THE LEOPOLD MATRIX
FOR EVALUATING ENVIRONMENTAL IMPACT

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• INTRODUCTION •

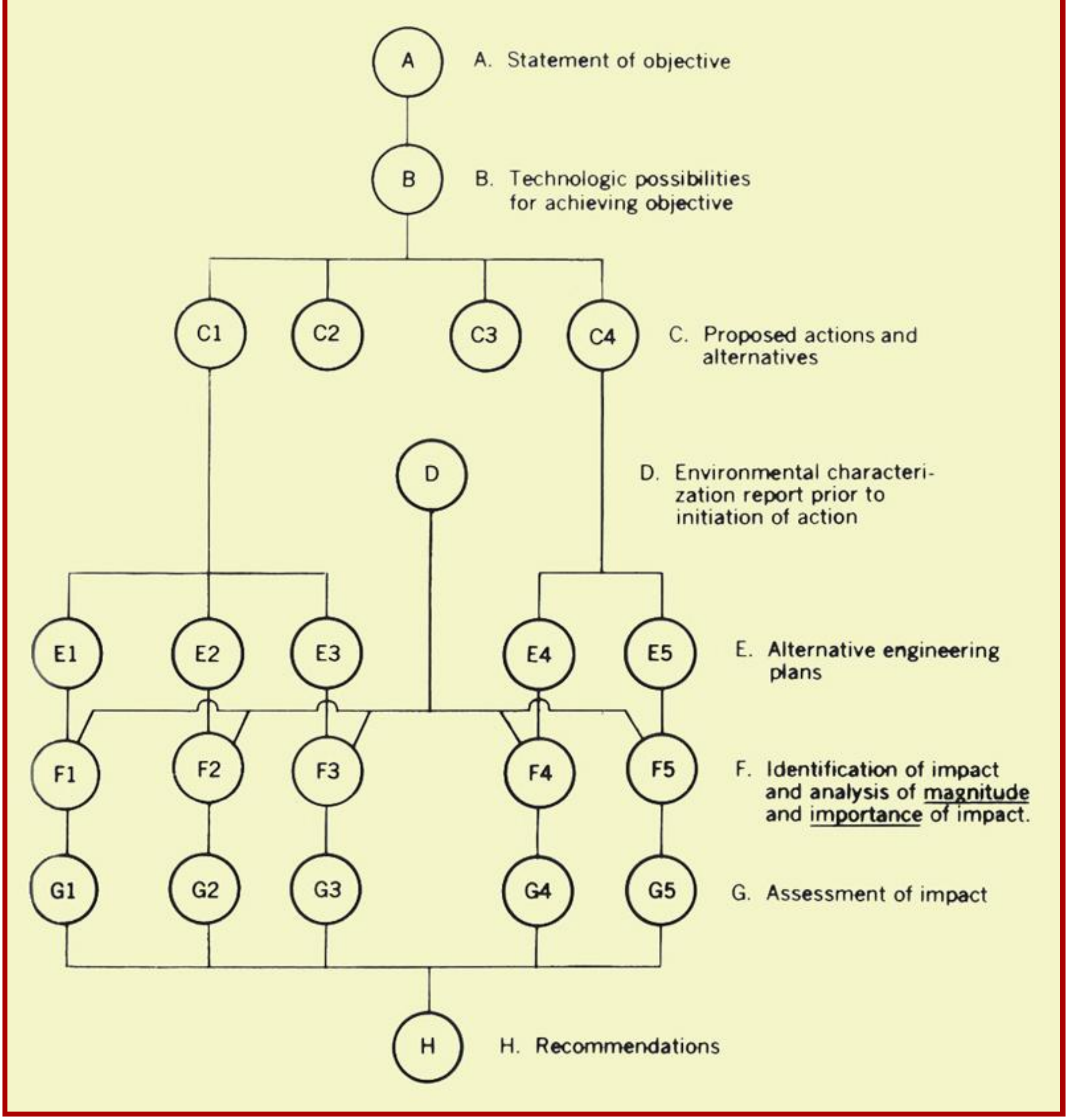
This document describes the Leopold matrix, a procedure for the evaluation of the effect or impact of a proposed development on the environment, and thus, for the evaluation of its ecological benefits and costs (Leopold et al., 1971). This evaluation comprises an Environmental Impact Statement (EIS).

The Leopold matrix (LM) was developed in 1971, in response to the Environmental Policy Act of 1969. The LM provides a system for the analysis and numerical weighting of probable impacts. The analysis does not produce an overall quantitative rating; instead, it portrays many value judgments. A primary purpose is to ensure that the impact of alternative actions is evaluated and considered in project planning.

• PROCEDURE •

The assessment of environmental impact is the next to last in a series of steps described below (Fig. 1):

- A statement of the major objective sought by the proposed project.
- Analysis of the technological possibilites for achieving the objective.
- A statement of one or more proposed actions, including alternatives, which may cause environmental impact.
- The characteristics and conditions of the environment prior to initiation of actions.
- The engineering proposals for actions, including analysis of monetary benefits and costs.
- An analysis of the environmental impacts of the proposed actions.
- An assessment of the impacts of the proposed actions on the [characteristics and conditions of the] environment.
- Summary and recommendations.



Source: Leopold et al. (1971).

Fig. 1 Flow chart for steps in the development of actions programs.

The environmental impact analysis (item F) requires the definition of two aspects of each action which may have an impact on the environment. The first is the "magnitude" of the impact upon specific sector(s) of the environment. The term "magnitude" is used here in the sense of degree, extensiveness, or scale. The second is the "importance," i.e., the significance of the proposed actions on the specific environmental characteristics and conditions. Unlike magnitude of impact, which can be readily evaluated on the basis of facts, the importance of impact is generally based on a value judgment [of the evaluator]. The numerical values of magnitude (quantitative) and importance (qualitative) reflect the best estimates of the impact of each action (item G).

The last item (H) of the Environmental Impact Statement (EIS) is a section of Summary and Recommendations. This section of the report explains:

- the relative merits of the proposed actions,
- the rationale behind the final choice of actions, and
- the plan for achieving the stated objectives.

The components of a Leopold matrix environmental impact study are shown in Fig. 2.

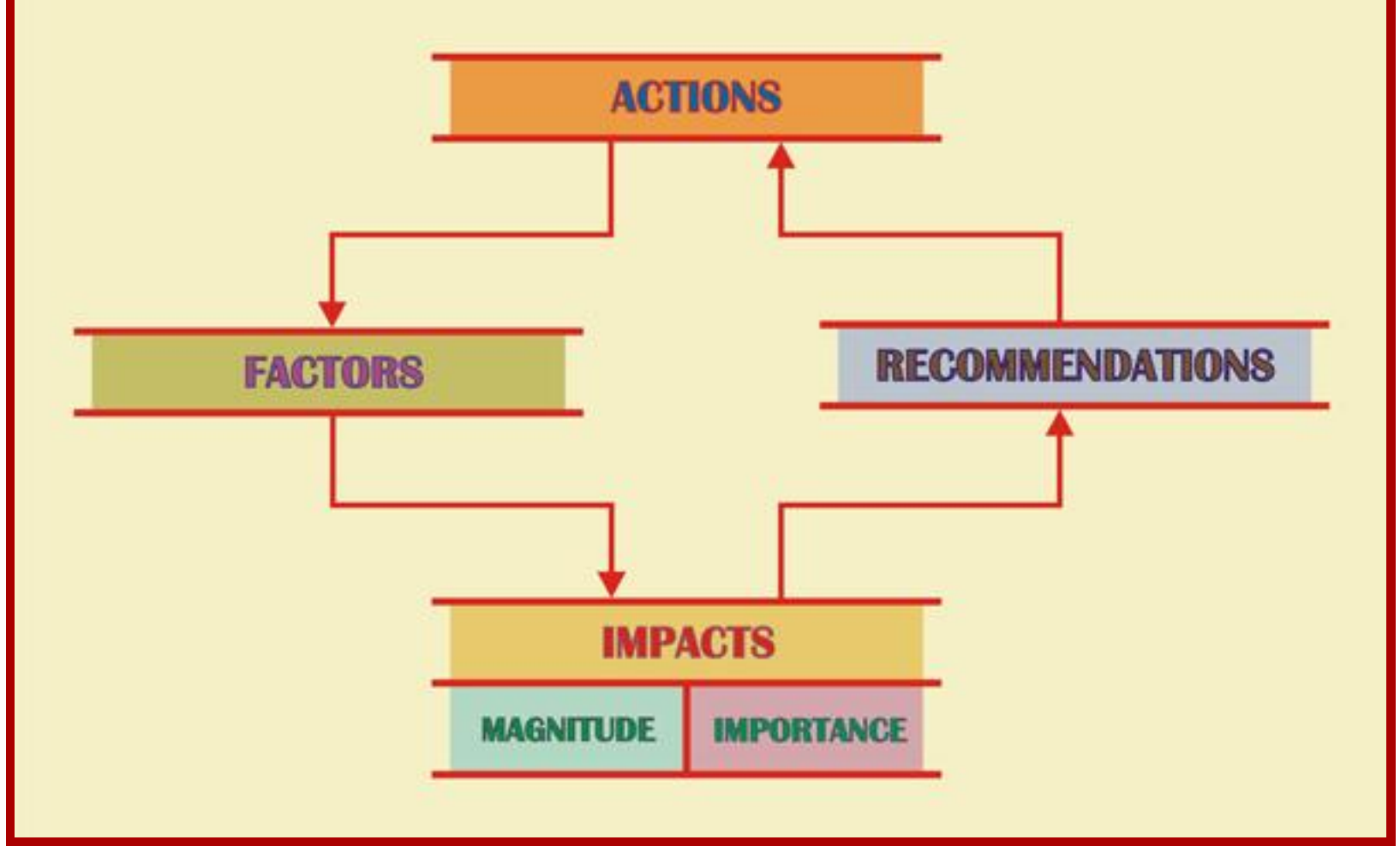


Fig. 2 Components of Leopold matrix environmental impact study.

• ENVIRONMENTAL IMPACT STATEMENT •

An Environmental Impact Statement (EIS) consists of four basic items:

1. An analysis of the need for the proposed actions (items A, B, and C of the procedure).
2. A description of the environment where the actions will take place, including delineation of pertinent boundaries (item D).
3. A discussion of the details of the proposed actions (item E).
4. An Environmental Impact Assessment (EIA) of the probable impacts of the proposed actions upon the variety of existing environmental factors [as expressed by its characteristics and conditions] (items F and G), and a summary and recommendations (item H).

Item 1 considers the full range of values to be derived, including economic and ecological.

Item 2 contains a description of the existing environmental elements and factors, with special emphasis on those rare or unique aspects. This item provides information to allow an objective evaluation of the environmental factors which could be affected [impacted] by the proposed actions. It includes all the factors which together make up the ecosystem of the area.

Item 3 includes discussion of possible alternative engineering methods or approaches to accomplish the proposed development objective. All the actions that have an impact on the environment are included.

Item 4 contains the impact assessment, which consists of four parts:

1. A listing of the effects [impacts] on the [characteristics and conditions of the] environment which would be caused by the proposed development,
2. An evaluation of the magnitude of each effect.
3. An evaluation of the importance of each effect.
4. The combining of magnitude and importance evaluations into a summary evaluation.

• LEOPOLD MATRIX •

The analysis is performed with the Leopold Matrix (LM) (Leopold et al., 1971). This matrix has: (1) on the horizontal axis, the actions which cause environmental impact, and (2) on the vertical axis, the existing environmental conditions which may be affected by those actions. This provides a format for comprehensive review of the interactions between proposed [anthropogenic] actions and environmental factors [characteristics and conditions].

The number of actions listed on the horizontal axis is 100 (Table 1). The number of environmental factors [characteristics and conditions] listed on the vertical axis is 88 (Table 2). This provides a total of 8,800 interactions. In practice, however, only a few of the interactions would be likely to involve impacts of such magnitude and importance

to warrant detailed treatment.

Table 1. Actions listed in the horizontal axis of the Leopold matrix.

ACTIONS • [Proposed actions which may cause environmental impact] •	A. Modification of regime	a. Exotic flora or fauna introduction
		b. Biological controls
		c. Modification of habitat
		d. Alteration of ground cover
		e. Alteration of groundwater hydrology
		f. Alteration of drainage
		g. River control and flow modification
		h. Canalization
		i. Irrigation
		j. Weather modification
		k. Burning
		l. Surface or paving
		m. Noise and vibration
	B. Land transformation and construction	a. Urbanization
		b. Industrial sites and buildings
		c. Airports
		d. Highways and bridges
		e. Roads and trails
		f. Railroads
		g. Cables and lifts
		h. Transmission lines, pipelines and corridors
		i. Barriers including fencing
		j. Channel dredging and straightening
		k. Channel revetments
		l. Canals
		m. Dams and impoundments
		n. Piers, seawalls, marinas, and sea terminals
		o. Offshore structures
		p. Recreational structures
		q. Blasting and drilling
		r. Cut and fill
		s. Tunnels and underground structures
	C. Resource extraction	a. Blasting and drilling
		b. Surface excavation
		c. Subsurface excavation and retorting
		d. Well drilling and fluid removal
		e. Dredging
		f. Clear cutting and other lumbering
		g. Commercial fishing and hunting
	D. Processing	a. Farming
		b. Ranching and grazing

	c. Feed lots
	d. Dairying
	e. Energy generation
	f. Mineral processing
	g. Metallurgical industry
	h. Chemical industry
	i. Textile industry
	j. Automobile and aircraft
	k. Oil refining
	l. Food
	m. Lumbering
	n. Pulp and paper
	o. Product storage
E. Land alteration	a. Erosion control and terracing
	b. Mine sealing and waste control
	c. Strip mining rehabilitation
	d. Landscaping
	e. Harbor dredging
	f. Marsh fill and drainage
F. Resource renewal	a. Reforestation
	b. Wildlife stocking and management
	c. Groundwater recharge
	d. Fertilization application
	e. Waste recycling
G. Changes in traffic	a. Railway
	b. Automobile
	c. Trucking
	d. Shipping
	e. Aircraft
	f. River and canal traffic
	g. Pleasure boating
	h. Trails
	i. Cables and lifts
	j. Communication
	k. Pipeline
H. Waste emplacement and treatment	a. Ocean dumping
	b. Landfill
	c. Emplacement of tailings, spoil and overburden
	d. Underground storage
	e. Junk disposal
	f. Oil well flooding
	g. Deep well emplacement
	h. Cooling water discharge

			i. Municipal waste discharge including spray irrigation
			j. Liquid effluent discharge
			k. Stabilization and oxidation ponds
			l. Septic tanks, commercial and domestic
			m. Stack and exhaust emission
			n. Spent lubricants
		I. Chemical treatment	a. Fertilization
			b. Chemical deicing of highways
			c. Chemical stabilization of soils
			d. Weed control
			e. Insect control with pesticides
		J. Accidents	a. Explosions
			b. Spills and leaks
			c. Operational failure
		K. Others	a. To be determined
			b. To be determined

Table 2. Factors listed in the vertical axis of the Leopold matrix.

FACTORS • [Existing characteristics and conditions of the environment] •	A. Physical and chemical characteristics	1. Earth	a. Mineral resources
			b. Construction material
			c. Soils
			d. Land form
			e. Force fields and background radiation
			f. Unique physical features
		2. Water	a. Surface
			b. Ocean
			c. Underground
			d. Quality
			e. Temperature
			f. Recharge
			g. Snow, ice, and permafrost
		3. Atmosphere	a. Quality (gases, particulates)
			b. Climate (micro, macro)
			c. Temperature
		4. Processes	a. Floods
			b. Erosion
			c. Deposition (sedimentation, precipitation)
			d. Solution
			e. Sorption (ion exchange, complexing)
			f. Compaction and settling
			g. Stability (slided, slumps)
			h. Stress-strain (earthquake)
			i. Air movements

	B. Biological conditions	1. Flora	a. Trees
			b. Shrubs
			c. Grass
			d. Crops
			e. Microflora
			f. Aquatic plants
			h. Endangered species
			h. Barriers
			i. Corridors
		2. Fauna	a. Birds
			b. Land animals, including reptiles
			c. Fish and shellfish
			d. Benthic organisms
			e. Insects
			f. Microfauna
			g. Endangered species
			h. Barriers
			i. Corridors
	C. Cultural factors	1. Land use	a. Wilderness and opne spaces
			b. Wetlands
			c. Forestry
			d. Grazing
			e. Agriculture
			f. Residential
			g. Commercial
			h. Industrial
			i. Mining and quarrying
		2. Recreation	a. Hunting
			b. Fishing
			c. Boating
			d. Swimming
			e. Camping and hiking
			f. Picnicking
			g. Resorts
		3. Aesthetics and human interest	a. Scenic view and vistas
			b. Wilderness qualities
			c. Open space qualities
			d. Landscape design
			e. Unique physical features
			f. Parks and reserves
			g. Monuments
			h. Rare and unique species or ecosystems
			i. Historical or archaeological sites and objects

		j. Presence of misfits
	4. Cultural status	a. Cultural patterns (life style)
		b. Health and safety
		c. Employment
		d. Population density
	5. Man-made facilities and activities	a. Structures
		b. Transportation network (movement, access)
		c. Utility networks
		d. Waste disposal
		e. Barriers
		f. Corridors
	D. Ecological relationships such as	a. Salinization of water resources
		b. Eutrophication
		c. Disease-insect vectors
		d. Food chains
		e. Salinization of surficial material
		f. Brush encroachment
		g. Other
	E. Others	a. To be determined
		b. To be determined

Not all the actions and factors apply to every project proposal; in some cases, other actions and factors not considered here may be warranted. According to Leopold et al. (1971), the number of interactions for a typical project is between 25 and 50.

The most efficient way to use the matrix is to check each significant action [listed on the horizontal axis]. Generally, only about a dozen actions will be significant. Each action checked is evaluated in terms of magnitude of effect on environmental characteristics and conditions [listed on the vertical axis]. A slash (/) is placed diagonally from upper right to lower left across each block where significant interaction is expected. The discussion in the text should indicate whether the assessment is on short-term or long-term impacts.

The most important blocks marked are evaluated individually, and a number between 1 and 10 is placed in the upper left-hand corner to indicate the relative magnitude of the impact (1 represents the least magnitude, and 10 the greatest). Likewise, a number between 1 and 10 is placed in the lower right-hand corner to indicate the relative importance of the impact (again, 1 represents the least magnitude, and 10 the greatest).

The next step is to evaluate the numbers which have been placed in the slashed boxes. It is convenient to construct a reduced matrix which consists only of those actions and environmental characteristics which have been identified as interacting. Special note may be taken of boxes with high numbers. The high or low numbers on any one box indicates the degree of impact of the applicable action on the given characteristic of the environment. The assignment of magnitude and importance numbers is based, to the extent possible, on factual data rather than on the evaluator's preference.

The rating scheme requires the evaluator to quantify his/her judgment regarding the probable impacts. The scheme allows the reviewers to systematically follow the evaluator's line of reasoning, to aid in identifying points of agreement and disagreement. In fact, the matrix is the abstract for the text of the environmental impact assessment.

• ENVIRONMENTAL IMPACT ASSESSMENT •

The Environmental Impact Assessment (EIA) is a discussion of the individual boxes marked with the larger numbers for magnitude and importance. Those columns which have a large number of factors marked are discussed in detail, regardless of the assigned numbers. Likewise, those rows which have a large number of actions marked are discussed in detail, regardless of the numbers.

The discussion covers the following points or aspects:

1. A description of the proposed action.

2. The probable impact of the proposed action on the individual factor.

3. Any adverse environmental effects which cannot be avoided.

4. Alternatives to the proposed action.

5. The relation between local short-term use of the human environment and the maintenance and enhancement of long-term productivity.

   Any irreversible and irretrievable commitments of resources which would be involved in the proposed action.

6. Any other issues raised by federal, state, and local agencies, and by appropriate organizations or individuals.

The text of the EIA is a discussion of the reasoning behind the assignment of numbers for the magnitude and importance of impacts. A discussion of the principal characteristics of the proposed action and of the affected ecosystem is included. A description of the geography, physical setting, vegetation, climate, and other facts about the physics, chemistry, and biology of the proposed action and the affected ecosystem is part of the EIA. However, the amount of detail should be only that needed to assess the environmental impact. The completed Environmental Impact Assessment (EIA) is an intrinsic part of the Environmental Impact Statement (EIS).

• CONCLUDING STATEMENT •

The Leopold matrix provides a simple way to summarize and rank environmental impacts, and to focus on those that are considered to be greatest. The advantage of the matrix format is its reminder of the full range of actions, factors, and related impacts. As far as possible, the assignment of magnitude is based on factual information. However, the assignment of importance may leave some room for the subjective opinion of the evaluator. This separation of fact from opinion is an asset of the Leopold matrix.

REFERENCES

Leopold, L. B., F. E. Clarke, B. B. Hanshaw, and J. E. Balsley. 1971. A procedure for evaluating environmental impact. U.S. Geological Survey Circular 645, Washington, D.C.