ASSESSING AND EVALUATING ENVIRONMENTAL IMPACTS AT PROPOSED NUCLEAR POWER PLANT SITES

Ralph L. Keeney
Gordon A. Robilliard*

February 1976

*Woodward-Clyde Consultants, Suite 700, Two Embarcadero Center, San Francisco, California, 94111.

ABSTRACT

The applicability of decision analysis for assessing, evaluating, and reporting possible environmental impacts of proposed large-scale projects is illustrated. A study concerning the ecological impacts of constructing and operating nuclear power facilities in the Pacific Northwest is used as an example. Possible impacts are quantified for two objectives: minimizing adverse impacts on salmonids and minimizing biological disturbance. The results provide information about both the direct and indirect consequences of the impact. This approach explicitly addresses the multiple objective and uncertainty issues inherent in environmental problems. It also provides a mechanism for illuminating conflicts among interested parties and promoting constructive compromise.

1. INTRODUCTION

The National Environmental Policy Act (NEPA) of 1969 [15] established, among other things, the requirement for an environmental impact statement (EIS) that would identify, describe, and evaluate the significance of the possible environmental consequences of projects requiring federal approval. Thus an EIS must be filed for most power generating facilities, dams, pipelines, and the like prior to beginning construction. The intent of NEPA is to describe and assess the environmental impact of the proposed project and its alternatives. Based on this assessment, the appropriate decision makers can evaluate the environmental impact to see whether it is acceptable or not. If it is not acceptable, then approval for the proposed project may not be given. The proposed project may be altered to have less detrimental impact and resubmitted for consideration, or it may simply be dropped.

NEPA provides few specific guidelines as to how one should prepare an EIS. It requires only that the EIS indicate the potential and expected environmental impacts due to the construction, operation, and existence of the facility. However, pursuant to Executive Order 11514 [4], guidelines for the preparation of detailed EIS's, including format and information content, have been prepared by the various federal agencies. The information required by these guidelines is often very explicit and extensive, especially for the sections on "Environmental Setting" and for <u>listing</u> the environmental impacts.

The decision of how to assess and evaluate the environmental impacts in the EIS and in what form to report these assessments and evaluations is left largely to the discretion of those filing the report. This lack of guidelines for reporting, together with the fact that the problem of assessing environmental impact is inherently difficult, has resulted in many EIS's falling short of providing the information for decision makers that NEPA intended. Many EIS's state only that an impact may occur, without giving any indication of the magnitude or significance of the possible direct or indirect consequences of the impact. The latter information should be important to the decision maker in deciding whether or not to approve a project.

In this paper, we illustrate an approach for assessing and reporting possible environmental impacts. Our vehicle is a siting study for a nuclear power facility that may be located in the Pacific Northwest of the United States. Specifically, we concentrate on the ecological component of the environmental impacts[2].

In Section 2, we discuss general characteristics of the problem of assessing, evaluating, and reporting environmental impact. Section 3 briefly describes decision analysis, the methodology used to quantify and assess the possible ecological impacts at each of the sites as a result of the proposed nuclear power facility. Sections 4 through 6 concern the case study. First, the ecological component is related to the overall decision to be examined in Section 4. Then we discuss the ecological impact on salmon in Section 5 and on other species of fauna and flora in Section 6. Conclusions are given in Section 7.

---

[2] In this paper, we define "environmental" in terms of the total environment, including economic, social, aesthetic, technological, and ecological characteristics. "Ecological" is loosely defined as the sum of natural biological characteristics (more or less exclusive of human influences) of the area being considered and is a subset of "environmental."

2. GENERAL CHARACTERISTICS OF ENVIRONMENTAL ISSUES

The assessment of the magnitude and significance of environmental impacts typically occurs at three stages, even if only informally, prior to the approval of major projects such as power plants. The first stage is the preliminary assessment during the process of selecting several desirable sites from a much larger number of potential sites or from previously determined candidate areas [9]. These preliminary assessments are then evaluated, and several, typically three to ten, candidate sites are selected.

In the second stage, a more detailed and comprehensive assessment of these candidate sites is required in order to evaluate the relative significance of the environmental impacts. On the basis of this evaluation plus similar assessments and evaluations for other economic, social, and technical characteristics, a prime site is selected for further study. In general, the analyses utilized in this second stage of assessment and evaluation comprise the methodology and discussion which should be presented in the "Alternatives" section of the EIS.

The third stage in the analysis is a very detailed assessment of the magnitude and significance of the impacts of the project at the prime site, based on the large volume of data collected by the applicant pursuant to the NEPA guidelines. This assessment should be evaluated as such by decision makers, using a formalized decision analysis approach to ascertain whether or not the proposed project has an acceptable or unacceptable level of impact.

There are many factors that account for the complexities of identifying and reporting environmental impact. Most of these can be categorized under three characteristics common to most environmental problems. These are: (1) multiple objectives; (2) uncertainties concerning the possible impacts; and (3) disagreements among the many interested parties, often with conflicting value structures, about the desirability (or undesirability) of any particular impact.

The multiple objective problem comes into play on at least two levels. First, essentially all those projects in our concern involve facilities thought to provide some public benefit (e.g., power, airport services, etc.). Thus one objective is to provide this service or consumer good to the highest degree possible and to do so in such a manner as to minimize costs, adverse health effects, and ecological impact. One is forced to make trade-offs affecting costs and material well-being, on the one hand, and environmental impact, on the other.

At another level, there are several objectives concerning the environment itself. One approach would be simply "to minimize adverse effects to air, water, and land." This implies that minimizing possible damage to biological species can be associated with one or more of these categories. An alternative approach might list the objective, "to mimimize harmful impact to the fauna." This might then be divided into several objectives concerning various identifiable species.

That there are major uncertainties concerning the possible ecological impacts should be clear. It is often difficult after the fact to identify exactly what impacts resulted from the construction and operation of a particular facility. Moreover, before the construction, it is unreasonable, especially given the long time periods involved, to expect to know precisely what the impacts will be. It is reasonable, though not at all easy, to articulate several possible impacts and their respective probabilities of occurring. To help in the articulation, there are various sources of information, including existing data, models relating the several ecological variables involved, experiments that can be performed, on-site visits, and professional judgment. All of these should be used where appropriate.

Many interested parties participate both formally and informally (for example, through lobbying) in the decision processes concerning approval of federally supported facilities. These several parties often have major disagreements concerning their value structures and priorities. That the "typical" environmentalist and the "typical" industrialist often disagree about value is clear. The industrialist may argue that to clear one square mile of virgin forest to make way for an isolated 1,000 MW(e) nuclear power plant is eminently reasonable, whereas the environmentalist would not sacrifice the state of the land for the power from five 1,000 MW(e) facilities.

Moreover, there often are major disagreements about different types of environmental impacts. A sportsman may be willing to accept more air pollution for more electrical power, but if the environmental impacts include the destruction of a prime hunting area, he may be very much opposed to the additional power generation. On the other hand, a city conservationist may be willing to destroy that hunting area, since he is against hunting anyway, to get the additional power, whereas he may not be willing to cut power use to reduce air pollution in the city. The point is that even if all concerned agreed on exactly what the magnitude of the environmental impact would be in each of the areas of concern, there would still be a large controversy about which of several options to pursue because of differences in value structures.

We should make one point clear: there is no such thing as a value-free analysis. This is true whether the analysis is aided by the formal use of models or simply conducted informally in one's head by balancing the pros and cons. If any decision is taken, a value structure is implied. The choice of which variables or which objectives to include in a model involves value judgments on the part of those building the model. Balancing the advantages against the disadvantages of each option also involves value judgments. One cannot simply ignore values; they are a part of the problem. Thus, when using any form of analysis, if one clearly articulates the value structure being used, others can better understand the reasoning being employed and appraise the implications.

Multiple objectives, uncertainties, and different value structures are important characteristics in most problems involving the environment.

They should be addressed in attempting to evaluate which of several alternatives is best and, hence, worthy of carrying forward to the licensing stage. They should also be addressed in EIS's explaining what the possible environmental impact may be, and assessing the magnitude of these impacts. Decision analysis, introduced in the next section, does address these three critical characteristics.

3. THE METHODOLOGY OF DECISION ANALYSIS

Decision analysis[3] provides a logical framework for addressing the two main problems raised in Section 2, namely (1) evaluating each alternative and making choices among these alternatives; and (2) assessing and reporting environmental impacts. For discussion purposes, it is convenient to categorize decision analysis into four steps:

(i) structuring the problem,

(ii) quantifying preferences for achieving the objectives to various degrees,

(iii) quantifying probabilities for achieving the objectives to various degrees, and

(iv) aggregating the above information to indicate the overall impact on each alternative and to make a choice among alternatives.

That the multiple objective, uncertainty, and value structure characteristics are indeed incorporated in decision analysis will become

---

[3] An easy-to-read introduction to decision analysis is Raiffa [10].

clear in Sections 4 through 6 when the case study is presented. But first, we wish to clarify the meaning of the four steps above.

Structuring the problem involves identifying a set of objectives, specifying attributes (i.e., measures of effectiveness) to indicate the degree to which each objective is achieved, and articulating the various alternatives.

It is important to quantify preferences in a manner convenient for further analysis. We want to know and communicate when one environmental impact is more detrimental than another and how much more so. Since uncertainties are involved in the problem, it would be particularly convenient if the average "intensity" of the possible impact could somehow be used as an overall indicator of possible impact. A sound, logical, and operational base for this is utility theory as developed by Von Neumann and Morgenstern [12]. The second step requires assessing utility functions over the multiple attributes in the problem and integrating these into one overall multiattribute utility function.

The third step involves quantifying the possible impacts of each alternative as measured in terms of the attributes. This often includes the integration of existing knowledge with experiments and on-site visits. Those who are in a position to do this best are experts in the area of concern. For instance, in assessing impact on the biota, a biologist would be best suited, whereas a meteorologist would be best able to predict impacts on air quality due to emission of pollutants at particular locations.

Once the first three steps of decision analysis are completed, the fourth one follows from computations. Given the utility function and the probabilities describing the possible impacts of each alternative, one can calculate the overall expected utility of each alternative. The alternative with the highest expected utility is the one that should then be chosen. By varying parameters in the utility function and in the probability distributions, it is conceptually easy to conduct sensitivity analyses at this stage. The result may help in selecting an alternative.

Using a single-attribute utility function and the probabilities describing the possible impacts on that attribute, a conditional expected utility can be calculated for that attribute for each alternative. These numbers indicate the relative magnitude of the impact of each alternative as captured by that attribute. Thus, for example, an indicator of the overall perceived ecological impact of each alternative is the conditional expected utility averaged over its ecological attributes.

4. A CASE STUDY

The Washington Public Power Supply System (WPPSS) is a joint operating agency of 21 publicly-owned utilities with a major responsibility to locate and oversee the construction of electrical power generating facilities. WPPSS, at the request of the Public Power Council, authorized Woodward-Clyde Consultants to conduct a study to identify and recommend potential new sites in the Pacific Northwest suitable for thermal (nuclear or fossil fuel) electric power generating stations having a nominal capcity of at least 3000 megawatts electrical [MW(e)]. It is intended that at least one of the recommended sites could be used by public utilities for additional thermal generating capacity that may be required after 1984, and that the remainder could be kept for future consideration if increased demand requires additional sites. The work described here is part of the Woodward-Clyde investigation.

The overall procedure for site selection is described elsewhere [9]. It involved a series of screening models' becoming more and more detailed to identify areas where suitable sites were most likely to be found. Considerations such as faults, availability of water, population centers, flood potential, and so on were used in these models. From site visits plus a knowledge of the designated areas, specific candidate sites were identified. These sites were then evaluated using decision analysis as outlined in Keeney and Nair [7]. There were nine alternative sites in this final evaluation.

The final model included several major objectives. These were: (1) maximize public health and safety; (2) minimize adverse socioeconomic effects; (3) maximize the quality of service; (4) minimize system cost; and (5) minimize adverse ecological effects. The overall evaluation of the sites is described in other reports [13]. Here we wish to concentrate on the manner in which the possible ecological effects were distinguished as to whether they pertained to "salmon" or "biologically important areas." These two were handled somewhat differently. Salmon impacts are discussed in Section 5 and impacts on other biologically important areas in Section 6.

5. THE POSSIBLE IMPACT ON SALMON

One of the two main ecological objectives was to minimize the adverse impacts on salmonids. Let us first define what we mean by the objective and then discuss its relevance to the problem.

Salmonids are defined as the five species of salmon (silver, chinook, chum, humpback, sockeye) and the steelhead trout which occur in Washington/ Oregon waters. These salmonids are all anadromous fish—that is, they spawn in gravel beds in fresh water streams and lakes, and the eggs incubate for several months. The fry emerge to spend some time (from a month to two years depending upon the species) in fresh water before heading downstream to the ocean as juveniles. They mature for two or more years in the ocean before returning to the fresh water to spawn, thus completing their life cycle.

Adverse impacts are defined as those which result in an immediate and/or long-term decrease in population size in the affected water bodies. The decrease could result from increased adult mortality during upstream migration, though this would probably not be a significant factor. Increased juvenile mortality during downstream migration as a result of being entrained in the power plant cooling system is probably the most significant source of mortality. Entrapment of juveniles or adults in the discharge plume, impingement at the intake structure, or sublethal effects on either adults or juveniles which result in lower reproductive success and destruction or alteration of spawning beds or juvenile maturation areas, etc., are also potentially significant adverse impacts.

Minimizing impacts involves several factors related to construction and operation of the power plant. The more important of these are: (1) control of sedimentation in streams, especially in spawning beds; (2) avoidance of physical disturbance of, and discharge of wastes or heat into, spawning beds; (3) reduction or elimination of physical or other barriers to upstream or downstream migration of juveniles or adults; (4) minimizing entrainment and impingement of fry and juvenile fish at the intake through design and construction of intake structure; (5) reduction or elimination of discharge of heat, chemical wastes, heavy metals, brine, and blowdown into water; and (6) minimizing temporal and spatial distribution and duration of any thermal plume. In other words, minimizing adverse impact means not disturbing the habitat of the fish.

Appropriateness of the Salmonid Objective. Salmonids, because of their commercial, recreational, and aesthetic value, are an extremely important economic resource to the people of the Pacific Northwest. The public, government agencies, environmental groups, commercial fishing interests, sports clubs, native Indians, and academia will all rise to the defense of the fish.

The egg, fry, and juvenile stages of salmon are generally considered more sensitive to environmental perturbations than are many other common or important aquatic species, and probably serve as a fair indicator of water quality and changes therein [1], [3]. Salmonids are generally widespread throughout the western states. Where there are no salmonids (as defined previously), there are dams or other impediments to their passage, suitable habitat is lacking, or the water is not accessible from the ocean [5].

If the impacts on salmonids are minimized, then most of the other aquatic resources such as trout, shad, sturgeon, plankton, and so on will experience at least a degree of protection. In addition, by minimizing the adverse impacts on the salmonids, the cost of replacing them through construction of hatcheries and related measures would be reduced.

<u>Measurement of the Salmonid Objective.</u> The major portion of actual mortality of salmonids will be the loss of juveniles and fry at the power plant itself. Unfortunately, it is difficult to estimate such losses, and relatively little historical information is readily available from the utility industry to use for comparative and interpretive purposes. It is desirable to identify a practical measure of adverse impact which has a historical record, is widely used and interpreted, and can be

applied in almost all situations. Two measurements seemed to satisfy these conditions: average annual number of spawning escapement lost and average annual percentage of spawning escapement lost. Spawning escapement is the number of adult fish that return to a particular stream to spawn. There are good historical records of the escapement of adult fish for most major salmon streams [2], [14].

Numbers alone are misleading. A loss of 10,000 fish in the Columbia River would represent 1 to 5 percent of the annual escapement, depending when and where the loss occurred. Such losses, although important, would probably not seriously disrupt the population dynamics of fish in any particular tributary river. On the other hand, a loss of 1,000 fish in the South Santiam River might represent 25-50 percent of the total escapement. Furthermore, there is considerable variation in escapement from year to year. In smaller streams, it is conceivable that the loss of 1,000 fish might represent the total population, especially in a low year, thus effectively eliminating the run in the ensuing cycle-year.

The point is that two important factors are influenced by salmonid losses. First, commercial, recreational, and aesthetic losses occur because of the number of fish lost. The second factor relates mainly to the percentage of fish lost in a given stream. The genetic history and composition of the salmonid population from each stream is somewhat distinct from that in other streams, and this cannot be replaced by restocking with fish from other streams or hatcheries. This latter factor is not considered significant in the Columbia River because most of the salmonids here are a collection of those from all the tributary streams; i.e., few salmonids spawn directly in the Columbia River, especially in the lower reaches. Also, salmon escapement in the Columbia River usually exceeds 300,000, whereas the next largest escapement is under 100,000.

For streams under 100,000 escapement, two measures (attributes) of adverse impact on salmonids are used:

X = percentage of adult salmonid escapement lost in a year,

Y = number of salmonids in the stream.

Attribute Y was chosen as number of fish in the stream rather than number of fish lost, because one implies the other when interpreted in conjunction with attribute X, and the preference assessments were easier using number of fish in the stream. For the Columbia River, the only attribute used was

Z = number of fish lost.

Obviously, the levels of attribute Z could always be calculated from levels of X and Y, but the reverse is not true. There is more information in knowing both X and Y.

5.1 Assessing Preferences for Salmonid Impact

Is it worse to lose 20 percent of the salmonids in a stream with 5,000 fish – that is, 1,000 fish – or 5 percent of the salmonids in a stream with 80,000 fish – that is, 4,000 fish? Such questions are not easy to answer, but those who are charged with assessing ecological impact in situations of this sort must make such decisions (explicitly or implicitly) if they intend to rank the degree of ecological disturbance to the salmon. The assessments below describe a formal manner of making these decisions. Comments on its usefulness are reserved for Section 7.

We want a measure of the magnitude of various impacts as described in terms of either attributes X and Y or attribute Z. It is necessary for the measure to be useful in situations involving uncertainty. The utility function is such a measure [10]. In what follows, we assess two utility functions, $u_1(x,y)$ and $u_2(z)$, where x, y, and z represent specific levels of X, Y, and Z respectively. These two utility functions are then consistently scaled. The requisite theory and details of several utility assessments are given in Keeney and Raiffa [8].

Assessing $u_1(x,y)$ and $u_2(z)$. First we wanted to specify the general structure of u_1. It was clear that if X, the percentage of escapement lost, was held fixed, then the greater the number of fish Y, the less desirable the (x,y) consequence. Also, with Y fixed, consequences became worse as X increased. These two conditions simply imply u_1 is decreasing in both x and y. It also seemed reasonable to assume X and Y were utility independent of each other. This meant, for instance, if Y were held fixed, the preferences among probability distributions of possible consequences in terms of X would not depend on the level where Y was fixed. As shown in Keeney [6], the utility independence assumptions imply that u_1 can be written as

$$u_1(x,y) = k_X u_X(x) + k_Y u_Y(y) + (1-k_X-k_Y) u_X(x) u_Y(y), \quad (1)$$

where $0 \leq x \leq 100$, $0 \leq y \leq 100$, and u_X and u_Y are single-attribute utility functions scaled from zero to one, X is measured in percentages, and Y in thousands of fish. Over the defined range, clearly (100,100) is the worst consequence; $(0,y)$ for all Y and $(x,0)$ for all X are all equivalently the best consequence. Hence we can scale (1) by

$$u_1(100,100) = 0 \quad (2)$$

and

$$u_1(0,y) = u_1(x,0) = 1. \quad (3)$$

Similarly, u_X and u_Y are scaled respectively by

$$u_X(100) = 0, \; u_X(0) = 1 \quad (4)$$

and

$$u_Y(100) = 0, \; u_Y(0) = 1. \quad (5)$$

Evaluating (1) at (0, 100), we find by substituting (3) and (4) into (1) that $k_X = 1$. Similarly, evaluating (1) at (100,0) and using (3) and (5), we conclude $k_Y = 1$. Thus

$$u_1(x,y) = u_X(x) + u_Y(y) - u_X(x) u_Y(y). \quad (6)$$

Techniques to assess single-attribute utility functions are fairly straightforward [11]. To illustrate, consider attribute X. We determined that an 80 percent loss for sure would be indifferent to a fifty-fifty chance of a 100 percent loss or a 0 percent loss. Thus, the utility $u_X(80)$ for $x = 80$ must be

$$u_X(80) = 0.5\ u_X(100) + 0.5\ u_X(0) = 0.5. \tag{7}$$

Also, 55 percent was indifferent to a fifty-fifty chance at 80 or 0, and 92 percent was indifferent to a fifty-fifty chance at 80 or 100. Thus

$$u_X(55) = 0.5\ u_X(0) + 0.5\ u_X(80) = 0.75 \tag{8}$$

and

$$u_X(92) = 0.5\ u_X(80) + 0.5\ u_X(100) = 0.25. \tag{9}$$

From (4), (7), (8), and (9), we have five points of u_X. These are plotted in Figure 1 and a curve fitted through them to give us u_X.

The utility functions for Y and Z were assessed in the same manner as u_X. They are illustrated in Figures 2 and 3 respectively.

<u>Scaling u_1 and u_2.</u> Next we needed to consistently scale u_1 and u_2. This required the empirical assessment of two pairs of consequences — one (x,y) and one z in each pair — felt to be indifferent and then scaling accordingly. Clearly $(x = 0,\ y = 0)$ is equivalent to $z = 0$. Thus, because utility functions are unique up to positive linear transformations, we want to find an a and b such that

$$u_1(0,0) = a + bu_2(0). \tag{10}$$

Also, (x = 50, y = 50) was assessed to be indifferent to z = 50. Hence,

$$u_1(50,50) = a + bu_2(50). \tag{11}$$

Using (6) and $u_2(z)$ from Figure 3, we solved (10) and (11) to give a = 0.568, b = 0.432. To measure the salmonid impact, one uses $u_1(x,y)$ if the spawning escapement is less than 100,000 fish, and $a + bu_2(z)$ if the escapement is more than 300,000 fish.

5.2 Assessing Probabilities for Salmonid Impact

Even though the water intake structure for the power plant is designed to minimize the entrainment and impingement of aquatic organisms, the main hazard to salmonids will probably be impingement and/or entrainment. However, there could also be loss of adult and juvenile salmon due to construction and operation of the intake and due to the thermal plume. Construction on the Columbia River will cause essentially no disturbance to spawning and rearing areas, since few exist. But on other, smaller rivers, spawning and rearing areas immediately downstream from the site will likely be eliminated. Adult fish may be blocked from reaching upstream spawning areas by construction activities or by the thermal plume. The possible impacts could be qualitatively described as follows. There is a small chance of very little loss of salmon; this chance increases up to a most likely level of between 1 and 15 percent loss, depending on the size and salmon-spawning potential of the river, and then decreases. There is a very small likelihood of a large — greater than 50 percent, or 100,000, fish — loss. Hence, the probability distribution is skewed, as illustrated in Figure 4. One could assess beta probability distributions to describe such impacts, but, after checking, it appeared that a normal distribution could adequately approximate the likely impacts. We used the normal distribution for convenience. The assessed parameters of the distributions are given for the nine prime sites in Table I.

Impacts were assessed by considering the total river flow, the annual average spawning escapement, the distribution of fish in the cross section of the stream (i.e., juvenile fish are often concentrated on the edges rather than in the middle), the likelihood of disturbing spawning grounds, and other related factors.

5.3 Evaluating Salmonid Impact

Using the probability distributions from Table I and the utility function $a + bu_2(z)$ to evaluate the Columbia River sites and $u_1(x,y)$ from (6) to evaluate the other sites, we calculated the expected utilities in Table I as an indicator of the salmonid impact at each of the nine sites. Higher utilities are preferred, so the least detrimental impact is at Linn 1 site (utility = 0.9988). The next best site (from the viewpoint of salmonid impact) is Clatsop 1 (utility = 0.9980), and so on. The expected utilities also have a cardinal interpretation. Loosely speaking, the impacts at either Linn 1 or Grays Harbor 1 are more similar in overall effect than those at Benton 1 and Umatilla 1. Less loosely, if one had a choice between the expected impact at Umatilla 1 for sure and a fifty-fifty chance of the impact at either Linn 1 or Lewis 1, he should prefer to take the chance, since the expected utility in the latter case — 0.5(0.9988) + 0.5(0.9895) = 0.9941 — is greater than the expected utility of 0.9913 at Umatilla 1.

6. THE POSSIBLE IMPACT ON BIOLOGICALLY IMPORTANT AREAS

During the construction and operation of the power plant, it is important to minimize the biological disturbance. Many features are included under this heading. For the sites under consideration, the main biological concerns are preservation of threatened and endangered species; protection of habitat of migratory species (especially waterfowl and game birds); maintenance of productive wetlands; and preservation of virgin or mature second-growth stands of timber or "undisturbed" sagebrush communities.

There did not seem to be any convenient measures to indicate the degree to which a power plant would cause biological disturbance as defined above. One possibility was to estimate the land area involved in each of the categories mentioned, but we felt it was too difficult to relate areas per se to impact. As an alternative, we chose to establish a subjective index of potential short-term and long-term impacts. This scale, illustrated in Table II, was defined after site visits by the client and the project team members, including two biologists. The scale goes from 0 to 8; larger numbers are associated with greater biological impact. The scale is defined to include the important features which distinguish the sites, as well as to illustrate and communicate in realistic terms the degree of biological impact.

6.1 Assessing Preferences for Biological Impact

The utilities for the nine points on the impact scale were directly assessed. First we arbitrarily set

$$u(0) = 1 \text{ and } u(8) = 0 \tag{12}$$

to establish the origin and unit for the utility scale. The task was to assess $u(x)$ for $x = 1, 2, 3, \ldots, 7$ relative to $u(0)$ and $u(8)$.

We asked for a probability p such that the consequences of impact level 4 were indifferent to a p chance at impact level 0 and a $(1-p)$ chance at impact level 8. The indifference probability was $p = 0.6$, implying

$$u(4) = 0.6\, u(0) + 0.4u(8) = 0.6. \tag{13}$$

Next, impact level 6 was found to be indifferent to a 0.25 chance at level 0 and a 0.75 chance at level 8, and impact level 2 was found indifferent to a 0.65 chance at level 0 and a 0.35 chance at level 8. Respectively, these imply

$$u(6) = 0.25u(0) + 0.75u(8) = 0.25 \tag{14}$$

and

$$u(2) = 0.65u(0) + 0.35u(8) = 0.65. \tag{15}$$

It is particularly important here to include consistency checks. In one such check, we found level 4 indifferent to a 0.6 chance at level 2 and a 0.4 chance at level 6, implying

$$u(4) = 0.6u(2) + 0.4u(6) = 0.49. \qquad (16)$$

This result did not match (13) very well. By reexamining the responses leading to (13) through (16) and their implications, it should be possible to identify the source of the discrepancies and make adjustments to generate consistent preferences. This is, in fact, one major purpose of the entire procedure: to force an internal consistency on the assessments and, hopefully, to improve the quality of the information transferred. After reconsideration of all the implications, the indifference probabilities leading to (13)-(16) were changed to 0.55, 0.25, 0.75, and 0.6, respectively. These assessments are consistent and imply

$$u(2) = 0.75,\ u(4) = 0.55,\ \text{and}\ u(6) = 0.25. \qquad (17)$$

Using the same procedures with several consistency checks, the utilities exhibited in Figure 5 were finally chosen.

6.2 Assessing Probabilities for Biological Impact

The likely biological impact at each site was assessed directly by a biologist after making site visits and reviewing available publications concerning biological activity in the vicinity of the sites. For each site, the probability that an impact fell in the range of 0 to 1, 1 to 2, . . ., 7 to 8 was asked. Several internal consistency checks were used in this activity also. For instance, refer to the

Lewis 2 and Lewis 3 data in Table III. One can ask: is the likelihood of a 2-3 impact twice as great at the former site as at the latter? The data in Table III represent the final adjusted numbers. The data are meant to quantify and thus complement brief qualitative descriptions such as the two which follow:

Benton 1 This area is used mostly for wheat farming and some grazing. There is relatively little undisturbed sagebrush habitat, and there are no wetlands or known endangered species habitat. The proportion of agricultural area to undisturbed habitat will vary depending upon exactly where the site is located; hence, the distribution is from 0-3.

Clatsop 1 The site region is made up of varying proportions of mature second-growth forest, logged areas, and some small agricultural areas. There are some small swampy areas and nearby wetlands. There is a strong possibility that Columbia white-tailed deer, an endangered species, may occupy the site or nearby environs. The distribution ranges from 3-6.

6.3 Evaluating Biological Impact

The overall biological impact is indicated by the expected utility calculated for each site. To do this, we assumed that the utility of the impact range from 2-3 at the Benton 1 site, for instance, was the average of the utilities of impact levels 2 (i.e., $u(2) = 0.75$) and 3 (i.e., $u(3) = 0.67$), or 0.71 in this case. Then for each site, we multiplied the probability of being in a range times the utility for that range and summed over the possible ranges. For Benton 1, the expected utility is

$$0.1(0.95) + 0.5(0.825) + 0.4(0.71) = 0.7915.$$

The expected utilities for each site are given in Table III.

7. CONCLUSIONS

The application described above was only a part of the larger study briefly outlined in Section 4. One of the important components of that problem was ecological impact. Treating the impacts as described in Sections 5 and 6 aided the project team in balancing ecological impact against other factors. It also was important in describing and communicating what the ecological impact might be.

There are two caveats which are relevant. We were working within rather tight time constraints, and the overall approach was new in the problem setting which faced us. In assessing the utilities, we relied on the knowledgeable judgment of two biologists, each of whom had significant experience in the field. To have the time and opportunity to improve the preference model based on other experts' judgments would be worthwhile. The estimates of the probabilities of various impacts could also likely be improved with more time to gather data and construct a formal probabilistic model. In this case, the information at hand does seem sufficient to select two or three prime sites. Then it may prove to be worth the effort to conduct more detailed environmental studies of these sites. We feel the methodology described is appropriate for the task.

Decision analysis does address several important issues inherent in ecological and other environmental problems: multiple objectives, uncertainty, and conflicting value structures. The manner in which it addresses the first two issues is illustrated in this paper. By conducting similar analyses for interested individuals and groups, it is possible to address the third issue. The various value structures (utility functions) and professional judgments (probabilities) and their implications can be examined to illuminate the conflicts, focus the discussion, generate creative alternatives, and promote constructive compromises.

In conclusion, let us quote one of the biologists who worked on the WPPSS project:

> Most EIS's only list the "adverse or beneficial" impacts which may occur without giving much indication of the realistic magnitude or ecological significance of the possible direct or indirect consequences of the impact. Using decision analysis to assess and evaluate ecological impact forces the project team, particularly the project biologists, to more or less rigorously define the characteristics of the environment and define a magnitude scale of impacts (even if subjective). To answer the specific questions that need to be

asked in the decision analysis process, the project team must focus their thinking on specific problems and information needs.

It was my experience from the WPPSS project that, in trying to determine the measures of effectiveness, etc., and to obtain data for them, I discovered where many of the major data gaps or inadequacies are. In designing field monitoring or baseline programs at the sites, I would now recommend that the first priority be given to filling these gaps. However, had we not used the decision analysis approach, I would not have been aware of those gaps as early in the environmental impact analysis process and would probably have suggested that the client do a full-scale baseline/monitoring program. Ultimately it boils down to the oft-repeated, but seemingly little-used, principle of scientific investigation: formulate a specific testable hypothesis to answer a specific question. Unfortunately, much environmental impact work instead takes a Baconian approach and attempts to obtain all the data on everything and hope that the answer falls out somewhere.

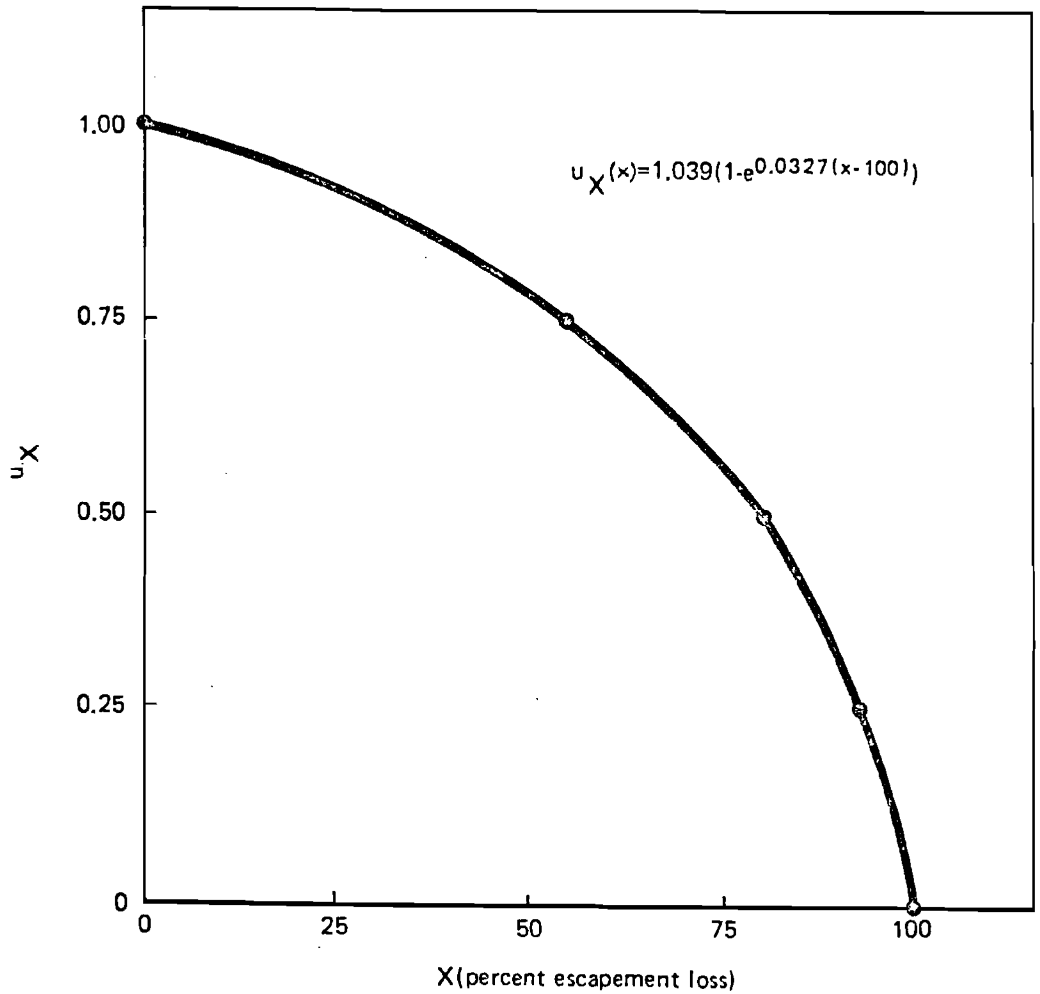

Figure 1. Utility function for escapement loss.

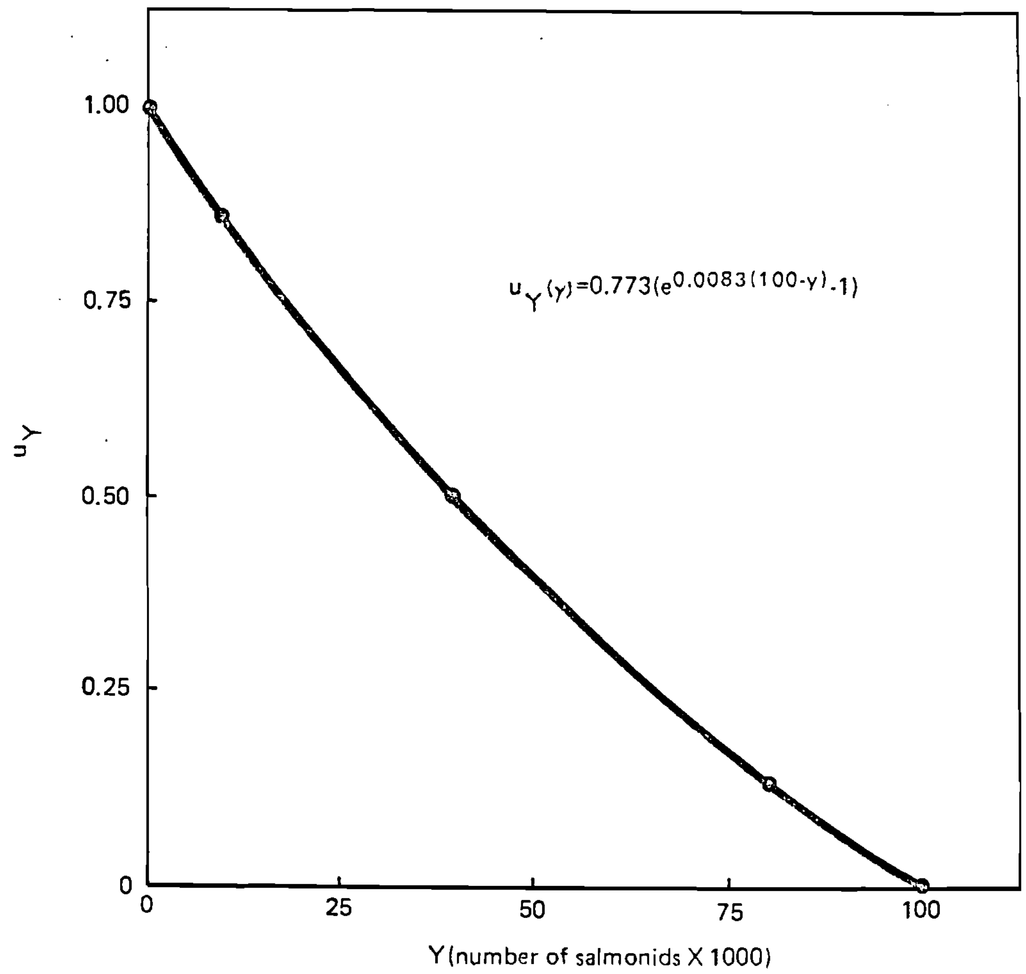

Figure 2. Utility function for number of salmonids in stream.

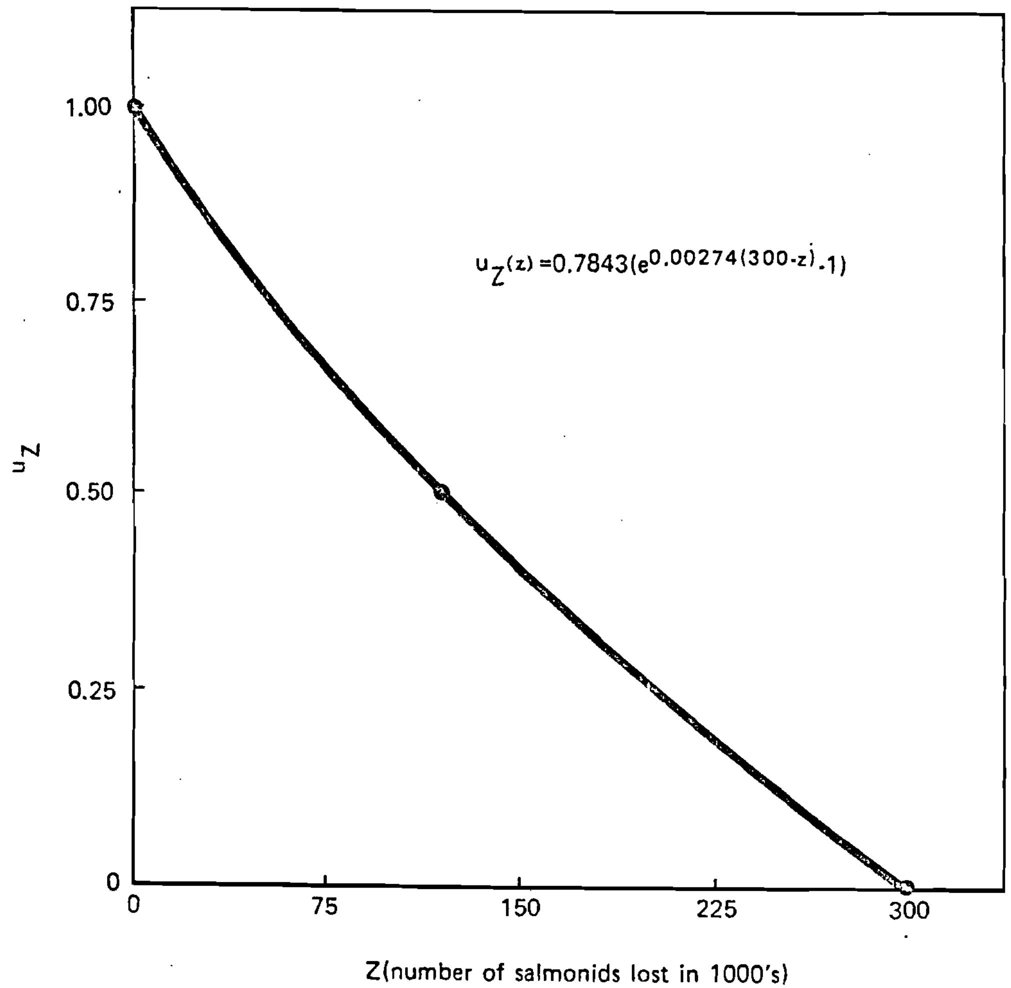

Figure 3 . Utility function for number of salmonids lost.

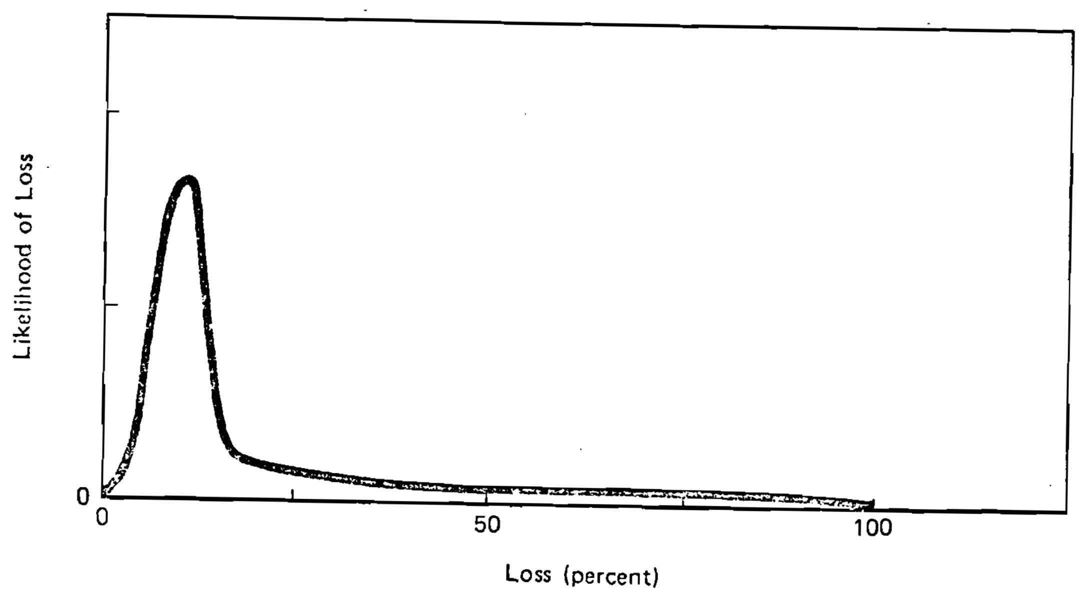

Figure 4. Probability distribution of possible salmonid escapement loss.

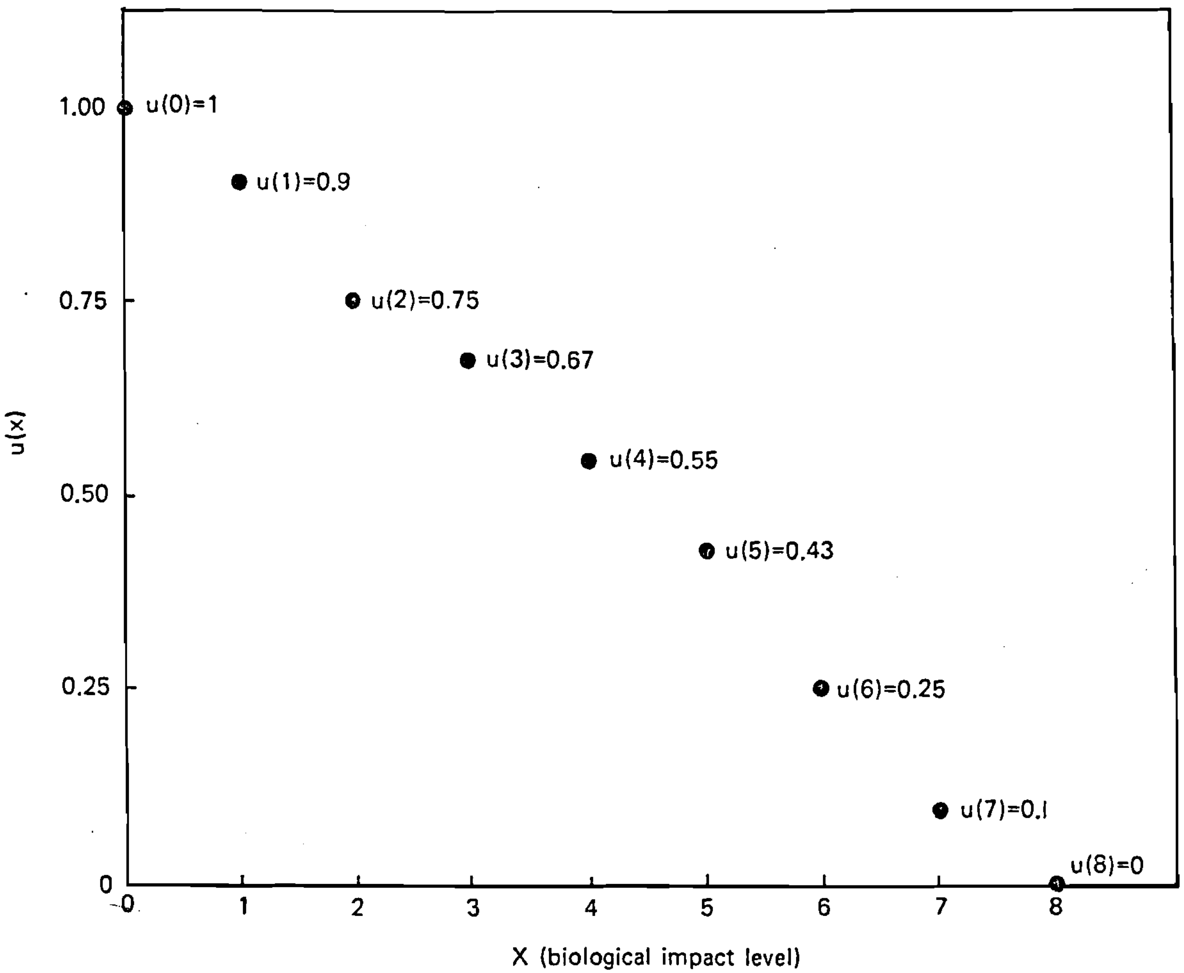

Figure 5. Utilities for level of impact on biologically important areas.

TABLE I. Salmonid Impacts

Site	River Affected	Y (annual average escapement)	Mean Impact	Standard Deviation of Impact	Overall Impact (expected utility)
Benton 1	Columbia R.	430,000	z = 4,300	σ_z = 2,000	0.9913
Umatilla 1	Columbia R.	365,000	z = 3,650	σ_z = 2,000	0.9926
Clatstop 1	Blind Slough on Columbia R.	5,000	x = 15%	σ_x = 7.5	0.9980
Grays Harbor 1	Wynoochee R.	5,500	x = 15%	σ_x = 7.5	0.9978
Wahkiakum 1	Elochoman R.	17,000	x = 15%	σ_x = 7.5	0.9936
Lewis 1	Cowlitz R.	55,000	x = 8%	σ_x = 4	0.9895
Lewis 2	Cowlitz R.	55,000	x = 8%	σ_x = 4	0.9895
Lewis 3	Cowlitz R.	55,000	x = 8%	σ_x = 4	0.9895
Linn 1	North Santiam R.	3,000	x = 15%	σ_x = 7.5	0.9988

TABLE II. Scale to Measure Biological Impact

0. Loss of 1.0 mi^2 of entirely agricultural or urban "habitat" with no loss of any "native" communities.

1. Loss of 1.0 mi^2 of primarily (75 percent) agricultural habitat with loss of 25 percent of second-growth; no measurable loss of wetlands or endangered species habitat.

2. Loss of 1.0 mi^2 of farmed (50 percent) and disturbed (i.e., logged or new second-growth) (50 percent) habitat; no measurable loss of wetlands or endangered species habitat.

3. Loss of 1.0 mi^2 of recently disturbed (logged, plowed) habitat with disturbance to surrounding (within 1.0 mi of site border) previously disturbed habitat; 15 percent loss of wetlands and/or endangered species habitat.

4. Loss of 1.0 mi^2 of farmed or disturbed area (50 percent) and mature second-growth or other undisturbed community (50 percent); 15 percent loss of wetlands and/or endangered species.

5. Loss of 1.0 mi^2 of primarily (75 percent) undisturbed mature desert community (i.e., sagebrush); 15 percent loss of wetlands and/or endangered species habitat.

6. Loss of 1.0 mi^2 of mature second-growth (but not virgin) forest community; 50 percent loss of big game and upland game birds; 50 percent loss of local wetlands and local endangered species habitat.

7. Loss of 1.0 mi^2 of mature second-growth forest community; 90 percent loss of local productive wetlands and local endangered species habitat.

8. Complete loss of 1.0 mi^2 of mature virgin forest; 100 percent loss of local wetlands and local endangered species habitat.

TABLE III. Possible Biological Impact[a] and Expected Utility

Site	Range of Impact[b] 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	Expected Utility
Benton 1	0.1	0.5	0.4						0.7915
Umatilla 1	0.7	0.3							0.9125
Clatsop 1				0.2	0.5	0.3			0.4690
Grays Harbor 1			0.2	0.8					0.6300
Wahkiakum 1				0.2	0.5	0.3			0.4690
Lewis 1		0.9	0.1						0.8135
Lewis 2		0.9	0.1						0.8135
Lewis 3		0.8	0.2						0.8020
Linn 1		0.3	0.6	0.1					0.7345

[a]Data represent the probability that the impact at each site will be in the range indicated.

[b]Based on Table II.

ACKNOWLEDGEMENTS

We were particularly fortunate to have a client who was willing to support the use of innovative approaches for assessing environmental impacts. The Public Power Council Siting Committee, Mr. William Hulbert, Chairman, and the WPPSS management, Mr. J.J. Stein, Managing Director, were supportive of our efforts. Mr. David Tillson, Siting Specialist of WPPSS, who monitored the contract was a source of constant encouragement. Without his support this study would not have been possible.

We acknowledge the assistance of the project team who contributed to the study, especially Gail Boyd, David White, Steve James, Ram Kulkarni, Keshavan Nair, and Wayne Smith, all of Woodward-Clyde Consultants' staff.

REFERENCES

1. R. Andrew, Effects of chemicals on aquatic life, "Water Quality Data Book" (Vol. 5), Environmental Protection Agency, Water Pollution Control Research Series 18050HLA 09/73 (1973).

2. Army Corps of Engineers, Annual fish passage report on Columbia River projects (Bonneville, The Dalles, John Day, McNary), Snake River projects (Ice Harbor, Lower Monumental, Little Goose), Oregon and Washington. North Pacific Division, Army Corps of Engineers, Portland, Oregon (published annually).

3. Milo C. Bell, "Fisheries Handbook of Engineering Requirements and Biological Criteria," North Pacific Division, Army Corps of Engineers, Portland, Oregon (1973).

4. *Federal Register,* March 5, 1970.

5. L. A. Fulton, Spawning areas and abundance of steelhead trout and coho, sockeye, and chum salmon in the Columbia River Basin—past and present, National Marine Fisheries Service, Special Scientific Report No. 618 (1970).

6. R. L. Keeney, Multiplicative utility functions, *Operations Research* 22(1), 22-34 (1974).

7. R. L. Keeney and K. Nair, Decision analysis for the siting of nuclear power plants—the relevance of multiattribute utility theory, *Proceedings of Institute of Electrical and Electronics Engineers, Inc.* 63(3), 494-501 (1975).

8. R. L. Keeney and H. Raiffa, "Decisions with Multiple Objectives," Wiley, New York (in press).

9. K. Nair, G. E. Brogan, L. S. Cluff, I. M. Idriss, and K. T. Mao, An approach to siting nuclear power plants: the relevance of earthquakes, faults, and decision analysis, in "Siting of Nuclear Facilities," International Atomic Energy Agency, Vienna (1975).

10. H. Raiffa, "Decision Analysis," Addison-Wesley, Reading, Mass. (1968).

11. R. O. Schlaifer, "Decisions Under Uncertainty," McGraw-Hill, New York (1969).

12. J. Von Neumann and O. Morgenstern, "Theory of Games and Economic Behavior," 2nd edition, Princeton University Press, Princeton, New Jersey (1947).

13. Woodward-Clyde Consultants, Project No. WCC 74-682, prepared for Washington Public Power Supply System, San Francisco (November, 1975).

14. S. G. Wright, Columbia River fish runs and commercial fisheries, 1938-1970: status report and addendums, Joint Investigational Report of Oregon Fish Commission and Washington Department Fisheries, 1(1974).

15. H. J. Yarrington, The National Environmental Policy Act, Monograph #17, *Environment Reporter* 4(36), 1-47 (1974).