An Environmental Evaluation System for Water Resource Planning

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The Environmental Evaluation System (EES) is a methodology for conducting environmental impact analysis. It was developed by an interdisciplinary research team and is based on a hierarchical arrangement of environmental quality indicators, an arrangement that classifies the major areas of environmental concern into major categories, components, and ultimately into parameters and measurements of environmental quality. The EES provides for environmental impact evaluations in four major categories: ecology, environmental pollution, esthetics, and human interest. These four categories are further broken down into 18 components and finally into 78 parameters. The EES provides a means for measuring or estimating selected environmental impacts of large-scale water resource development projects in commensurate units termed 'environmental impact units' (EIU). Results of using the EES include a total score in EIU 'with' and 'without' the proposed project; the difference between the two scores is one measure of environmental impact. Environmental impact scores developed in the EES are based on the magnitude of specific environmental impacts and their relative importance. Another major output from the EES is an indication of major adverse impacts called 'red flags', which are of concern of and by themselves. These flags indicate 'fragile' elements of the environment, which must be studied in more detail.

It has become increasingly clear that as a nation we are not being very good stewards of our environment. Perhaps more disturbing, we lack a national consensus on what constitutes good stewardship in light of seemingly conflicting objectives, such as economic growth and environmental quality enhancement, and the limited resources available to tackle the majority of contemporary problems. Further, even if we knew the elements of good stewardship there is some question whether we possess the mechanisms for incorporating those practices into our public and private decision-making processes.

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Our poor environmental stewardship in the water resource development field has been singled out on numerous occasions. Water resource development, which by its very nature changes the environment, has been labeled the destructor of the environment in cases such as the Florida Barge Canal, Hells Canyon, Grand Canyon, and Glen Canyon.

Historically, water resource developers have been unable to measure adequately environmental impacts within the context of benefit-cost analysis and focus only on dollar values. Another problem has been the absence of any requirement to incorporate environmental considerations into resource development planning. This problem has been partially overcome by the passage of the National Environmental Policy Act of 1969 [*U.S. Congress*, 1969], which made it mandatory for all federal agencies to evaluate noneconomic environmental impacts of their projects. Recognizing this dilemma, the

Water Resources Council recommended that a separate account for the environment be established to evaluate environmental impacts of water resource projects. The council further suggested that these impacts need not be measurable in dollar values to be considered important.

During 1970 and 1971, a research team at Battelle-Columbus developed a methodology for the Bureau of Reclamation to evaluate the environmental impacts of water resource development [*Whitman et al.*, 1971; *Dee et al.*, 1972]. This research has included a field test of the methodology to insure its practicality. In addition to the approach suggested in this paper, other methodologies have been developed to measure environmental impacts by *Leopold et al.* [1971], *Dearinger* [1968], and *Morisawa and Murie* [1969]. Each of these approaches is conceptually similar to the methodology developed here.

DESCRIPTION OF THE METHODOLOGY

The environment is a complex system consisting of physical, biological, and social resources. Use of these resources by man can have both beneficial and adverse impacts on the environment. Evaluation of these impacts is an important but often difficult task.

To insure that the impact evaluation methodology followed the guidelines of the Water Resources Council and the National Environmental Policy Act [*U.S. Congress*, 1969], the framework for the development was comprehensive (including all elements affected by water resource development), systematic (assessments being replicable by different analysts), and interdisciplinary (including a research team having a broad range of talents and disciplines including the physical, biological, and social sciences).

The Environmental Evaluation System (EES) developed for the Bureau of Reclamation is hierarchical in nature, measures environmental impacts in commensurate units, and alerts the user to environmentally sensitive areas.

Hierarchical System

The structure of the EES is hierarchical in nature to account for the different levels of information used in the impact analysis. The four levels of information used in the EES are shown in Figure 1.

Level 3 is the key level for environmental impact analysis using the EES. Each environmental parameter, of which there are 78 in the EES, represents a unit or an aspect of environmental significance worthy of separate consideration in water resource development. A screening process was used in the selection of the parameters. To keep the EES manageable, a special effort was made to minimize the number of parameters incorporated in the system.

The environmental measurements constitute the data needed to obtain a representative parameter estimate. These data may be obtained from historical records or from several different measurements that are functionally related to obtain the desired estimate. Groups of similar parameters in the EES are defined as environmental components. Each of these components represents terms of intermediate generality. The major classification, environmental categories, is the grouping of components into broad general areas.

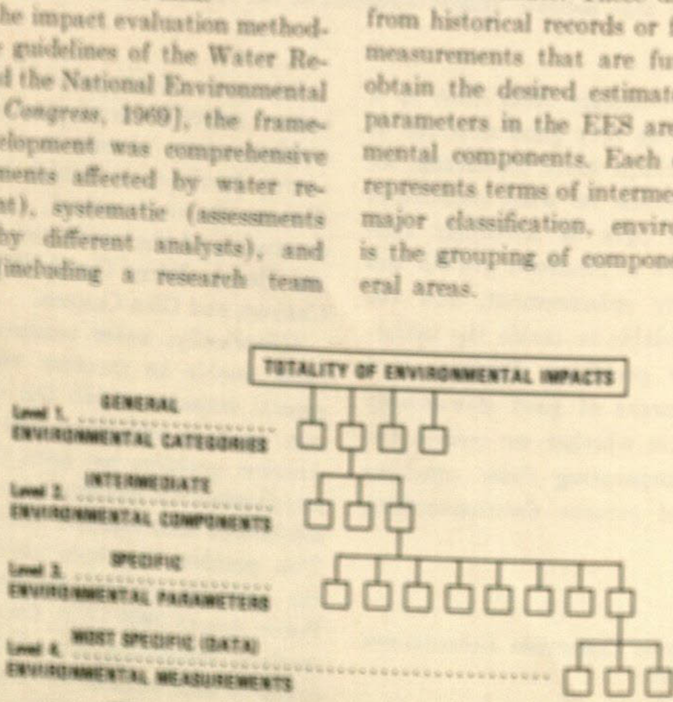

Fig. 1. Hierarchical structure of the EES.

Impacts Expressed in Commensurate Units

Water resource developments may create both beneficial and adverse impacts on the environment. Because properties of the environment are not commonly measured in commensurate units, it is difficult to evaluate the net environmental effects of a project and to make trade offs in selecting among alternatives. To solve this trade off problem, a technique was developed to transform all parameters into commensurate units. This technique consists of three steps.

Step 1: Transforming parameter estimates into environmental quality. At the present time, the evaluation of water resource projects with respect to their impact on environmental quality is based almost entirely on standards for physical/chemical aspects of the environment. In many cases these standards are represented as the upper concentration limits or maximum ranges for selected parameters that will be acceptable to maintain some desired 'quality.'

The use of standards is important in administering and enforcing a desired policy, but they are not a complete tool for evaluating environmental quality. Essentially, environmental quality is not confined to a bad or a good scale, but includes a range of values.

In the EES, environmental quality is defined in the following fashion. It is a value between 0 and 1, where 0 denotes extremely bad quality and 1 denotes very good quality. When environmental quality is defined in this way, it is possible to account for any changes that improve quality and are, therefore, beneficial impacts on the environment. It is also possible to account for marginal deterioration of the environment without waiting until the standard is reached or exceeded. An additional benefit of this approach is the resulting common base necessary to express impacts in commensurate units.

The transformation of a parameter estimate into environmental quality is achieved through the use of a value function relating the various levels of parameter estimates to the appropriate levels of environmental quality. The concept of a value function is given in Figure 2; typical value functions are illustrated later. The parameter estimate used in the value function is

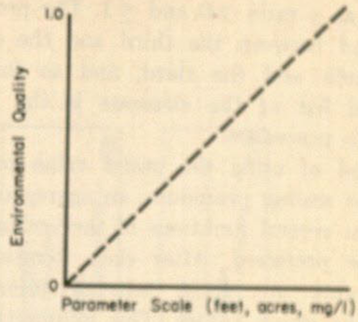

Fig. 2. Typical value function.

a representative value obtained from environmental measurement data, level 4 of the EES.

Step 2: Weighting of parameters. Each of the parameters used in the EES represents only a part of the total environment. It is, therefore, important to view these parts together as part of the environmental system. In doing so, however, it must be recognized that some parameters are more important than others. Parameters of 'lower' importance cannot be discarded, however, since they are still part of the overall system.

To reflect the relative importance of the EES parameters, a total of 1000 points or parameter importance units (PIU) were distributed among the parameters. The number of PIU assigned to a parameter is an indicator of the degree to which water resource projects may disturb or enhance the dynamic stability of man's relationship with the natural and social environment; all parameters were assigned relative weights.

An assignment of the relative weights (PIU) was made by quantifying the research team's subjective value judgments. Sociopsychological scaling techniques and the Delphi procedure were used to quantify the value judgments. The process consisted of ranked pairwise comparisons and controlled feedback.

In using ranked pairwise comparisons, the list of elements to be ranked is compared according to selected criteria and then successive pairwise comparisons are made between contiguous elements to determine for each element pair the ratio in importance. For example, the element ranked second is compared to the first to determine how much less important the second is to the first. This importance is expressed as a ratio >0 and ≤1. The process is continued between the third and the second, the fourth and the third, and so forth. A weighted list of the elements is the output from this procedure.

Instead of using the initial value resulting from the scaling procedure, an aggregate value based on several iterations of the scaling technique is preferred. After each iteration, the participants are given selected information about the group values. This information can include the group mean and variance, or other pertinent information. In the weighting procedure employed in this research, the participants' mean value was given at the feedback stage. All the scaling and feedback was performed through formal feedback statements, thereby avoiding undesirable direct interchange of judgments between the individuals in the test [*Miller*, 1967; *Pill*, 1971].

Because the weights developed for the EES represent the relative importance within the overall environmental system, they should not vary from project to project once they have been established by society. Further, if weights were allowed to vary from project to project, the assignment of weights would be the responsibility of the investigating team. Essentially, each team would have their own special weights depending on their views and background; thus results would be produced that would be extremely difficult to replicate.

Step 3: Obtain commensurate units. In step 1 each set of parameter measurements was related to an environmental quality scale between 0 and 1, and in step 2 each parameter was assigned a relative importance. The results of both of these steps are combined in step 3 to obtain the desired commensurate units for environmental impact trade offs.

The EES is used by evaluating the expected future condition of environmental quality 'without' the project and then 'with' the project. The former evaluation is an expression of the modified current condition of the environment, whereas the latter is an expected (predicted) condition of the environment with the proposed development. A difference in environmental impact units (EIU) between these two conditions constitutes either an adverse (loss in EIU) or a beneficial (gain in EIU) impact. Mathematically this process may be represented as

$$E_I = \sum_{i=1}^{m} (V_i)_1 w_i - \sum_{i=1}^{m} (V_i)_2 w_i \qquad (1)$$

where

E_I, environmental impact;
$(V_i)_1$, value in environmental quality of parameter i with a project;
$(V_i)_2$, value in environmental quality of parameter i without a project;
w_i, relative weight (importance) of parameter i;
m, total number of parameters.

Warning System

It is important for a development agency to know if any 'fragile' elements of the environment would be disturbed by a given project development. Unfortunately these fragile elements change from project to project, and there is no special formula to identify them in general. Thus each parameter in the EES must be considered a potential fragile element that could, for some project, be crucial in determining the magnitude and significance of the overall environmental impact.

The approach used to identify these potential problem areas is to key out with red flags parameters that change significantly in the adverse direction. These red flags are measured by percentage changes in the environmental quality of a parameter without and with a proposed project.

It must be reemphasized that a red flag is only a warning, not an absolute definition of a problem. After a red flag is identified, the developmental agency must investigate the potential problem area in detail to determine whether or not a problem exists. All red flags are treated with equal importance. To differentiate between the magnitude of the potential problem both a minor and a major red flag are used.

CONTENT OF THE ENVIRONMENTAL EVALUATION SYSTEM

Water resource development has impacts on both the physical and the social environments. For this reason environment, as used in the EES, was defined to include the four categories of ecology, environmental pollution, esthetics, and human interest [*Dee*, 1971; *Whitman and Dee*, 1971].

Ecology covers the spectrum of impacts on the living system elements in the natural en-

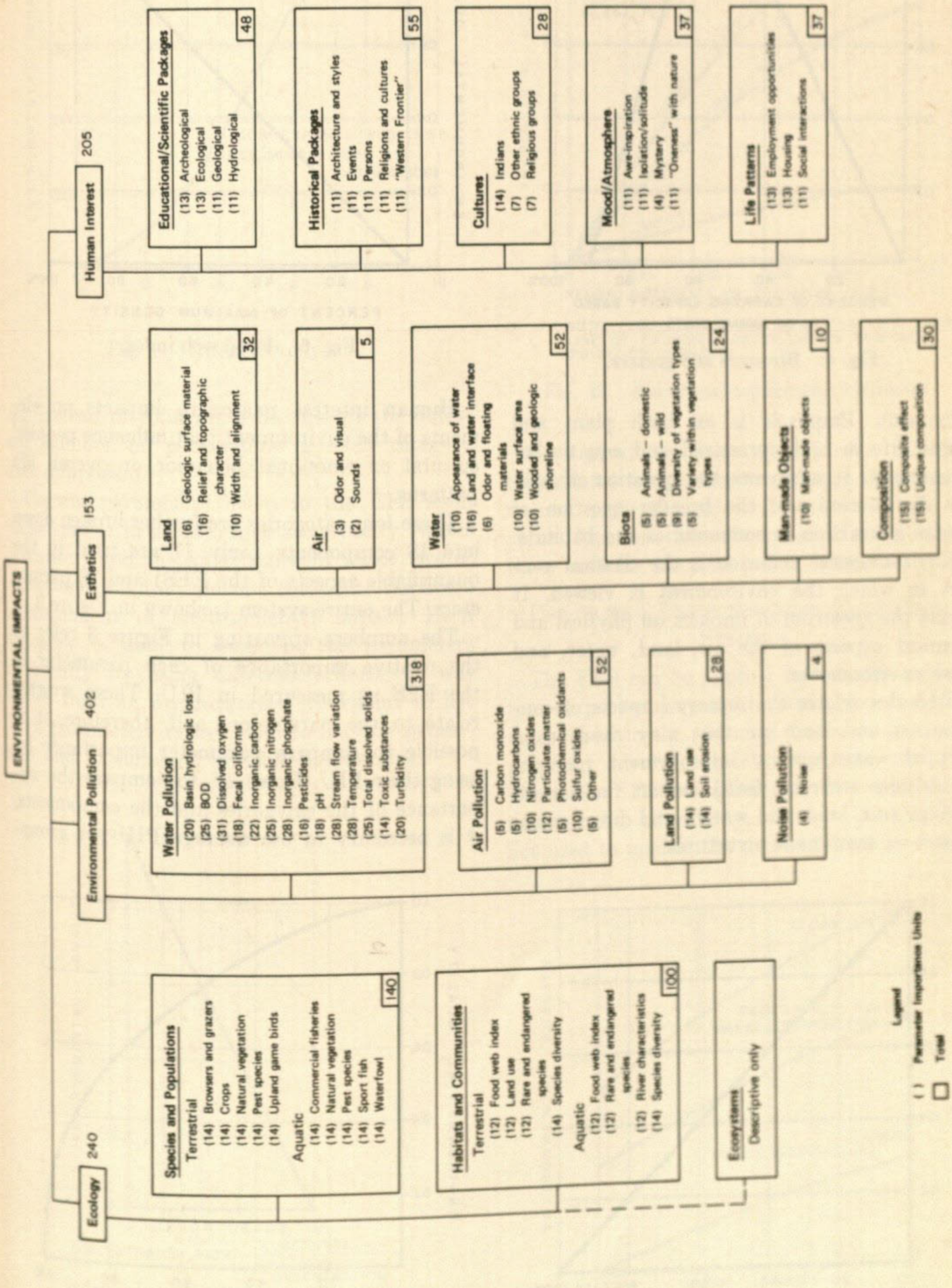

Fig. 3. Environmental evaluation system.

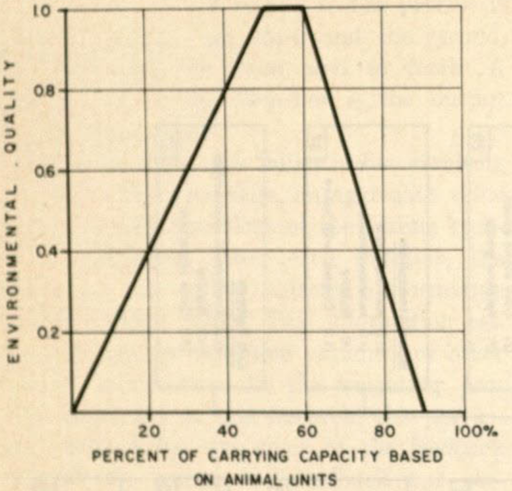

Fig. 4. Browsers and grazers.

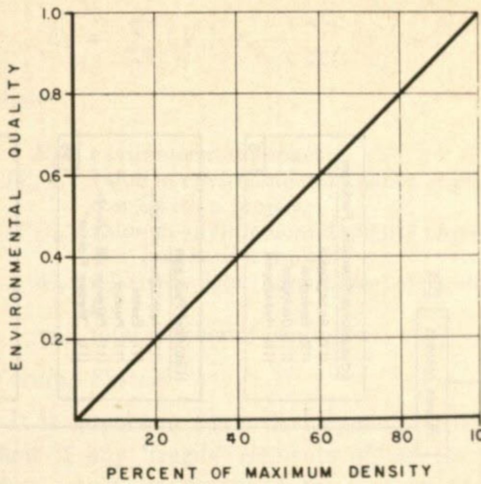

Fig. 6. Food web index.

vironment. Emphasis is on both plant and animal life in both terrestrial and aquatic environments. It addresses the question of species distribution and the broader question of species interaction in communities and habitats.

Environmental pollution is the classical context in which the environment is viewed. It covers the spectrum of impacts on physical and chemical aspects of the air, land, water, and noise environments.

Esthetics relates the sensory impacts of construction and land use that may result as a part of water quality improvement projects. It includes indirect visual impact on natural settings (air, land, and water) and direct visual impact of man-made structures.

Human interest relates to impacts on elements of the environment that influence peoples' cultural or emotional behavior or overall life patterns.

These four categories are further broken down into 18 components (only 17 are used in the quantifiable aspects of the EES) and 78 parameters. The entire system is shown in Figure 3.

The numbers appearing in Figure 3 refer to the relative importance of each parameter in the EES as measured in PIU. These weights relate to the parameters and, therefore, it is possible to compare parameter importance by using their PIU. However, to compare the importance of the categories and the components, it is necessary to use average PIU per group-

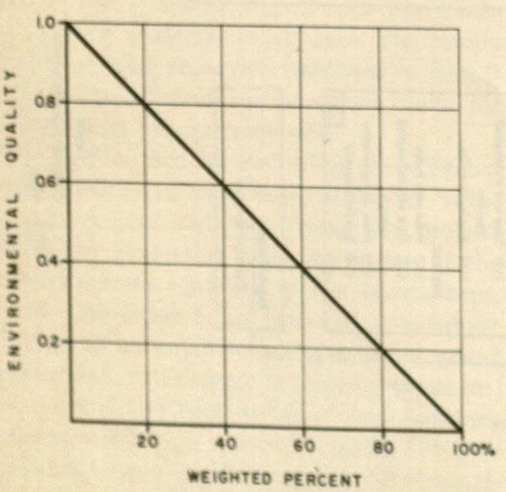

Fig. 5. Pest species.

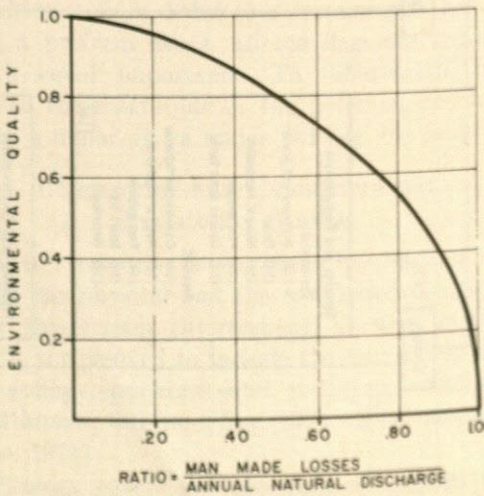

Fig. 7. Basin hydrologic loss.

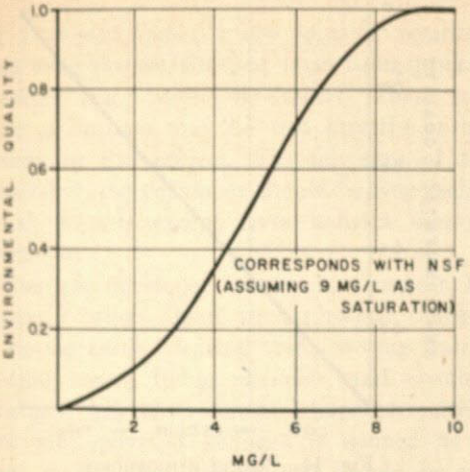

Fig. 8. Dissolved oxygen.

ing instead of total units because of the different number of parameters in each category and component.

Certain parameters listed in the EES seem to be similar in nature, such as turbidity (water pollution) and the appearance of water (water esthetics), but they do not constitute duplicate measurement of environmental impact. Each category is used to evaluate the parameters differently by using different criteria. It was easier from an organizational viewpoint to list both parameters rather than to list one parameter and to define all possible interactions.

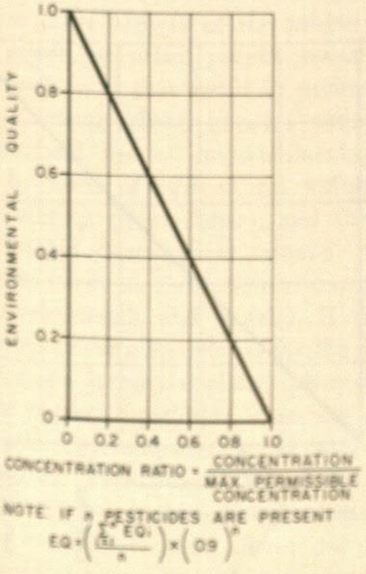

Fig. 9. Pesticides.

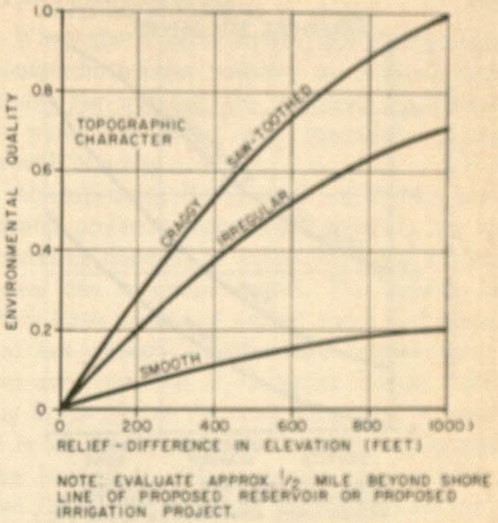

Fig. 10. Relief and topographic character.

Each parameter has a specific value function that relates the parameter estimate to environmental quality. A selected number of the 78 value functions are shown in Figures 4–15, three each for the four major categories.

Use of the Environmental Evaluation System

The EES can be applied both in the evaluation of project impacts to select specific alternatives and in the planning process to minimize potential adverse impacts in future projects. When the EES is applied only to screen alternatives, the information obtained is normally not used to modify the project. However, when

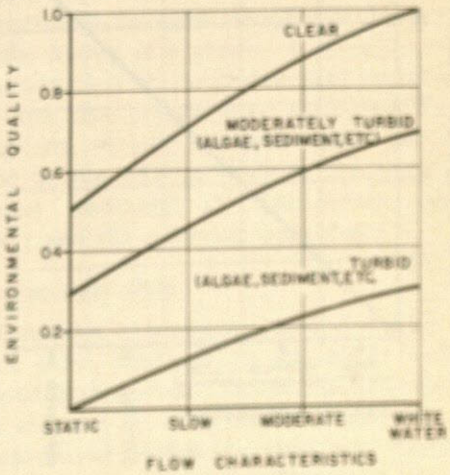

Fig. 11. Appearance of water.

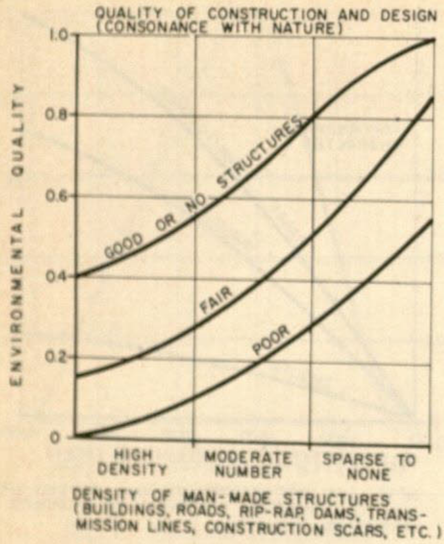

Fig. 12. Man-made objects.

the EES is applied in the planning process, a feedback loop is used to continually modify the proposed project through successive iterations of the development process. Projects developed with the assistance of the EES would be expected not only to avoid adverse environmental impacts but to improve selected portions of the environment.

In using the EES to perform an environmental analysis, it is necessary to consider four elements: (1) the boundaries of the analysis, (2) the measurement data, (3) environmental impact units for all parameters, and (4) red flags for all parameters.

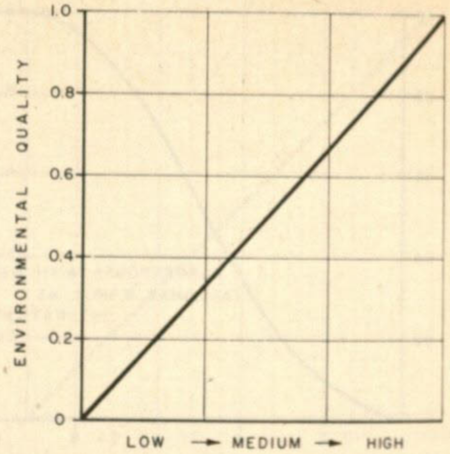

Fig. 14. Mood/atmosphere.

Boundaries of the Analysis

Boundaries are used in a broad context to denote (1) the developer's responsibility and (2) spatial and temporal considerations.

Developer's responsibility. To evaluate the impacts of a water resource project, some guidelines must be set to determine where the developer's responsibility ends and others begin. Two kinds of impacts result from water resource projects: (1) construction impacts resulting from physical changes made in the environment by a developing agency in build-

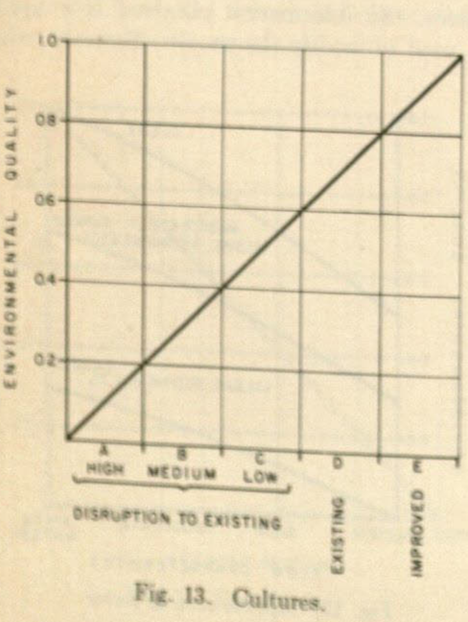

Fig. 13. Cultures.

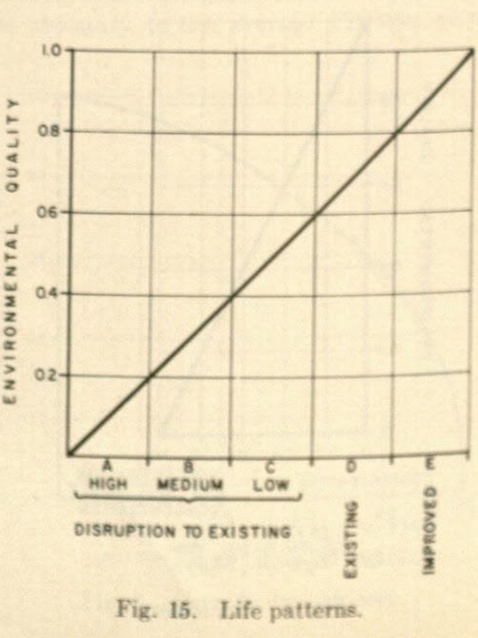

Fig. 15. Life patterns.

ing a project and (2) use impacts resulting from using project sites, or from using project resources (e.g., water or power). These two types of impacts may be tied directly or indirectly to the project. For purposes of responsibility, the developer should be responsible for all impacts except from indirect uses of the project.

When the developer constructs a project, he purposely brings about such physical changes as moving earth, clearing trees, storing water, dredging rivers, lining channels, and erecting structures. Any environmental impact resulting from such physical changes is defined as a direct construction impact and should be reflected by an EES evaluation.

In the construction of a project, certain physical changes occur in the environment, either predictably or unpredictably, that are incidental to the purposes of the project. Such changes include increased evaporation rates, changes in river temperature, reduced streamflow, changes in flyway patterns of migratory birds, and decreases in the number of aquatic species. Any environmental impact resulting from such physical changes is defined as an indirect construction impact, which should also be reflected in evaluations conducted with the EES.

Water resource development is always carried out with specific users or beneficiaries clearly identified. These may be users of water, power, or other aspects of the project. Often, water, power, or other project resources are used in such ways that result in environmental impacts. Among these impacts are: effects of recreational use of impoundments, effects caused by users of agricultural waters (such as high salinity return flows), and the effects of predictable development around reservoir perimeters (such as recreation areas, vacation home developments, and motels). If water or power is specifically designated for the development of a new industrial plant, urban complex, or other potential polluters, then the impacts from these developments would also fall in this category. Thus where the use of projects leads directly to environmental effects, these may be considered to be direct use impacts that should also be reflected in project evaluations.

Where the projects benefit users in a general, nonspecific manner, indirect use impacts may result. For instance, the increased availability of water and power may contribute to the growth of a city.

Accompanying this growth will be environmental problems such as air pollution due to increasing numbers of automobiles and wildlife losses due to urban sprawl. The impacts of these kinds of uses of project water and power are not directly attributable to the project, but are a function of conditions already existing in the city at the time the project is built. It is felt that impacts of this nature are beyond the bounds of the developer's responsibility, and the developer should not be held accountable for them.

Spatial and temporal considerations. Construction and use impacts occur at various locations in the project area and during different time horizons. To avoid omitting any impacts, it is important to systematically include both spatial and temporal considerations in the EES.

Spatial areas that must be considered are divided into four sectors: (1) upstream from the proposed development, (2) at the site of the proposed development, (3) along routes of water transfer from one sector in the development to another, and (4) downstream from the proposed development. The extent of the area to be included in each of these sectors is determined by the individual doing the impact analysis.

In the evaluation of 'with' the project, it is important to recognize the different time frames in the history of a project. A project has different impacts on the environment during each of these time periods, some short-term, others long-term. At least two time frames should be used in the EES to evaluate the 'with' the project conditions: (1) construction (short-term) and (2) operation (long-term).

Measurement Data

Parameter estimates are used in conjunction with value functions to determine environmental quality scores. The parameter estimates are obtained by using statistical methods and mathematical models to transform historical data into a specific value. This value depends on the scope of the developer's environmental responsibility and spatial and temporal considerations. This estimate is used in the value functions to determine environmental quality.

Environmental Impact Units for All Parameters

The difference between the 'with' and 'without' a project is defined as the environmental impact. This impact can be adverse in nature (loss in EIU) or beneficial in nature (gain in EIU).

To obtain either the with or the without evaluation in EIU, it is necessary to determine the EIU for each specific parameter and then to sum over all 78 parameters. An impact evaluation is determined by using equation 1. In the formulation used, a negative (−) change indicates an adverse environmental impact and a positive (+) indicates a beneficial impact.

Red Flags

Problem areas and data gaps in any proposed project are keyed in the EES by the use of red flags. Elements of the environment that may be significantly changed in an adverse direction are represented as either a minor or a major red flag. These red flags indicate where a detailed investigation is necessary. In areas where there are either no data or only qualitative data, red flags are also used to indicate data needs.

Four rules are used to determine if a negative change in a parameter constitutes a red flag and the type of flag that should be used. Each of these rules is based on a change in the environmental quality of a parameter as measured by the extent of difference between the with and without evaluations. The percent change is calculated as

$$\text{percent change} = \frac{\text{without EIU} - \text{with EIU}}{\text{without EIU}} \qquad (2)$$

For ecology parameters the following rules apply:

Rule 1: Minor flag. The negative change in percent between the with and without environmental quality is between 5 and 10%.

Rule 2: Major flag. The negative change in percent between the with and without environmental quality is >10%.

For all other parameters the following rules apply:

Rule 3: Minor flag. The negative change between the with and without environmental quality is ≥ 0.1 in absolute value. This change in percent is <30.

Rule 4: Major flag. The negative change between the with and without environmental quality is ≥ 0.1 in absolute value. This change in percent is ≥ 30.

These rules were determined by an analysis of the sensitivity of various parameters to change and the significance of the change as determined from the field test described in the next section of this paper. Because these rules are based on a small sample, further tests are necessary to substantiate them. The broad nature of the ecology category is the primary reason for the differentiation in the red flag rules. Field tests indicated that a small change in the ecology parameters was comparable in impact to larger changes in all other parameters.

Field Testing of the Environmental Evaluation System

Field tests were conducted to modify and refine the EES. The area selected for the field tests was the Bear River project in Utah, Idaho, and Wyoming operated by the Bureau of Reclamation.

Description of the Bear River System

Bear River is the largest river in the United States that has no outlet to the ocean. Its headwaters are in Utah, high in the Uinta Mountains, and it flows northward crossing the state lines of Wyoming and Idaho until it reaches Soda Springs, Idaho. It then reverses its northern course and flows southward ending in the Great Salt Lake. Although the river is 500 miles long, the distance between its headwaters and its terminus in the Great Salt Lake is only about 90 air miles.

Bear River water is presently used for irrigation, hydroelectric power, municipal and industrial water supply, and maintenance of the Bear River Migratory Bird Refuge. These water needs are supplied by reservoirs throughout the system. The average annual flow in the headwaters is about 130,000 ac ft and the flow at Corinne, Utah, near the Great Salt Lake, is about 1 million acre-feet.

Oneida Narrows Study Area

Because a primary objective of the research was to field test the EES and not to conduct a complete environmental impact analysis of the Bear River, only portions of the Bear River were investigated in detail. Oneida Narrows was selected as one area of investigation.

The Oneida Narrows segment of the Bear River project would provide a 435,000 ac ft reservoir formed by a 315-foot dam. The proposed reservoir would extend 32 river miles upstream from the dam and would inundate an existing hydroelectric dam (30,000 kw) and about 1400 acres of irrigated land. The stored water would be distributed by gravity flow through a 75-mile canal to other valleys for irrigation and other uses. Additional irrigation service from this water amounts to 88,600 acres.

The Oneida Narrows reservoir would also be used to improve the fish, wildlife, and recreation resources in the area. Coulam National Wildlife Refuge would be established in Franklin County, Idaho, on 4693 acres of land, and three existing reservoirs currently being used for irrigation would become potential fishery pools.

The availability of water in the Oneida Narrows reservoir would, by exchange, allow for the supply of 20,000 ac ft of water for municipal and industrial requirements. This water would be used primarily for future residential and phosphate industry development in the area.

TABLE 1. Selected Environmental Changes

Parameter	Weight (PIU)	With (EIU)	Without (EIU)	Change (EIU)
Ecology				
Species and populations				
Browsers and grazers	14	14.00	14.00	0.00
Crops	14	9.24	8.12	+1.12
Sport fish	14	5.74	4.90	+0.84
Habitats and communities				
River characteristics	12	6.72	8.52	−1.80
Environmental pollution				
Water pollution				
Basin hydrologic loss	20	15.80	17.00	−1.20
Biochemical oxygen demand	25	18.00	21.25	−3.25
Dissolved oxygen	31	29.45	31.00	−1.55
pH	18	7.20	9.00	−1.80
Streamflow variation	28	19.32	8.68	+10.64
Temperature	28	4.20	8.40	−4.20
Total dissolved solids	25	14.50	15.00	−0.50
Esthetics				
Land				
Geologic surface material	6	1.50	1.86	−0.36
Relief and topographic character	16	4.32	5.60	−1.28
Width and alignment	10	3.10	4.30	−1.20
Composition				
Composite effect	15	7.65	8.25	−0.60
Unique composition	15	0.90	2.85	−1.95
Human interest				
Educational/scientific packages				
Ecological	13	7.54	6.37	+1.17
Geological	11	2.75	3.52	−0.77
Hydrological	11	2.20	1.10	+1.10
Life patterns				
Employment opportunities	13	6.76	9.10	−2.34
Housing	13	4.42	9.10	−4.68
Social interactions	11	5.50	7.70	−2.20

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Environmental Evaluation of the Oneida Narrows Project

The EES was applied to the Oneida Narrows project to determine the beneficial and adverse changes. Selected changes that occurred in the evaluation are shown in Table 1.

A summary of the changes in EIU calculated by equation 1 is given in Table 2. Included in the evaluation is qualitative information or data that cannot be substantiated by a reliable documented record or reduced to a quantifiable form. This information is useful in the determination of impacts and is, therefore, included in the analysis. Also included in the summary table is a list of the red flags [illegible] project.

SUMMARY

The EES is useful as an aid in [illegible] mination of environmental impacts [illegible] resource development projects. It [illegible] ever, be used with caution, and [illegible] and should not become a mechanical [illegible] perform evaluations.

The system of parameters, value [illegible] and weights given in this paper is [illegible] ing point in environmental evaluation [illegible] must be improved as the system is used.

TABLE 2a. EES Summary for Oneida Narrows: Value of Impact in EIU

Category	Quantitative Change: With Project	Quantitative Change: Without Project	Quantitative Change: Difference	Qualitative Change Estimate	Net Ch[illegible]
Ecology	96	96	0	−1	[illegible]
Environmental pollution	195	201	−6	0	[illegible]
Esthetics	56	60	−4	0	[illegible]
Human interest	49	66	−17	0	[illegible]
Total	396	423	−27	−1	[illegible]

TABLE 2b. EES Summary for Oneida Narrows: Number of Red Flags, Problem Areas and Da[illegible]

[illegible]ategory	Component	Problem Areas: Minor	Problem Areas: Major	Data Nee[illegible]
[illegible]	Species and populations	0	1	[illegible]
	Habitats and communities	0	1	[illegible]
[illegible]nmental [illegible]tion	Water pollution	2	2	[illegible]
	Air pollution	0	0	[illegible]
	Land pollution	0	0	[illegible]
	Noise pollution	0	0	[illegible]
[illegible]thetics	Land	1	0	[illegible]
	Air	1	0	[illegible]
	Water	0	0	[illegible]
	Biota	0	0	[illegible]
	Man-made objects	0	0	[illegible]
	Composition	0	1	[illegible]
Human interest	Educational/scientific packages	0	0	[illegible]
	Historical packages	0	0	[illegible]
	Cultures	0	0	[illegible]
	Mood/atmosphere	1	3	[illegible]
	Life patterns	2	1	[illegible]
Total		7	9	[illegible]

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