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QUANTITATIVE ASSESSMENT OF ENVIRONMENTAL IMPACT

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ABSTRACT

The history of environmental impact and the current requirements, guidelines, and coverage of environmental impact statements are briefly reviewed. A procedure for the assessment of environmental impact is presented, of the following design. The individual components of the environment induced by a proposed action and of the natural environment of the project area are listed, and each impact generated by their interaction is assigned value ratings. The ratings are assembled in an impact-incidence matrix, which is then reordered using a data analysis technique, the bond energy algorithm. The new matrix obtained displays interrelated clusters of high-valued ratings, corresponding to critical environmental areas. The impacts comprising each area are grouped according to similarity of action and effect, and their association may suggest environmental alternatives. The environmental impact from the construction of an additional wastewater treatment plant in a resort area is assessed to illustrate the effectiveness of the procedure.

Introduction

Man first had an impact on the environment when he discovered fire (air pollution) and started living in caves (land use) by a stream (water pollution). However, it is only since the 1800's, when man started covering the face of the earth and mass-producing artifacts through the industrial revolution, that such impact became broadly felt.

As long as industry fulfilled basic needs and pollution products were not a subject of interest (as is still the case in developing

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countries), effects on the environment were considered secondary, and were associated with decreased unemployment and a rising standard of living. Under these conditions, an industry or a developer was free to set up operations anywhere, and, if extensive harm to the environment resulted and a public outcry was raised, corrective measures were taken.

A major policy change was initiated on January 1, 1970, with the signing of the National Environmental Policy Act (NEPA), which requires Federal Agencies to write and present for review an environmental impact statement before initiating a range of activities. Even if confined to Federal activities, the law immediately concerned all citizens because of the extent of Federal involvement in the United States.

Furthermore, the regulatory activity of many Federal agencies falls under NEPA. For example, environmental impact statements accompany permits to discharge for new point sources issued by the Environmental Protection Agency and dredging permits for harbor construction issued by the Corps of Engineers; the material for the statements (sometimes called an "environmental assessment") has to be provided to the agency by the permit requestor.

As of to-date twelve states have followed the Federal example by legislating State Environmental Quality Acts modeled after NEPA; some of their guidelines, as for the California CEQA, specifically cover private activity whenever subject to the issuance of a State lease, permit, license, or certificate, and expected to have a significant effect on the environment. A number of cities and counties are now also requiring environmental impact reports.

As for any new law, considerable doubt existed on NEPA's extent of coverage and means of implementation. In the first three years of its existence the law was shaped by the Courts through the many suits which were brought against it [1], and its present scope was crystallized in the latest "Federal Guidelines on the Preparation of Environmental Impact Statements," issued by the Council on Environmental Quality on August 1, 1973 [2].

According to the guidelines, an environmental impact statement should cover the following points:

1. A description of the proposed action.
2. A description of the natural environment of the area affected, including population and growth characteristics.
3. The relationship of the proposed action to land use plans, policies and controls for the affected area.
4. The analysis of the environmental impact of the proposed

action. Secondary or indirect impacts, such as growth stimuli and changes in social patterns have to be considered.
5. Alternatives to the proposed action.
6. Unavoidable adverse environmental effects, including a discussion of how such effects can be mitigated.
7. Relationships between short term and long term environmental effects, and tradeoffs involved.
8. Irreversible and irretrievable commitments of natural and cultural resources.
9. A cost-benefit analysis or similar study where the Federal policy gains are balanced with the environmental losses.

Among new developments mentioned in the guidelines, the requirement of environmental impact statements for legislative proposals and for the commitment of Federal funds to major R&D programs extends significantly the scope of the law.

Impact Assessment Procedure

The crucial point in a NEPA proceeding is the assessment of the environmental impact of the proposed action, because it involves quantifying a series of subjective judgments. The writer and the reviewer of an environmental impact statement are presumed to assume an impartial position and strive to consider at all times both sides of the environmental question, i.e., the preservation of a natural environment vs. the development of the environment for useful purposes. The environmental impact is generated by the interaction of the natural environment of the area affected with the environment which is induced by the proposed action.

This environmental interaction may be assessed by assigning value ratings to the amount of impact judged to occur, for example:

0	none	3	definite
1	slight	4	considerable
2	moderate	5	severe

This may appear a simple judgment, but in reality involves considerable effort, because most of the aspects involved are not directly measurable. The analyst and the decision maker have to draw at all times from their own life experience and social awareness. Some statistical projections, such as the OBERS Tables may help in visualizing growth patterns, but only a small number of studies have attempted to quantify externalities and intangible values, and the data produced are often not directly applicable [3]. For

example, the information that estimates of recreational expenditures in 1965 showed that people were willing to pay $0.30 per hour for outdoor recreation is of very limited value when deciding if 50 acres of beach bluffs should be sacrificed to enlarge an existing nuclear power plant [4].

Attempts to use more complex value ratings are usually not justified. Thus, distinctions between "negative" and "positive" impact can only be validated by the test of time. Some authors have suggested that two parameters should be considered for each impact, its "magnitude" (objective) and its "importance" (subjective); however, the data required to evaluate the former are seldom available [5].

Considering as an example the proposed construction of an additional waste-water treatment plant in a resort area, an activity requiring an environmental impact statement, the following aspects of the natural environment of the project area can be listed:

1. Topography (land form)
2. Soil conditions
3. Surface waters
4. Ground water
5. Air quality
6. Terrestrial vegetation
7. Aquatic vegetation
8. Birds
9. Land animals
10. Aquatic life
11. Endangered species
12. Wilderness areas
13. Wetlands
14. Agriculture
15. Land recreational activities
16. Water recreational activities
17. Historical and/or archeological sites
18. Residential development
19. Commercial development
20. Industrial development
21. Utilities
22. Transportation
23. Employment
24. Population density
25. Social patterns
26. Aesthetics
27. Remote areas (beyond the immediate geographic location) which may be affected

The environment induced by the project, on the other hand, is described by the following components (divided into a construction and an operation phase; the tertiary treatment plant will employ adsorption on activated carbon and sludge incineration; the effluent will be used for groundwater recharge):

Construction

1. Earth leveling (cut and fill)
2. Rock blasting
3. Soil erosion
4. Siltation of natural waters
5. Damming of natural waters
6. Dust generation
7. Burning of combustible wastes

Construction

8. Increased exhaust emissions
9. Clearing of vegetation
10. Open air storage of construction materials
11. Construction noise
12. Debris generation
13. Temporary spur to economy

Operation

14. Land use change
15. Ash leachate
16. Thermal pollution
17. Stack emissions
18. Noise generation
19. Solid waste generation
20. Use of energy
21. Use of resources (chemicals)
22. Increased wastewater treatment
23. Increased groundwater recharge

Each aspect of the natural environment interacts with each aspect of the induced environment. Value ratings as mentioned above are assigned to each impact generated. The ratings are best presented in tabular form as an impact-incidence matrix shown in Figure 1; the aspects of the natural environment are listed across the top, and the components of the induced environment are listed down the side [6].

It can be argued at this point that the value rating procedure was a useless exercise, because the matrix obtained is exceedingly complex and it is not possible to identify problem areas (where severe or considerable impact occurs) on inspection. Workers in the environmental impact field agree with this opinion, because the value-rating/matrix procedure is very seldom used.

The application of data analysis techniques was found helpful here. The "Bond Energy Algorithm" technique, which was developed in 1969 by McCormick et al. at the Institute for Defense Analyses (Arlington, Va.), and recently acquired widespread diffusion is especially useful [7]. This procedure, by means of a simple computer program (documented in the reference cited), reorganizes and reorders the matrix data by performing row and column permutations; the goal is to produce clusters of high similarity ratings (where similarity is measured by the scalar product of row or column pairs). The particular value of the procedure is that in this way latent data patterns, groupings, and structural relationships which were not apparent from the raw matrix data are revealed.

When a raw matrix is rearranged by the bond energy algorithm, a number of new data matrices is obtained, according to the increment, or starting point for columns or rows, chosen; very low increments produce larger number of matrices and increase

Induced Environment	Natural Environment																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	5	4	3	2	2	3	1	1	3	1	3	5	3	0	3	0	0	0	1	0	2	2	4	2	1	5	0
2	5	3	2	2	2	1	1	2	4	0	4	5	0	0	3	2	0	3	2	1	1	0	0	0	0	4	0
3	4	5	4	1	0	5	3	1	2	2	2	4	4	3	3	1	0	1	0	0	0	2	1	0	0	5	0
4	0	1	5	2	0	2	5	1	1	5	1	2	4	2	1	4	0	0	0	0	0	0	0	0	0	4	0
5	3	4	5	4	0	3	4	1	3	5	3	4	5	3	3	3	0	0	0	0	0	2	0	0	0	4	0
6	0	1	1	1	5	3	1	4	5	0	3	3	1	1	4	2	0	3	3	2	0	1	0	1	0	4	0
7	0	0	0	2	5	2	0	4	4	0	3	3	0	1	3	3	0	2	1	0	0	1	0	1	0	3	0
8	0	0	1	1	4	2	0	3	2	0	2	2	0	1	2	1	0	2	1	0	0	0	0	1	0	0	0
9	3	5	4	5	1	5	0	3	5	0	3	5	4	2	3	0	0	0	0	0	0	0	0	1	0	5	0
10	0	0	2	1	0	4	0	0	2	0	2	4	0	0	2	0	0	0	0	0	0	0	0	0	0	4	0
11	0	0	0	0	0	0	0	3	3	0	3	3	0	0	3	3	0	4	2	1	0	0	1	0	0	2	0
12	2	3	3	4	1	3	3	2	3	4	3	4	3	2	3	3	0	0	0	0	3	1	0	0	0	4	0
13	0	0	1	1	2	0	0	0	0	0	0	0	0	1	2	2	0	4	5	1	3	3	5	4	5	3	3
14	5	3	3	2	2	5	0	2	3	0	3	5	2	2	5	2	0	2	2	2	4	2	3	1	0	5	2
15	0	2	2	5	0	2	2	1	1	3	1	2	3	2	2	2	0	1	1	1	0	0	0	0	0	0	0
16	0	0	5	1	1	2	5	1	1	5	3	3	5	2	1	1	0	0	0	0	0	0	0	0	0	2	0
17	0	0	1	1	5	2	1	2	0	1	2	3	1	2	2	2	0	3	2	1	1	0	1	1	0	3	0
18	0	0	0	0	0	0	0	3	3	0	3	3	0	0	3	2	0	2	1	0	0	0	0	0	0	2	0
19	0	3	1	2	1	2	1	0	1	1	1	1	1	1	0	0	0	0	0	0	1	0	0	0	0	3	0
20	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	5	0	1	0	0	0	2
21	0	1	1	2	1	1	2	2	2	2	2	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
22	0	0	5	5	0	3	3	1	2	3	0	3	2	4	4	4	0	5	4	4	3	3	4	4	3	0	4
23	0	3	2	5	0	4	1	1	1	2	1	2	5	4	2	0	0	4	3	4	3	0	4	4	2	0	3

Figure 1. Impact-incidence matrix.

computer time without a corresponding benefit in relevancy. The most significant matrix is selected using the measure of effectiveness (ME) indices provided by the program; the highest ME value points immediately to the matrix of election for square matrices; for unsymmetrical matrices, two ME values are given, and the selection is based both on high numerical value and on closeness between the two numbers.

By applying the McCormick algorithm to the matrix in Figure 1, the reordered data matrix in Figure 2 was obtained. When rectangles are constructed around clusters of higher-valued ratings, as shown in Figure 2, two immediate benefits are apparent: (i) critical environmental impact areas are identified, and (ii) similar actions and similar effects are grouped together.

Six clusters can be outlined in Figure 2. Four of these identify critical areas where adverse environmental effects should be mitigated; these impact areas, however, were easily predictable from the nature of the project. These are the clusters:

7, 6 Induced Environment and 5, 8, 9, 15 Natural Environment: air pollution effects.

2, 1 Induced Environment and 12, 26 Natural Environment: land form disturbance effects.

14, 9, 12, 5, 3 Induced Environment and 12, 26, 6, 3 Natural Environment: soil, surface waters, and vegetation disturbance effects.

4, 16 Induced Environment and 3, 7, 10, 13 Natural Environment: possible damage to natural waters and aquatic life.

The two remaining clusters, on the other hand, show controversial aspects that were not clearly evident from the initial data, as follows:

9, 12, 5, 3, 23 Induced Environment and 13, 4, 2 Natural Environment: when the increased groundwater recharge is grouped with disturbance effects, a synergistic action on groundwater, wetlands, and soil conditions results; the possibility of environmental damage from groundwater recharge should be investigated; alternate ways of utilization of the tertiary effluents such as use for recreational activities may be preferable.

23, 22, 13 Induced Environment and 18, 19, 25, 24, 23 Natural Environment: the construction and operation of the additional wastewater treatment plant represent a definite stimulus for the development of the area, its employment capacity, and its population density, with corresponding changes in social patterns.

Induced Environment	Natural Environment																										
	22	1	11	5	8	9	15	12	26	6	3	7	10	13	4	2	14	16	18	19	25	24	23	21	27	20	17
21	0	0	2	1	2	2	0	1	0	1	1	2	2	0	2	1	0	0	0	0	0	0	0	0	1	1	0
8	0	0	2	4	3	2	2	2	0	2	1	0	0	0	1	0	1	1	2	1	0	1	0	0	0	0	0
17	0	0	2	5	2	0	2	3	3	2	1	1	1	1	1	0	2	2	3	2	0	1	1	1	0	1	0
7	1	0	3	5	4	4	3	3	3	2	0	0	0	0	2	0	1	3	2	1	0	1	0	0	0	0	0
6	1	0	3	5	4	5	4	3	4	3	1	1	0	1	1	1	1	2	3	3	0	1	0	0	0	2	0
2	0	5	4	2	2	4	3	5	4	1	2	1	0	0	2	3	0	2	3	2	0	0	0	1	0	1	0
1	2	5	3	2	1	3	3	5	5	3	3	1	1	3	2	4	0	0	0	1	1	2	4	2	0	0	0
14	2	5	3	2	2	3	5	5	5	5	3	0	0	2	2	3	2	2	2	2	0	1	3	4	2	2	0
9	0	3	3	1	3	5	3	5	5	5	4	0	0	4	5	5	2	0	0	0	0	1	0	0	0	0	0
12	1	2	3	1	2	3	3	4	4	3	3	3	4	3	4	3	2	3	0	0	0	0	0	3	0	0	0
5	2	3	3	0	1	3	3	4	4	3	5	4	5	5	4	4	3	3	0	0	0	0	0	0	0	0	0
3	2	4	2	0	1	2	3	4	5	5	4	3	2	4	1	5	3	1	1	0	0	0	1	0	0	0	0
23	0	0	1	0	1	1	2	2	0	4	2	1	2	5	5	3	4	0	4	3	2	4	4	3	3	4	0
22	2	0	0	0	1	2	4	3	0	3	5	3	3	2	5	0	4	4	5	4	3	4	4	3	4	4	0
13	3	0	0	2	0	0	2	0	3	0	1	0	0	0	1	0	1	2	4	5	5	4	5	3	3	1	0
11	0	0	3	0	3	3	3	3	2	0	0	0	0	0	0	0	0	3	4	2	0	0	1	0	0	1	0
18	0	0	3	0	3	3	3	3	2	0	0	0	0	0	0	0	0	2	2	1	0	0	0	0	0	0	0
10	0	0	2	0	0	2	2	4	4	4	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	1	0	1	1	1	2	4	2	5	5	5	4	2	1	2	4	0	0	0	0	0	0	0	0	0
16	0	0	3	1	1	1	1	3	2	2	5	5	5	5	1	0	2	1	0	0	0	0	0	0	0	0	0
15	0	0	1	0	1	1	2	2	0	2	2	2	3	3	5	2	2	2	1	1	0	0	0	0	0	1	0
19	0	0	1	1	0	1	0	1	3	2	1	1	1	1	2	3	1	0	0	0	0	0	0	1	0	0	0

ME1 = 2487 ME2 = 2426 I = 10

Figure 2. Reordered impact-incidence matrix (I = increment; ME = measure of effectiveness).

Of course the interpretations drawn were implicit in the original value ratings chosen, but the reordered matrix procedure brought out the salient aspects and revealed latent associations.

Conclusions

The value rating-matrix-reordered matrix procedure provides:

1. A thorough coverage of the environmental aspects through the listing of the individual components of the natural and the induced environments.
2. An approach to a quantitative assessment of the environmental impact by assigning value ratings to each natural-induced environment interaction.
3. The overall environmental picture, the identification of critical or controversial areas, the grouping together of similar actions with similar effects, by assembling the value ratings in an impact-incidence matrix, then reordering the matrix via the bond energy algorithm.

The particular association of environmental aspects in the critical area clusters may suggest to the decision maker partial or total alternatives to the proposed action. The procedure may also represent a step leading to more sophisticated system analysis techniques, such as isoquants, for the determination of the most effective environmental configurations [8].

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