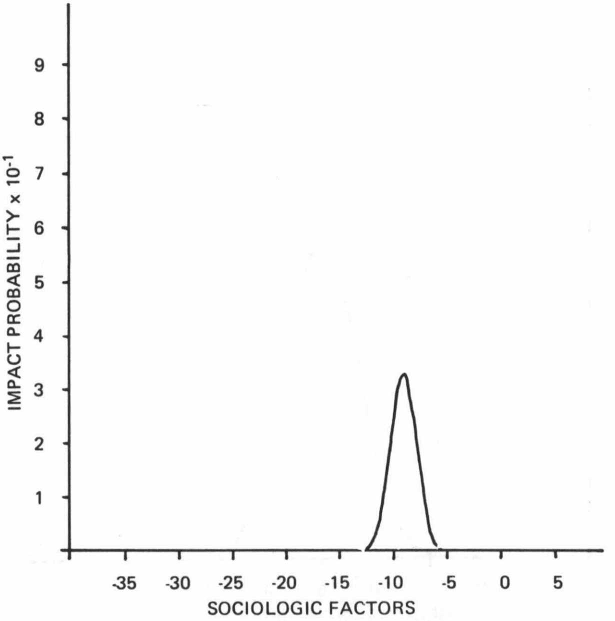
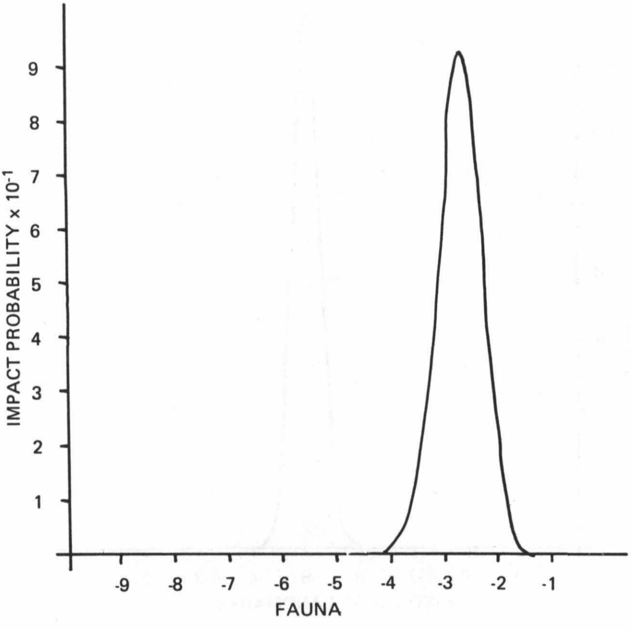


FIGURE 11

Graphic Analysis of Fauna and Geologic Stability for Alternative One



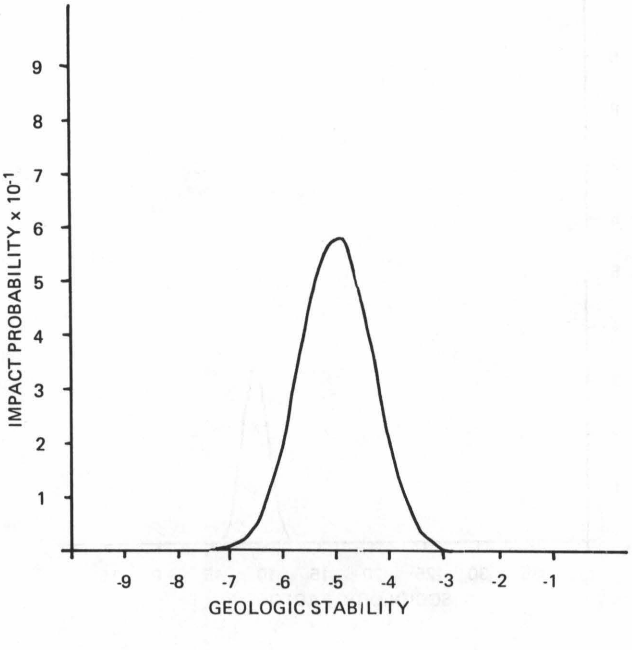
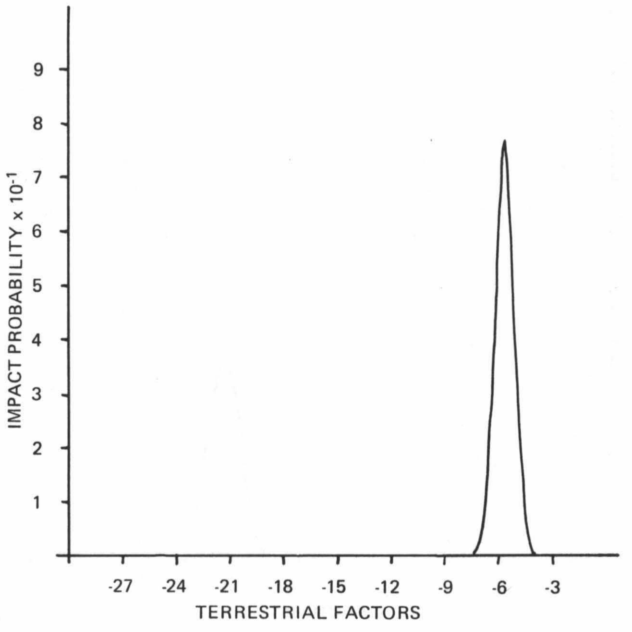


FIGURE 12
Graphic Analysis of Terrestrial Factors and Water Quality for Alternative One



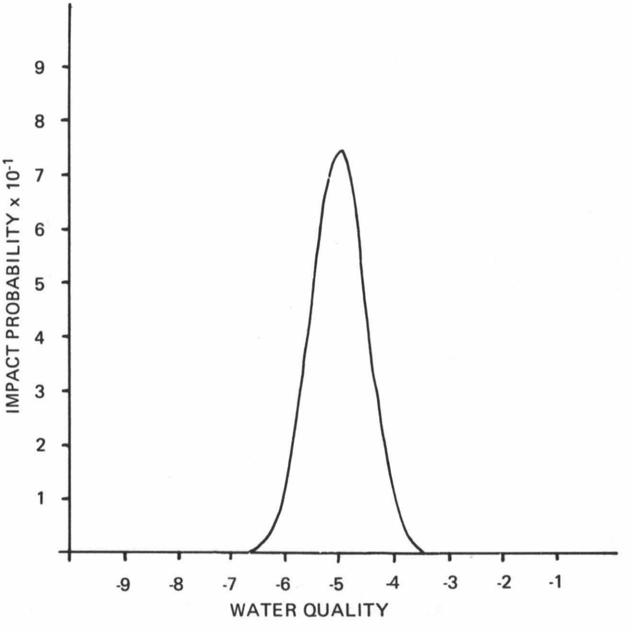
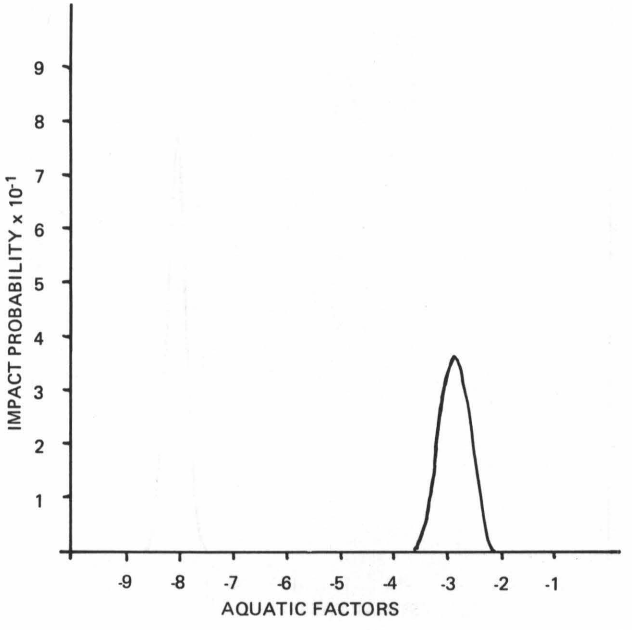


FIGURE 13
Graphic Analysis of Aquatic Factors and Total Project for Alternative One



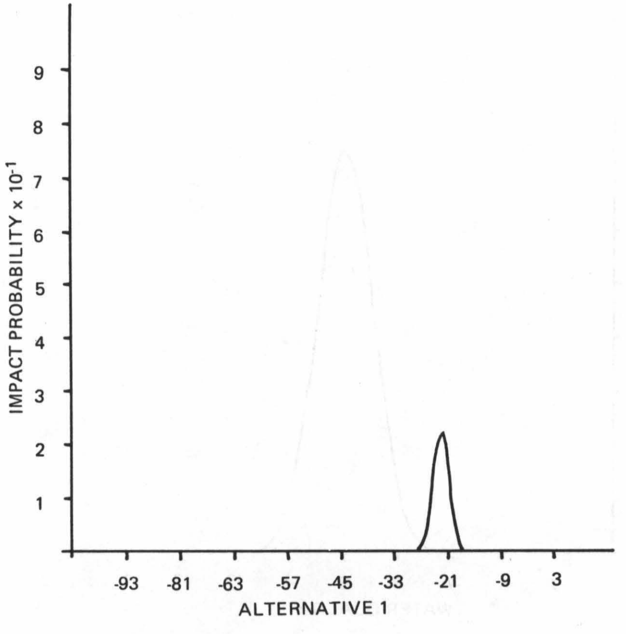


FIGURE 14
Graphic Analysis of Fishing and Hunting for Alternative Two

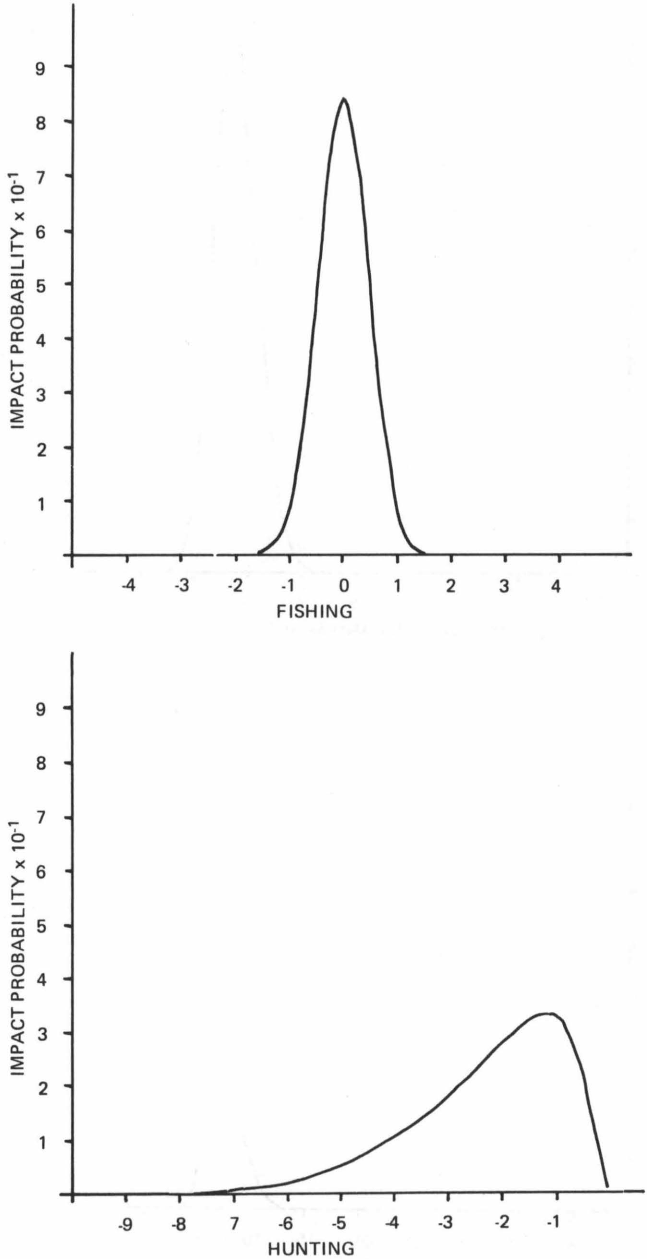


FIGURE 15
Graphic Analysis of Historical Landmarks and Sociologic Factors for Alternative Two

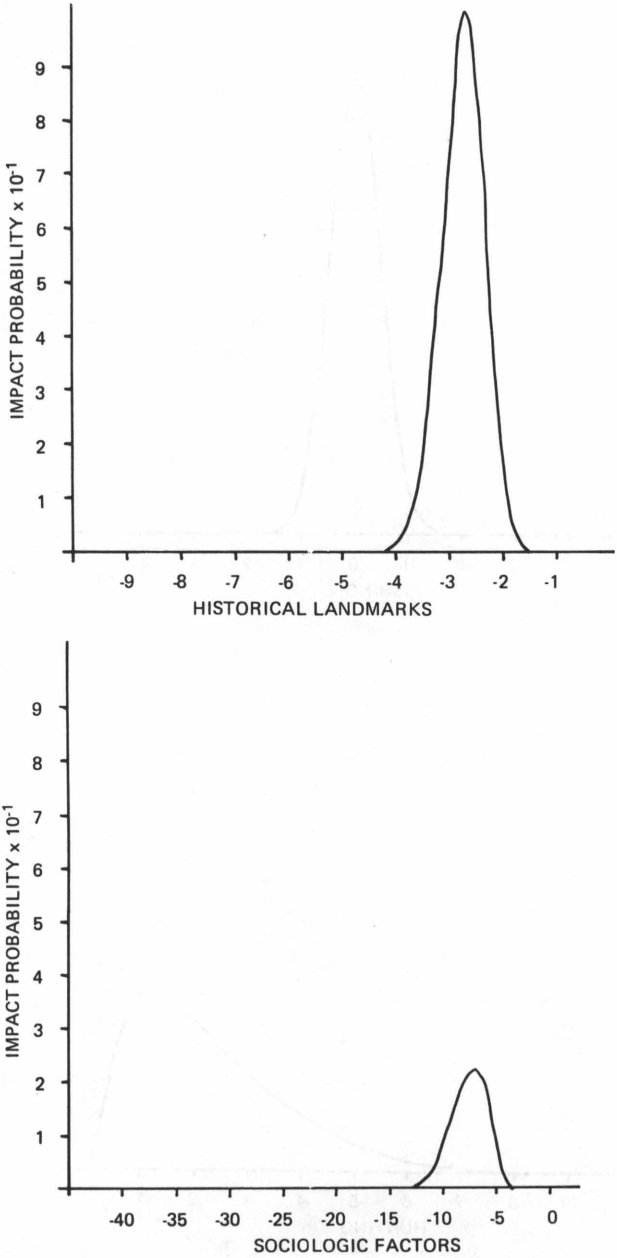
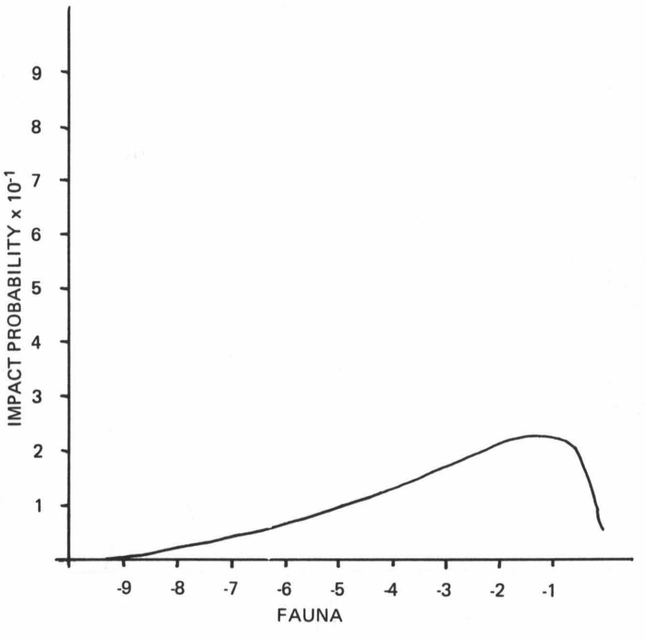


FIGURE 16
Graphic Analysis of Fauna and Geologic Stability for Alternative Two



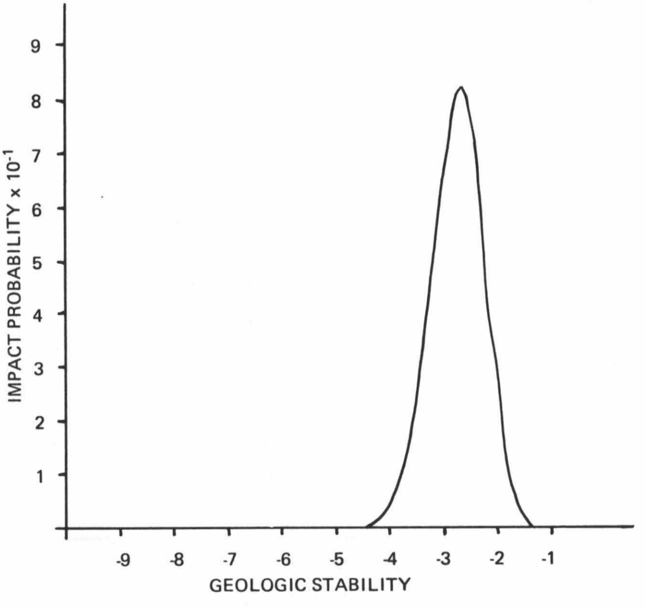


FIGURE 17
Graphic Analysis of Terrestrial Factors and Water Quality for Alternative Two

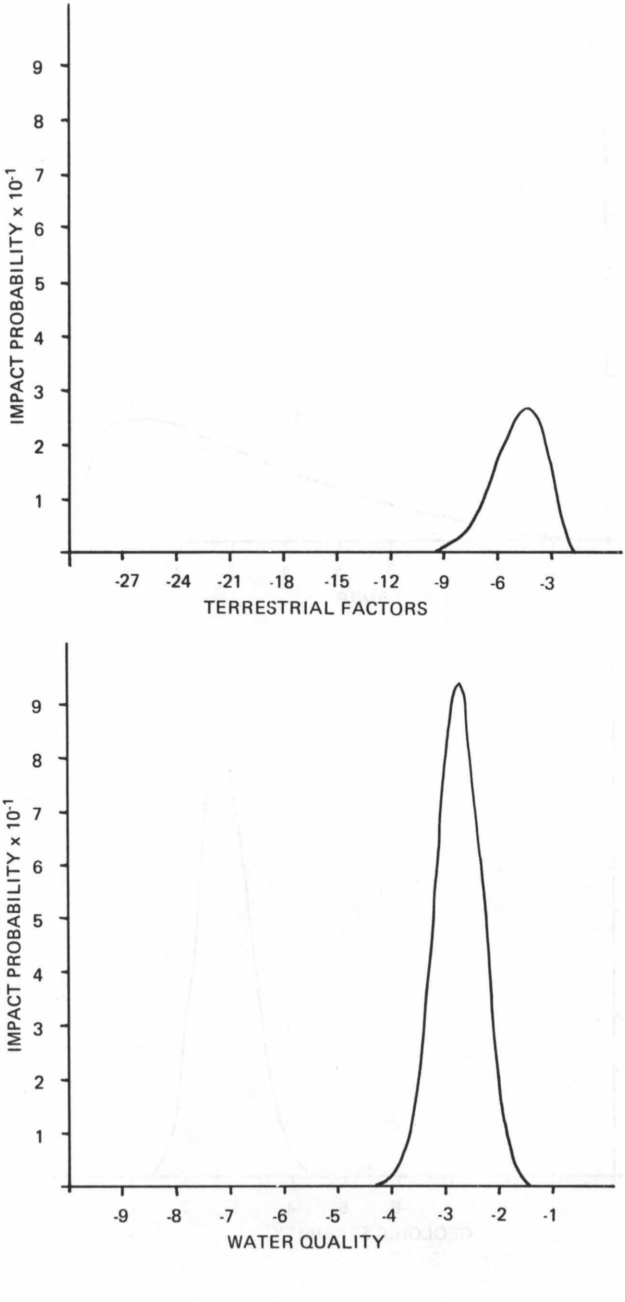


FIGURE 18
Graphic Analysis of Aquatic Factors and Total Project for Alternative Two

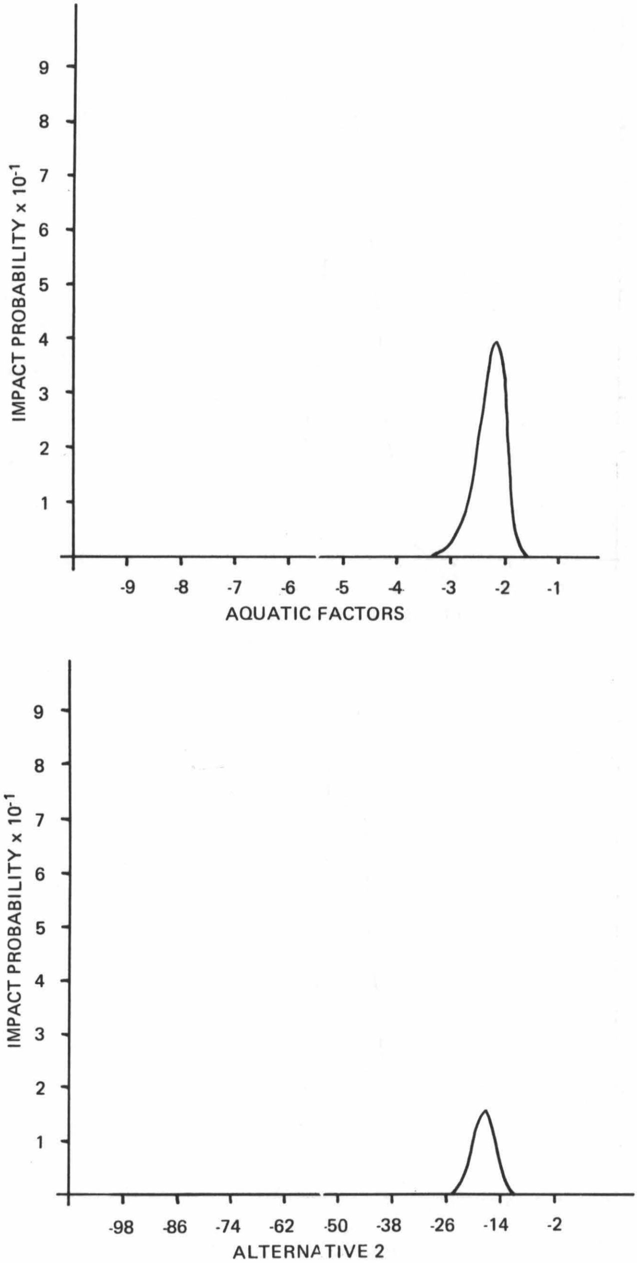
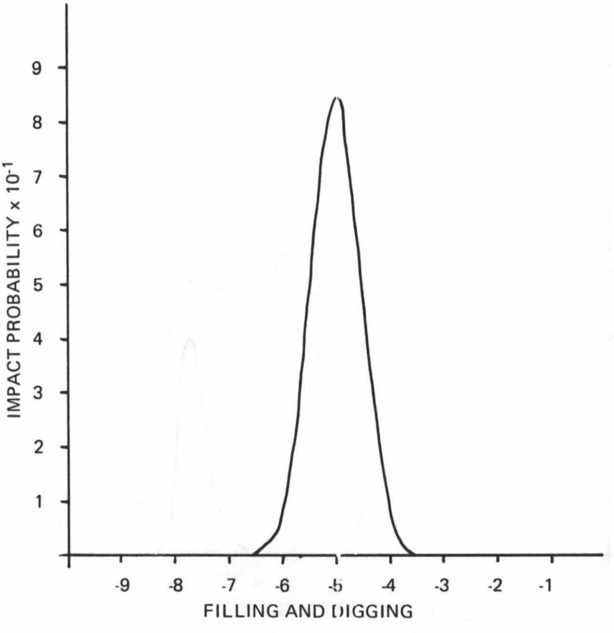


FIGURE 19
Graphic Analysis of Filling and Digging and Erosion for Alternative One



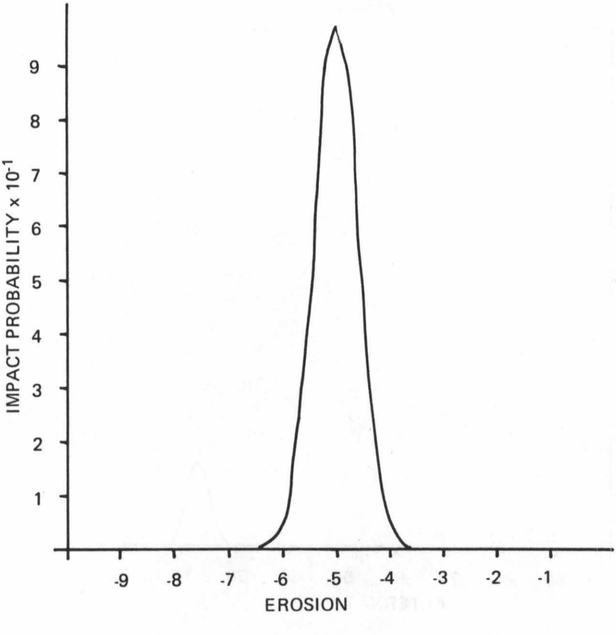
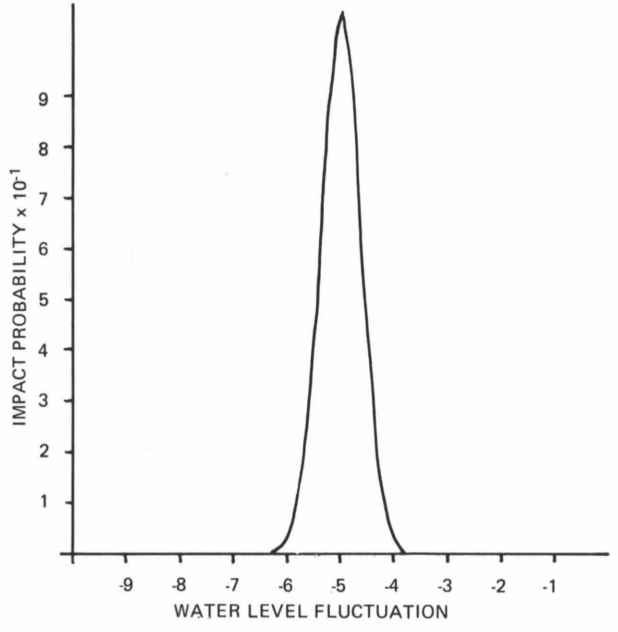


FIGURE 20
Graphic Analysis of Water Level Fluctuation and Channel Modification for Alternative One



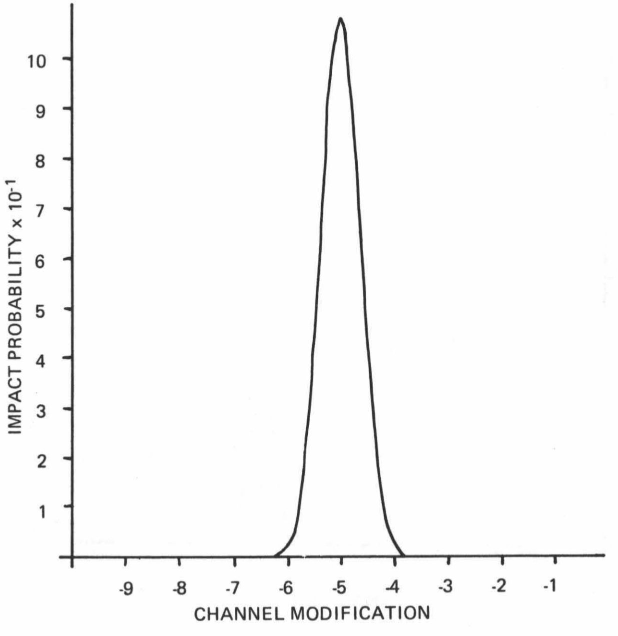


FIGURE 21
Graphic Analysis of Flood Control and Total Project Activities for Alternative One

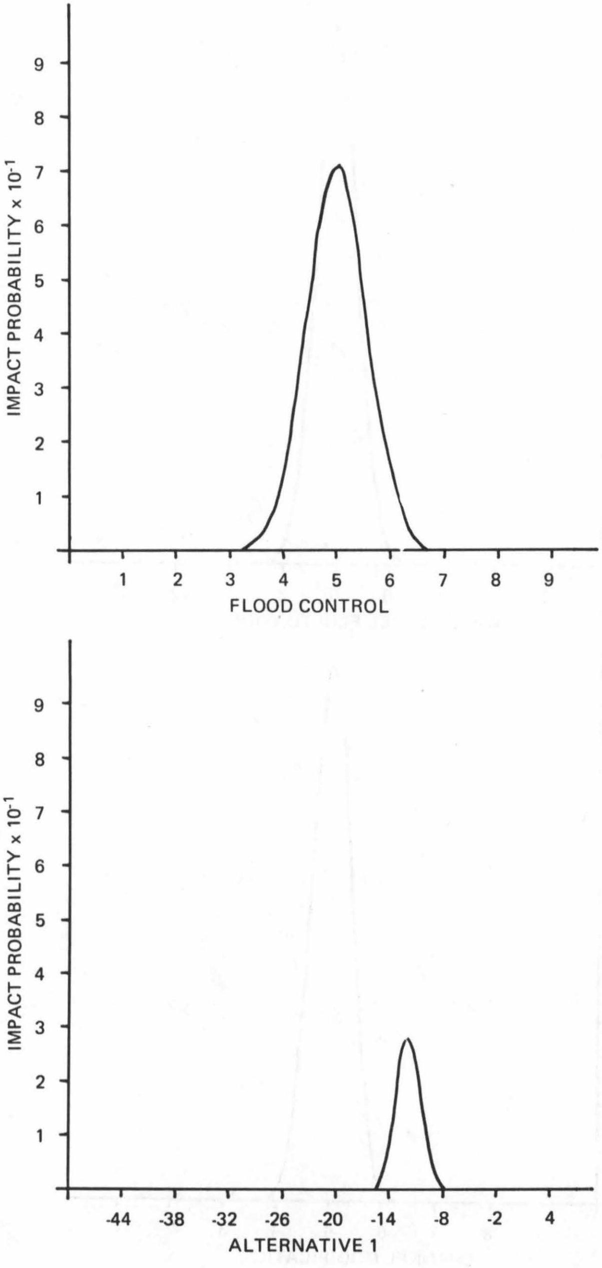
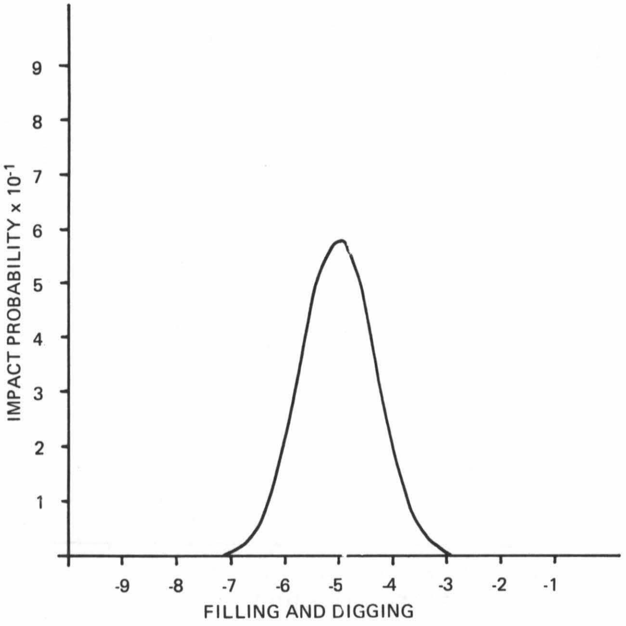


FIGURE 22
Graphic Analysis of Filling and Digging and Erosion for Alternative Two



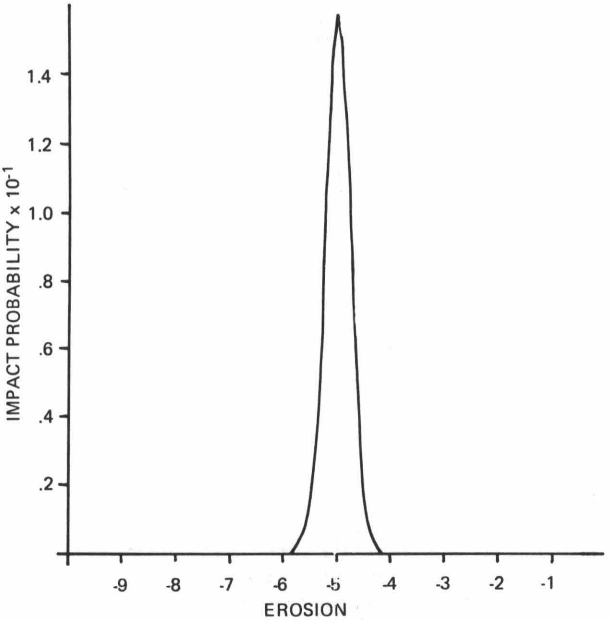
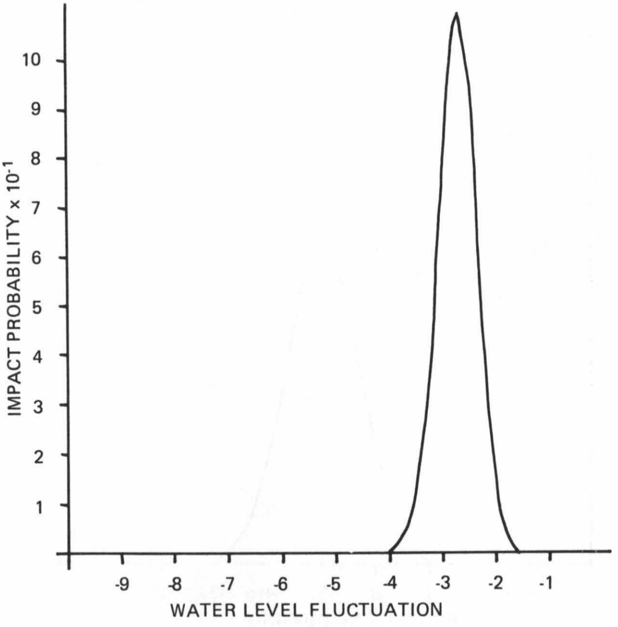


FIGURE 23
Graphic Analysis of Water Level Fluctuation and Channel Modification for Alternative Two



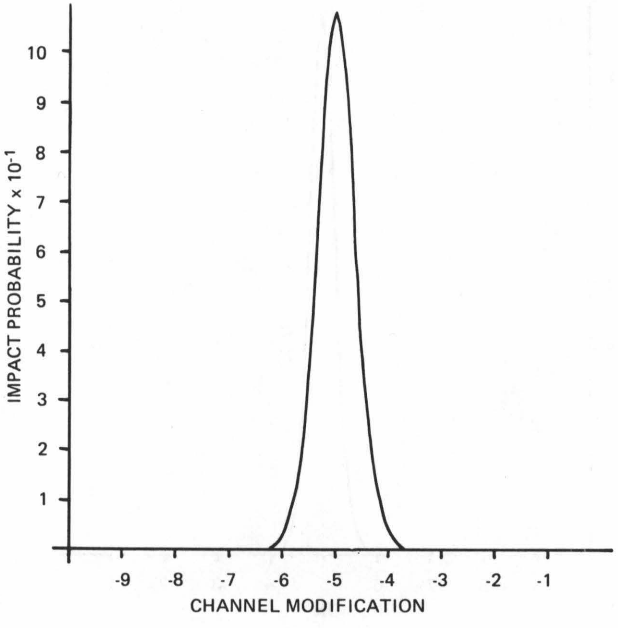
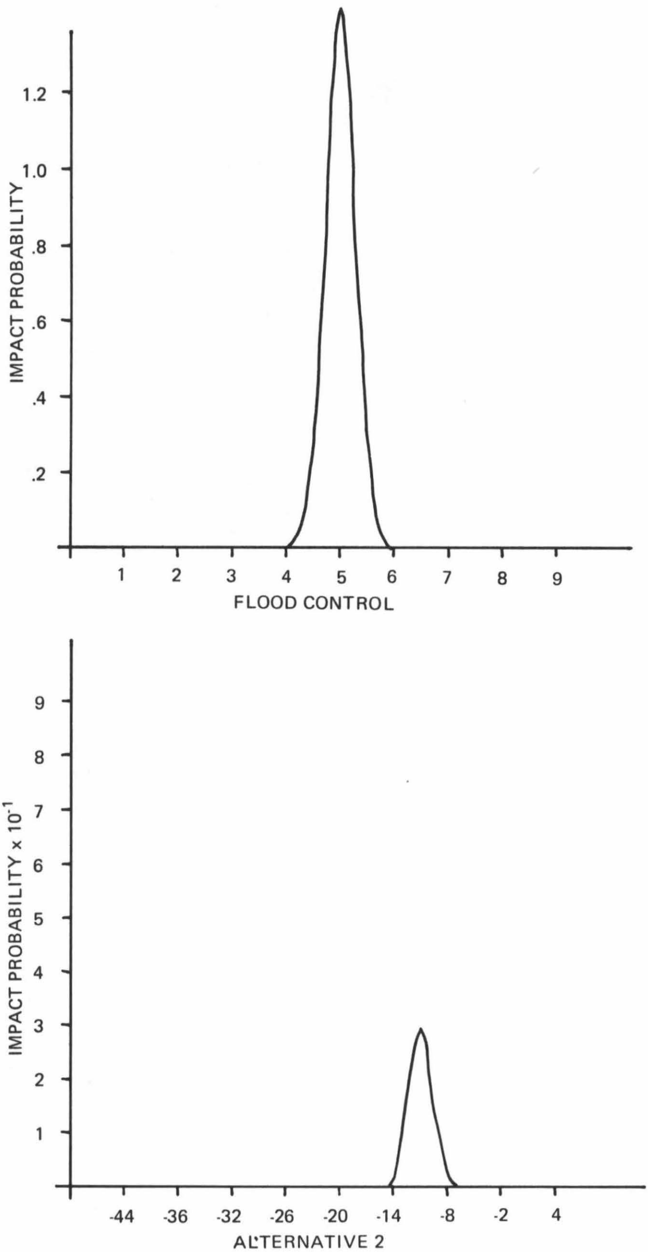


FIGURE 24
Graphic Analysis of Flood Control and Total Project Activities for Alternative Two



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