Impact identification methods

4

Environmental impact assessment (EIA) is an approach developed to protect the nature and the environment in a systematic and scientific manner. Mesopotamia provides a convenient starting point for the review of EIA issues. The people are effective at constructing cities and large-scale agricultural projects to provide food to support the various dwelling units. Unfortunately, their irrigation schemes and approach to the land resulted in salting, flooding and destruction of the countryside, and damage to the environment resulting reduction in the quality of human life. It is significant that the first urban societies were also the first societies to abandon a religious attitude of oneness with nature and to adopt one of separation. In some cases, the stewardship approach has been extended to fit the situation of development with an environment conscience. For example, in India, it was said that concern for the natural environment was not limited to the protection of resources and maintenance of natural processes, but society has been helping to the transformation of nature, in many ways like deliberate changes for the benefit of people, enrichment of natural resources for their fuller utilization, for the increased productivity of the environment, and for the suppression of harmful natural processes.

To apply the remedial measures, one should understand and identify the potential impacts due to developmental activities. Based on such identified impacts, the impacts on the surrounding environment can be predicted, and assessment should be done by using appropriate methods. The methods are frequently embodied in policies and actions. The pertinent information can be procured from various government institutions both national and local level. Such information products are very much useful in EIA study and to prepare the report.

Environmental impact study comprised a number of activities including impact identification, preparation of the description of the affected environment, impact prediction and assessment, selection of the remedial measures from the alternatives evaluated to meet identified needs, and summarization and communication of information. The objectives of the various activities differ, as do the pertinent methodologies for accomplishing the activities. The term methodology as used herein refers to structured approaches for accomplishing one or more of the basic activities. The structured approaches encompass various substantive areas within the biophysical and socioeconomic environments, thus distinguishing them from impact prediction methods or models for specific substantive areas. There are a number of factors that will influence the approach adopted for the identification and assessment of direct, indirect, cumulative impacts, for a particular project. The method should be practical and suitable for the project given the data, time, and financial resources available. However, the method adopted should be able to provide a meaningful conclusion from

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which it would be possible to develop, where necessary, mitigation measures and monitoring strategies. Key points to consider when choosing the method(s) include nature of the impact(s), availability and quality of data, and availability of resources like time, finance, and staff. The method chosen should not be complex, but should aim at presenting the results in a way that can be easily understood by the developer, the decision-maker, and the public.

Numerous methodologies have been developed to aid in achieving the various activities in the EIA process. The purpose of this chapter is to describe some simple methods for impact identification.

4.1 Impact identification (II) methodologies

Impact identification methodologies can be broadly categorized into five types. They are interaction matrices, checklists, networks, overlay techniques, and expert system.

Interaction matrices range from simple considerations of project activities and their impacts on environmental factors to stepped approaches that display interrelationships between impacted factors. Based on the consideration of project activities, the interaction matrices are classified as simple matrices, stepped matrices, and other matrices.

Checklists range from simple listings of environmental factors to descriptive approaches that include information on the measurement, prediction, and interpretation of changes for identified factors. Checklists may also involve the scaling or rating (or ranking) of the impacts of alternatives on each of the environmental factors under consideration. Scaling or rating techniques include the use of numerical scores, letter assignments, or linear proportioning. Alternatives can be ranked from best to worst in terms of potential impacts on each factor. The most sophisticated checklists are those involving the assignment of importance weights to environmental factors and the scaling-rating of the impacts for each alternative on each factor. The index or score is determined by multiplying importance weights by the scale-rating value for each alternative. Hence, based on the concept, checklists are termed as simple checklist and descriptive checklist.

The third category is networks. This method is mainly based on the integration of impact causes, consequences, and interrelationships between them. The fourth category is called as overlay technique that is mainly based on environmental factors, impacts, and advanced technologies like geographic information systems (GIS). The fifth category is termed as expert systems.

Methodologies for impact identification can be useful, although not specifically required, throughout the impact assessment process, with certain ones being of greater value for specific activities. For example, matrices and networks are particularly useful for impact identification, while weighting and scaling, rating, or ranking checklists find greatest application in the final evaluation of alternatives and the selection of proposed action (Lee, 1983). It is not necessary to use a methodology in an impact study; it may be instructive to use portions of several methodologies for certain requisite activities. Some desirable characteristics of an EIA method selected for usage include the following: (1) It should be appropriate to the necessary task, such as impact identification or comparison of alternatives, and not all methods are equally useful for all tasks; (2) it should be sufficiently free from assessor bias, and the results should be essentially reproducible from one assessor group to another; and (3) it should be economical in terms of costs and the requirements of data, investigation time, personnel, and equipment and facilities (Lee, 1983).

In addition to matrices, checklists, networks, and overlay techniques, several other classifications of methodologies have been developed. For example, impact methodologies are divided into five main classes: ad hoc procedures, overlay techniques, checklists, matrices, and networks (Canter, 1986). Ad hoc procedures involve assembling a team of specialists to identify impacts in their areas of expertise. While numerous methodologies have been developed and still additional methodologies are emerging, there is no "universal" methodology that can be applied to all project types in all environmental settings. It is unlikely that an all-purpose methodology will be developed, given the lack of technical information and the need for exercising subjective judgment about predicted impacts in the environmental setting wherein the project may occur. Accordingly, an appropriate perspective is to consider methodologies and tools that can be used to aid the EIA process. In that sense, every utilized methodology should be project- and location-specific, with the basic concepts derivable from existing methodologies. These could be called "ad hoc" methods.

4.2 Uses of impact identification (II) methods

Methodologies do not provide complete answers to all questions related to the impacts of a potential project or set of alternatives. Methodologies are not "cookbooks" in which a successful study is achieved by meeting the detailed requirements of the methodologies. Methodologies must be selected based on appropriate evaluation and professional judgment, and they must be used with the continuous application of judgment relative to data inputs and analysis and interpretation of results. The purpose and uses of impact identification methods are the following:

- **(i)** To insure that all pertinent environmental factors are included in the study and contain lists of environmental factors ranging from about 50–500 items, with the majority having between 50 and 120 items. These numericals are based on the experience of the author of this book.
- **(ii)** To aid in planning baseline studies in locations where relevant environmental data are lacking. For example, if information is not available on the factors identified using appropriate methodologies, it may be determined by field studies.
- **(iii)** To provide a means for the synthesis of information and the evaluation of alternatives on a common basis. In many cases, alternatives have been eliminated from detailed consideration based on economic comparisons. Usage of structured methodologies can provide the basis for the evaluation of alternatives using a common framework of decision factors.
- **(iv)** To evaluate the cost-effectiveness of proposed impact mitigation (IM) measures. Evaluation of a proposed project with and without mitigation will enable a clearer delineation of the effectiveness of potential IM measures.
- **(v)** To communicate the resultant information to other practitioners, regulatory agencies, and the general public that is an important element in impact studies. Some methodologies

have features that are particularly useful in communicating impact information in summary form; an example is the simple interaction matrix.

(vi) To ensure that unquantified environmental amenities and values be given appropriate consideration in decision-making, along with more traditional economic and technical considerations.

The term "overlay techniques" describes several well-developed approaches used in planning and landscape architecture. These techniques are based on the use of a series of overlay maps depicting environmental factors or land features (McHarg, 1971a, 1971b). The overlay approach is generally effective for selecting alternatives and identifying certain types of impacts; however, it cannot be used to quantify impacts or to identify secondary and tertiary interrelationships. Overlay techniques utilizing computerization for more effective data analysis have been developed. GIS are now being used as layered overlay mapping techniques.

The primary focus of this chapter will be on the use of matrix, network, simple descriptive checklist methods, and overlay and expert systems for impact identification. In using these methodologies, it is important to delineate the uncertainty associated with impact predictions (Lee, 1983). In other words, the use of scientific approaches will require the exercise of professional judgment in the interpretation of the results.

4.3 Interaction-matrix methods

A matrix is a grid-like table that is used to identify the interaction between project activities, which are displayed along one axis, and environmental characteristics, which are displayed along the other axis. Using the table, environment-activity interactions can be noted in the appropriate cells or intersecting points in the grid. "Entries" are made in the cells to highlight impact severity or other features to the nature of the impact; for instance, tick or symbols can identify impact type (such as direct, indirect, and cumulative) pictorially, numbers or a range of dot sizes can indicate scale, or descriptive comments can be made.

An early, well-known example is the Leopold interaction matrix. This is a comprehensive matrix, which has 88 environmental characteristics along the top axis and 100 project actions in the left hand column. Potential impacts are marked with a diagonal line in the appropriate cell, and a numerical value can be assigned to indicate their magnitude and importance. Use of the Leopold matrix is less common than its adoption to develop other, less complex matrices.

Interaction matrices are one of the earliest types of EIA methodologies. A "simple interaction matrix" displays project actions or activities along one axis, with appropriate and corresponding environmental factors listed along the other axis of the matrix. When a given action or activity is expected to cause a change in an environmental factor, this is noted at the intersection point in the matrix and further described in terms of separate or combined magnitude and importance considerations. Many variations of the simple interaction matrix have been utilized in impact studies, including stepped matrices (Canter, 1986). The three types of interaction matrices are described in the following para.

4.3.1 Simple matrices

The interaction-matrix method developed by Leopold et al. (1971) will be used as an example of a simple matrix. The matrix lists approximately 100 specified actions and 90 environmental items. Fig. 4.1 illustrates the concept of the Leopold matrix, and Table 4.1 contains the list of the actions and environmental items. In the use of the Leopold matrix, each action and its potential for creating an impact on each environmental item must be considered. Where an impact is anticipated, the matrix is marked with a diagonal line in the appropriate interaction box.

The second step in using the Leopold matrix is to describe the interaction in items of its magnitude and importance. The "magnitude" of an interaction is its extensity or scale and is described by the assignment of a numerical value from 1 to 10, with 10 representing a large magnitude and 1 a small magnitude. Values near 5 on the magnitude scale represent the impacts of intermediate extensity. Assignment of a numerical value for the magnitude of an interaction should be based on an objective evaluation of facts related to the anticipated impact. The "importance" of an interaction is related to its significance or an assessment of the probable consequences of the anticipated impact. The scale of importance also ranges from 1 to 10, with 10 representing a very important interaction and 1 an interaction of relatively low importance. Assignment of a numerical importance value is based on the subjective judgment of the individual, small group, or interdisciplinary team working on the study.

One of the attractive features of the Leopold matrix is that it can be expanded or contracted—that is, the number of actions can be increased or decreased from the total of about 100, and the number of environmental factors can be increased or decreased from about 90. The primary advantages of using the Leopold matrix are that it is very useful as a gross screening tool for impact identification purposes and it can provide a

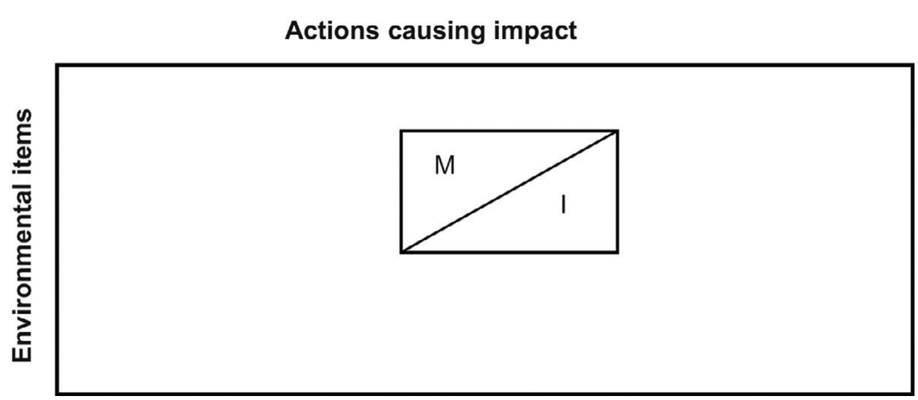

Fig. 4.1 Leopold interaction matrix; M, magnitude; I, importance (Leopold et al., 1971).

Table 4.1 **Actions and environmental items in Leopold interaction matrix (Leopold et al., 1971)**

Actions		Environmental items	
Category	**Description**	**Category**	**Description**
A. Modification of regime	(a) Exotic fauns introduction	A. Physical and chemical characteristics	
	(b) Biological controls		
	(c) Modification of habitat		
	(d) Alteration of ground cover	1. Earth	(a) Mineral resources
	(e) Alteration of groundwater hydrology		(b) Construction material
			(c) Soils
	(f) Alteration of drainage		(d) Land form
	(g) River control and flow modification		(e) Force fields and background radiation
	(h) Canalization		(f) Unique physical features
	(i) Irrigation	2. Water	(a) Surface
	(j) Weather modification		(b) Ocean
	(k) Burning		(c) Underground
	(l) Surfacing or paving		(d) Quality
	(m) Noise and vibration		(e) Temperature
B. Land transformation and construction	(a) Urbanization		(f) Recharge
	(b) Industrial sites and buildings		(g) Snow, ice, and permafrost
	(c) Airports	3. Atmosphere	(a) Quality (gases and particulates)
	(d) Highways and bridges		
	(e) Roads and trails		(b) Climate (micro and macro)
	(f) Railroads		(c) Temperature
	(g) Cables and lifts		
	(h) Transmission lines, pipelines, and corridors	4. Processes	(a) Floods
			(b) Erosion
	(i) Barriers, including fencing		(c) Deposition (sedimentation and precipitation)
	(j) Channel dredging and straightening		
			(d) Solution
	(k) Channel		(e) Sorption (ion exchange and complexing)
	(l) Canals		

	(m) Dams and impoundments		(f) Compaction and settling
	(n) Piers, seawalls, marinas, and sea terminals		(g) Stability (slides and slumps)
	(o) Offshore structures		(h) Stress-strain (earthquakes)
	(p) Recreational structures		(i) Air movements
	(q) Blasting and drilling	B. Biological conditions	
	(r) Cut and fill	1. Flora	(a) Trees
	(s) Tunnels and underground structures		(b) Shrubs
			(c) Grass
			(d) Crops
C. Resource extraction	(a) Blasting and drilling		(e) Microflora
	(b) Surface excavation		(f) Aquatic plants
	(c) Subsurface excavation and retorting		(g) Endangered species
			(h) Barriers
	(d) Well dredging and fluid removal		(i) Corridors
	(e) Dredging		
	(f) Clear cutting and other lumbering	2. Fauna	(a) Birds
	(g) Commercial fishing and hunting		(b) Land animals including reptiles
D. Processing	(a) Farming		(c) Fish and shellfish
	(b) Ranching and grazing		(d) Benthic organisms
	(c) Feed lots		(e) Insects
	(d) Dairying		(f) Microfauna
	(e) Energy generation		(g) Endangered species
	(f) Mineral processing		(h) Barriers
	(g) Metallurgical industry		(i) Corridors
	(h) Chemical industry		
	(i) Textile industry	C. Cultural factors	(a) Wilderness and open spaces
	(j) Automobile and aircraft	1. Land use	(b) Wetlands
	(k) Oil refining		(c) Forestry
	(l) Food		(d) Grazing

Continued

Table 4.1 Continued

Actions		Environmental items	
Category	**Description**	**Category**	**Description**
	(m) Lumbering		(e) Agricultural
	(n) Pulp and paper		(f) Residential
	(o) Product storage		(g) Commercial
			(h) Industry
E. Land alteration	(a) Erosion control and terracing		(i) Mining and quarrying
	(b) Mine sealing and waste control		
	(c) Strip-mining rehabilitation	2. Recreation	(a) Hunting
	(d) Landscaping		(b) Fishing
	(e) Harbor dredging		(c) Boating
	(f) Marsh fill and drainage		(d) Swimming
			(e) Camping and hiking
F. Resource renewal	(a) Reforestation		(f) Picnicking
	(b) Wildlife stocking and management		(g) Resorts
	(c) Groundwater recharge	3. Esthetics and human interest	(a) Scenic views and vistas
	(d) Fertilization application		(b) Wilderness qualities
	(e) Waste recycling		(c) Open-space qualities
			(d) Landscape design
G. Changes in traffic	(a) Railway		(e) Unique physical features
	(b) Automobile		(f) Parks and reserves
	(c) Trucking		(g) Monuments
	(d) Shipping		(h) Rare and unique species or ecosystems
	(e) Aircraft		
	(f) River and canal traffic		(i) Historical or archeological sites and objects
	(g) Pleasure boating		
	(h) Trails		(j) Presence of misfits
	(i) Cables and lifts		
	(j) Communication		
	(k) Pipeline		

H. Waste emplacement and treatment	(a) Ocean dumping (b) Landfill (c) Emplacement of tailings, spoils, 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	4. Cultural status	(a) Cultural patterns (lifestyle) (b) Health and safety (c) Employment (d) Population density
		5. Manufactured facilities and activities	(a) Structures (b) Transportation network (movement and access) (c) Utility networks (d) Waste disposal (e) Barriers (f) Corridors
		D. Ecological relationships	(a) Salinization of water resources (b) Eutrophication (c) Disease and insect vectors (d) Food chains (e) Salinization of surficial material (f) Brush encroachment (g) Other
I. Chemical treatment	(a) Fertilization (b) Chemical deicing of highways, etc. (c) Chemical stabilization of soil (d) Weed control (e) Insect control (pesticides)	E. Others	
J. Accidents	(a) Explosions (b) Spills and leaks (c) Operational failure		
K. Others			

valuable means for impact communication by providing a visual display of the impacted items and of the major actions causing impacts.

Summation of the number of rows and columns designated as having interactions can offer insight into impact assessment. Additional refinements can be used to discuss the results of a simple interaction matrix. For example, assume that a matrix incorporates the impacts of 8 actions on 20 environmental factors. Further, assume that the average action would cause 10 factors to be impacted and the average number of impacts per factor is 6. The impacts could be grouped and discussed in items of those actions exhibiting a greater-than-average, near-average, and fewer-than-average number of impacts. A similar approach could be used for addressing the impacted factors.

The Leopold matrix can also be utilized to identify beneficial and detrimental impacts through the use of appropriate designators, such as plus and minus signs. In addition, the Leopold matrix can be employed to identify impacts at various temporal phases of a project, for example, construction, operation, and post operation phases, and to describe impacts associated with various spatial boundaries, namely, at the site and in the region.

Many uses of the Leopold matrix have involved the assignment of three levels of magnitude and importance. Major interactions would be assigned maximum numerical scores, with minor interactions being assigned minimal scores. Intermediate-level interactions would be assigned values between the major and minor scores.

In Table 4.2, there are very few items in the list of environmental factors that are oriented to the socioeconomic environment. This does not mean that these items could not be added, but rather that in 1970 and 1971, the period of time in which the matrix concept was developed, less emphasis was given to this substantive area.

Variations of the Leopold matrix have been utilized for impact analysis for many types of projects, like aviation-type projects, highway projects, power projects, infrastructure projects, and mining projects. Condensed versions of the Leopold matrix have also been employed in EIA studies for a coal mine, a generation plant, a country road and railroad project, a water supply system, and a transmission line, etc.

Information expressed by means of ranks other than numerical values for magnitude and importance can be included in the impact scales associated with identification of an interaction. In an earth-filled dam project, the potential impact of various actions on environmental factors has been shown in 11 categories: neutral, a range of 5 degrees of beneficial impact (Chase, 1973). Scales have also been used to describe the probability of occurrence of an impact, with the scale ranging from low to intermediate to high probability of impact. Impact scales can also be developed to show the extent of potential reversibility associated with a beneficial or detrimental impact. This varies based on the type and nature of developmental project.

Another approach for impact rating in a matrix involves the use of a predefined code denoting the characteristics of the impacts and whether or not certain undesirable features could be mitigated. Table 4.3 displays an example of this type of an interaction matrix for a proposed wastewater collection, treatment, and disposal project, for example, Maa wastewater treatment plant at Nacharam and Mallapur industrial area

Table 4.2 List of environmental attributes

Actions that may cause impact		Environmental conditions	
Category	**Action**	**Category**	**Factor**
A. Elements of design and location	(a) Modification of habitat	A. Physical and chemical characteristics	(a) Mineral resources, precious
1. Modification of regime	(b) Alteration of groundwater hydrology	1. Earth	(b) Mineral resources, common
	(c) Canalization		(c) Soils
	(d) Irrigation		(d) Land form
	(e) Surfacing and paving		
3. Well drilling	(a) Reforestation	B. Biological characteristics	(a) Trees
4. Resource renewal and protection	(b) Scenic-strip acquisition	1. Flora	(b) Shrubs
5. Changes in traffic	(a) Railway		(c) Grass
	(b) Automobile		(d) Crops
	(c) Trucking		(e) Microflora
	(d) River and canal traffic		(f) Aquatic plants
	(e) Pleasure boating		(g) Endangered species
	(f) Trails		(h) Barriers
	(g) Communication		(i) Corridors
	(h) Pipeline		
		2. Fauna	(a) Birds
			(b) Land animals
			(c) Fish and shellfish
			(d) Other aquatic organisms
			(e) Insects
			(f) Microfauna
			(g) Endangered species
			(h) Barriers
			(i) Corridors

Continued

Table 4.2 Continued

Actions that may cause impact		Environmental conditions	
Category	**Action**	**Category**	**Factor**
B. During construction 1. Modification of regime	(a) Exotic flora and fauna introduction (b) Biological controls (c) Alteration of ground cover (d) Alternation of drainage (e) River control and flow modification burning		
3. Resource extraction	(a) Blasting and drilling (b) Surface excavation (c) Subsurface excavation (d) Well drilling and fluid removal (e) Dredging		
4. Changes in traffic	(a) Railway (b) Automobile (c) Trucking (d) River and canal traffic (e) Pleasure boating (f) Trails (g) Communication (h) Pipeline	2. Recreation	(a) Hunting (b) Fishing (c) Boating (d) Swimming (e) Camping (f) Hiking (g) Picnicking (h) Resorts (i) Winter sports (j) Rockhounding
5. Waste emplacement and treatment	(a) Landfill (b) Emplacement of tailings, spoil, and overburden (c) Liquid and exhaust discharge (d) Stack and exhaust emissions (e) Occurrence of spent lubricants	3. Esthetics and human interest	(a) Scenic views and vistas (b) Wilderness qualities (c) Open-space qualities (d) Landscape design (e) Unique physical features

6. Chemical stabilization of soil			
7. Accidents	(a) Explosions (b) Spills and leaks (c) Operational failure		
8. Chemical treatment	(a) Fertilization (b) Chemical deicing (c) Weed control (d) Insect control		
9. Accidents	(a) Explosions (b) Spills and leaks (c) Operational failures	5. Manufactured facilities and activities	(a) Structures (b) Transportation (c) Utility networks (d) Waste disposal (e) Barriers (f) Corridors (g) Government activities

Table 4.3 Interaction matrix a typical example (CETP)

Environmental attributes	Baseline quality	Construction phase				Operation phase			
		Collection system	Treatment plant	Outfall line	Resultant quality	Collection system	Treatment plant	Outfall line	Resultant quality
Air quality	In compliance with air quality standards	A/M	A/M	a	Dusts, CO	a (odor at lift station sites)	A/m	O	Localized odor
Noise	Typical of urban residential areas	A/M	A/M	a	Increase in local noise	a (pumps)	a	a (pumps)	Small increase in noise
Groundwater	Satisfactory for area	O	O	O	Same as existing	b	b	b	Better quality due to less sheet water discharge
Beach erosion, coral reef, and coastal water quality	Erosion of 0.1–0.3 m/yr. deteriorating coral reef and coastal water quality	NA	NA	a (Water quality)	Turbidity increase	b	SB	NA	Improve quality
Traffic	No problem as it is inside the industry	SA/M	a	a	Increase in congestion	a	a	a	Continued problem due to the movement of vehicles

A, adverse impact; M, mitigation measure planned for adverse impact; a, small adverse impact; O, no anticipated impact; NA, environmental factor not applicable; SA, significant adverse impact; b, small beneficial impact; B, beneficial impact; SB, significant beneficial impact.
(*Source*: Canter, L.W., 1991. Interdisciplinary teams in environmental impact assessment. Environ. Impact Assess. Rev., 11(4), 375–387.

developed jointly by Indwa group, Government of India and Government of Andhra Pradesh. The following definitions are used for the codes (Canter, 1991):

SB = Significant beneficial impact represents a highly desirable outcome in terms of either improving the existing quality of the environmental factor or enhancing that factor from an environmental perspective.

SA = Significant adverse impact represents a highly undesirable outcome in terms of either degrading the existing quality of the environmental factor or disrupting that factor from an environmental perspective.

B = Beneficial impact represents a positive outcome in terms of either improving the existing quality of the environmental factor or enhancing that factor from an environmental perspective.

A = Adverse impact represents a negative outcome in terms of their degrading the existing quality of the environmental factor or disrupting that factor from an environmental perspective.

B = Small beneficial impact represents a minor improvement in the existing quality of the environmental factor or a minor enhancement in that factor from an environmental perspective.

A = Small adverse impact represents a minor degradation in the existing quality of the environmental factor or a minor disruption in that factor from an environmental perspective.

O = No measurable impact is expected to occur as a result of considering that project action relative to the environmental factor.

N = Some type of mitigation measure can be used to reduce or avoid a minor adverse, adverse, or significant adverse impact.

NA = The environmental factor is not applicable or not relevant to the proposed project.Simple interaction matrices have been used for analyzing the impacts include flood control and/or hydropower, highway, transmission line, offshore projects, coal mine, power plant, industrial plant, industrial park, construction and building projects, and area development projects.

4.3.2 Stepped matrices

A stepped matrix, also called as cross impact matrix, can be used to address secondary and tertiary impacts of initiating actions. A stepped matrix is one in which environmental factors are displayed against other environmental factors. The consequences and of initial changes in some factors on other factors can be displayed. Fig. 4.2 displays the concept of a stepped matrix.

In the figure, action 3 impacts factor D; changes in factor then cause changes in factors A and F. Finally, changes in factor A cause changes in factors B and I, while changes in factor F cause changes in factor H. Stepped matrices facilitate the tracing of impacts and the recognition of the environment as a system; they represent an intermediate method between simple matrices and networks. Stepped matrices with multiple actions and several types and levels of impact can become visually complicated (Canter, 1986).

Johnson and Bell (1975) developed both a simple and stepped (cross impact) interaction matrix for identifying impacts from the construction and operation of water resource reservoir projects. Project activities and the 92 included environmental attributes are listed in Table 4.4. Definitions for each were included in the method. Both

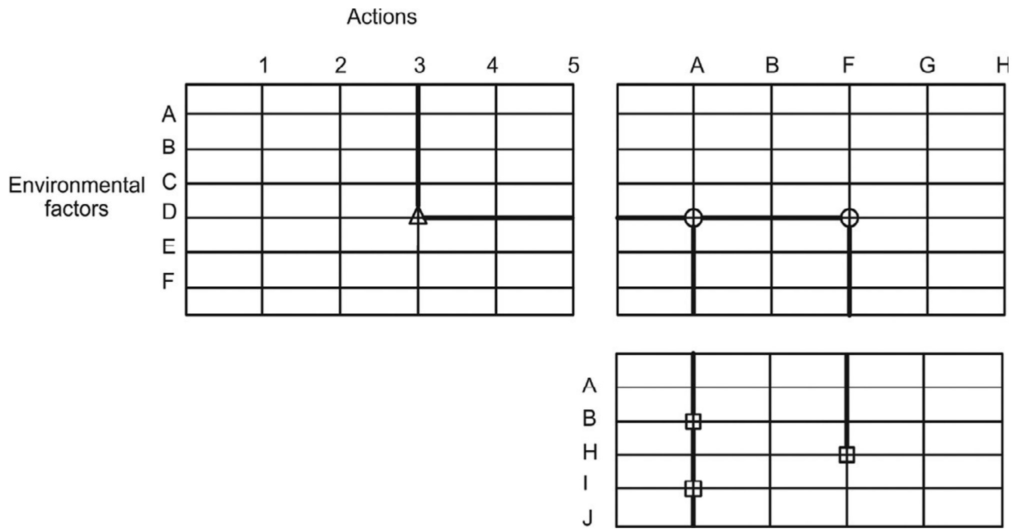

Fig. 4.2 Concept of stepped matrix.

Table 4.4 Concept of an environmental baseline matrix

Identification	**Evaluation**		
Environmental elements/units	**Scale of importance**	**Scale of present condition**	**Scale of management**
	1 2 3 4 5 **Low high**	**1 2 3 4 5** **Low high**	**1 2 3 4 5** **Low high**
Biological:			
Flora Fauna Ecological relationships			
Physical-chemical:			
Atmosphere Water Earth			
Cultural:			
Households Communities Economy Communications			
Biocultural linkages/units:			
Resources Recreation Conservation			

letters and numbers were used in impact rating; for example, a rating could be A3, based on the following categories (Johnson and Bell, 1975, p. 3):

A = adverse, always occurs
B = adverse, usually occurs
C = adverse, sometimes occurs
N = not necessary good or bad
X = beneficial, always occurs
Y = beneficial, usually occurs
Z = beneficial, sometimes occurs
1 = strong, permanent
2 = moderate, permanent
3 = minor, permanent
4 = strong, temporary
5 = moderate, temporary
6 = minor, temporary
Blank = no impact

4.3.3 Development of a simple matrix

It is considered better to develop a specific matrix for the project, plan, program, or policy being analyzed, rather than using a generic matrix. The following steps can be used by an individual or an interdisciplinary team in preparing a simple interaction matrix:

1. List all anticipated project actions and group them according to temporal phase, such as construction, operation, and postoperation.
2. List all pertinent environmental factors from the environmental setting and group them (a) according to physical-chemical, biological, cultural, and socioeconomic categories and (b) based on spatial considerations such as site and region or upstream site and downstream.
3. Discuss the preliminary matrix with study team members and/or advisors to team or study manager.
4. Decide on an impact-rating scheme (e.g., numbers, letters, or colors) to be used.
5. Talk through the matrix as a team and make ratings and notes in order to identify and summarize impacts (documentation).

4.3.4 Other types of matrices

Simple matrices can also be used for purposes other than impact identification. For example, Table 4.4 shows a matrix framework that can be used to summarize baseline environmental conditions. In this example, relative factor importance, present condition, and extent of management can be taken into consideration.

Importance weighting of impacts can also be included in interaction matrices (Lohani and Halim, 1990). A final example of using a matrix approach relates to the adaptive environmental assessment (AEA) process developed in the early 1970s. The methodology uses short, intensive workshops in which participants, resource specialists, managers, and policy makers are assisted by a workshop staff in the construction of an interactive, computerized simulation model of the resource system being studied. The modeling exercise is used to promote communication and understanding among participants, to identify data gaps and research priorities and to examine possible results of various management alternatives.

Based upon the experiences of the author of this book, the following observations can be made in using matrix methods:

- It is critical to carefully define the spatial boundaries associated with environmental factors and specific actions associated with the proposed project.
- A matrix should be considered as a tool for purposes of systematic and scientific analysis of impact rating within a given spatial boundary and environmental factor.
- The development of one or more preliminary matrices can be a useful technique in discussing a proposed action and its potential environmental impacts.
- The interpretation of impact ratings should be very carefully considered, particularly when realizing that there may be large differences in spatial boundaries and temporal phases, for a proposed project.
- If interaction matrices are used to display comparisons between different alternatives, it is necessary to use the same basic matrix in terms of spatial boundaries and environmental factors and temporal phases and project actions for each alternatives being analyzed.
- Impact quantification and comparisons to relevant standards can provide a valuable basis for the assignment of impact ratings to different project actions and environmental factors.
- Color codes can be used to display and communicate information on anticipated impacts. For example, beneficial impacts could be shown by using green or shades of green; whereas, detrimental or adverse effects could be depicted with red or shades of red.
- The development of a preliminary interaction matrix does not mean that it would have to be included in a subsequent EA or EIS. The preliminary matrix could be used as an internal working tool to study planning and development.
- It is possible to utilize importance weighting for environmental factors and project actions in a simple interaction matrix.

4.4 Checklist methodologies

Checklists annotate the environmental features or factors that need to be addressed when identifying the impacts of projects and activities. They can vary in complexity and purpose, from a simple checklist to a structured methodology or system that also assigns significance by scaling and weighting the impacts. Both simple and descriptive checklists can be improved and adapted to suit local conditions as experience with their use is gained. Checklists provide a systematized means of identifying impacts. They also have been developed for application to particular types of projects and categories of impacts (such as dams or road building). Sectoral checklists often are useful when proponents specialize in one particular area of order impacts or the interrelationships between impacts, and therefore, when using them, consider whether impacts other than those listed may be important.

Checklist methodologies range from listings of environmental factors to highly structured approaches involving importance weightings for factors and the application of scaling techniques for the impacts of each alternative on each factor. The simple checklists represent the lists of environmental factors that should be addressed. However, no information is provided on specific data needs, methods for measurement, and impact prediction and assessment. The descriptive checklists refer to methodologies that include lists of environmental factors along with information on measurement and impact prediction and assessment.

Checklists represent one of the basic methods used in environmental assessment. Checklists are a structured approach for the identification of the relevant environmental factors to be included in the EIA. Encourage discussion during the early stages of the assessment process may range from a simple listing of environmental factors to a listing that incorporates mathematical modeling to describe environmental conditions. These lists are representing the collective knowledge and judgment of those who have developed them and should be exhaustive to ensure that nothing has been left out.

Importantly, Sadar (1994) notes that neither can checklists represent the interdependence, connectivity, or synergism between interacting environmental components nor are they able to describe variation of environmental conditions with time. Canter (1986) suggests that there are five broad categories of checklists. They are simple checklists, descriptive checklists, threshold-of-concern checklists, scaling checklists, and scaling-weighting checklists.

4.4.1 Simple checklists

A simple checklist is a straightforward list of relevant parameters with no guidelines being provided about how the environmental effects are to be measured or interpreted. An example would be short descriptive statements used to outline the effects associated with a proposal. For instance, with a coal-based power project descriptive comments could be planning and design phase impact on land use through speculation and acquisition of property for the project. In the construction phase, the comments may be noise and displacement of people.

Another approach would be to list the potential effects and indicate the phase(s) in which the effects would be expected. In either case, while the effects have been identified, there is no attempt to measure or interpret the effects, for all the reader knows the effects may be positive or negative. Simple checklists may provide some indication of whether there will be changes associated with each environmental effect.

4.4.2 Descriptive checklists

Descriptive checklists are widely used in environmental impact studies. For example, Carstea et al. (1976) developed a descriptive checklist approach for projects in coastal areas. The methodology addressed the following issues, actions, and project: riprap placement; bulkheads; groins and jetties; piers, dolphins, mooring piles, and ramp construction; dredging (new and maintenance); outfalls, submerged lines, and pipes; and aerial crossings. For each of the items, environmental impact information was provided on potential changes in erosion, sedimentation, and deposition; flood heights and drift; water quality; ecology; air quality; noise; safety and navigation; esthetics; and socioeconomics.

Descriptive checklists are also used for transportation projects and land development projects. The transportation methodology addresses social, economic, and physical impacts of highway construction and operation (U.S. Department of Transportation, 1975). "Social impacts" include effects related to community cohesion, accessibility of facilities and services, and displacement of people. "Economic impacts" relate to those on employment, income and business activity, residential activity, property taxes, regional and community plans and growth, and resources. "Physical impacts" address changes on esthetics and historic values, terrestrial and aquatic ecosystems, air quality, noise, and vibration. For each of the identified environmental factors, workable state-of-the-art methods and techniques for impact identification, data collection, analysis, and evaluation are included.

4.4.3 Threshold of concern checklists

In these cases, a list of environmental effects is again presented, and alongside, each factor is a threshold that indicates a level at which the assessor should become concerned about the impact. See Table 4.5 for an example.

On the basis of the above analysis, air quality and recreation would be unacceptably impacted upon. Impacts can also be rated for their durations; in Table 4.5, A indicates a duration of the impact of 1 year or less, B indicates 1–10 years, C is for 10–50 years, and D indicates an irreversible impact. Additional columns can be added to assess the effects of other alternatives.

Table 4.5 Example of a threshold of concern checklist

Environmental component	Criterion	Threshold of concern (TOC)	Impact (alternative 1)	Impact > TOC? (alternative 1)
Air quality	Emission standards	1	2C	Yes
Economics	Benefit-cost ratio	1:1	3:1	No
Endangered species	No. of pairs breeding spotted owls	35	50D	No
Water quality	Water quality standards	1	1C	No
Recreation	No. of camping sites	5000	2800C	Yes

Source: Glasson et al., 1994.

4.4.4 Scaling checklists

Similar to descriptive checklists, these include additional information that is basic to the scaling of parameter values; that is, they use scaling techniques. For example, with a transport project, the environmental effects may be outlined as follows:

	Alternative			
Environmental	**A**	**B**	**C**	**Comments**
Noise effect	−2	−1	0	Reduction of local traffic
Air pollution	−5	+2	+4	Improved traffic flow
Open space	+3	+1	−6	Some structures removed, etc.

In this case, the scaling values have been assigned from a range of −6 to +5 using subjective evaluation. From this list or table, an assessment of three alternatives could be made by comparing the number of plus and minus ratings, taking the ratio of plus to minus ratings, taking the algebraic sum of the ratings, comparing the average of the ratings, and so on.

4.4.5 Scaling-weighting checklists

These checklists are essentially scaling checklists with information provided to enable the subjective evaluation of each parameter with respect to every other parameter. Canter (1986) explains that using the battle method involves the following steps:

- Obtain existing condition data for each of the 78 environmental factors. Convert these parameter data to EQ scale values. Multiply the scale values by the weighting factor for each environmental factor to develop a composite score for the environment without the project.
- For each alternative, predict the change in the environmental parameters.
- Using these predicted changes, determine the EQ scale value for each parameter and for each alternative.
- Multiply the EQ values by the relevant weighting factor and aggregate the information for a total composite score for each alternative.

The Battelle system is a highly organized method, and as such, it helps to ensure a systematic and comprehensive approach to identifying critical changes. There is no passing or falling score, as the numerical evaluation has to be interpreted by the reader. As in the case with other methods, very little emphasis is given to socioeconomic facts; some more points to be noted are the following:

- The method is inflexible in terms of application to different types of projects.
- Although the method appears to be scientific in its development of quantitative measures of environmental quality and the weighting factors, in reality, it entails little more than summing the value judgments of the analysts (the method makes these judgments reasonably explicit so that they may be questioned and perhaps changed).
- Impacts that cannot be readily quantified are likely to be distorted or masked in such an analysis.

- Aggregation to a single index is undesirable in that when alternatives are being considered it may be possible to consider modifications that would make an alternative more acceptable.
- There is no effective mechanism for estimating or displaying interactions between the environmental effects.
- The method is not strictly mutually exclusive. While effects are not counted twice, the same effect may appear in different parts of the method; for example, water quality appears in the physical/chemical section and may come into the section on esthetics (if the water is turbid).

As environmental impact computer system (EICS) will be developed by the proponent or consultant, this system uses computer techniques to identify potential environmental impacts broad, environmental categories (Jain et al., 1973). The functional areas are construction, operation, maintenance, and repair; training; mission change; real estate; procurement, army, and industrial activities; research, development, testing, and evaluation; and administration and support. Each of these functional areas has a number of additional basic activities. Examples of basic activities in the construction functional area include clearing trees, removing broken concrete, backfilling foundations, curing bituminous pavement, cleaning used concrete forms, installing insulation, and landscaping sites. In the EICS system, the environment is divided into 11 topical areas: ecology, health science, air quality, surface water, groundwater, sociology, economics, geology, land use, noise, and transportation. Within each of these categories, additional parameters are defined. Approximately 1000 specific environmental factors are defined for the 11 environmental categories. On this basis, it is possible to have a checklist that addresses the impacts of approximately 2000 basic army activities on 1000 environmental factors.

The computer system is used to identify potential impacts associated with various types of activities. In a sense, this method is similar to a computerized interaction matrix. It is considered here a descriptive checklist because each of the environmental factors is described in detail, with information given on actual measurement and data interpretation.

4.4.6 Uses of checklists

Simple and descriptive checklists of environmental factors and/or impacts to consider can be helpful in planning and conducting an EIS, particularly if one or more checklists for the specific project type can be utilized. The following are some of the uses of checklists:

1. Published agency checklists and/or project specific checklists represent the collective professional knowledge and judgment of their developers; hence, they have professional credibility and usability.
2. Checklists provide a structured approach for identifying key impacts and/or pertinent environmental factors for consideration in impact studies. More extensive list of factors or impacts does not necessarily represent better lists, since relevant factors or impacts will need to be selected.
3. Checklists can be used to stimulate or facilitate interdisciplinary—team discussions during the planning, conduction, and/or summarization of EISs.

4. In using a checklist, it is important to carefully define the utilized spatial boundaries and environmental factors. Any special impact codes or terminology used within the checklist should also be defined.
5. Documentation of the rationale basic for identifying key factors and/or impacts should be accomplished. In this regard, factor-impact quantification and comparison to pertinent standards can be helpful.
6. Factors and/or impacts from a simple or descriptive checklist can be grouped together to demonstrate secondary and tertiary impacts and/or environmental system interrelationships.
7. Importance weights could be assigned to key environmental factors or impacts; the rationale and methodology for such importance weight assignments should be clearly delineated.
8. Key impacts that should be mitigated can be identified through the systematic usage of a simple or descriptive checklist.

4.5 Network methods

Networks are those methodologies that integrate impact causes and consequences through identifying interrelationships between causal actions and the impacted environmental factors, including those representing secondary and tertiary effects. Several illustrations of networks, also known as "sequence diagrams," will be shown. Network analyses are particularly useful for identifying anticipated impacts associated with potential projects. Networks can also aid in organizing the discussion of anticipated project impacts. Network displays are useful in communicating information about an environmental impact study to interested publics. The primary limitation of the network approach is the minimal information provided on the technical aspects of impact prediction and the means for comparatively evaluating the impacts of alternatives. In addition, networks can become very visually complicated.

Networks illustrate the cause-effect relationship of project activities and environmental characteristics. They are, therefore, particularly useful in identifying and depicting secondary impacts (indirect, cumulative, etc.). Simplified networks, used in conjunction with other methods, help to ensure that important second-order impacts are not omitted from the investigation. An example of network method is illustrated in Fig. 4.3.

More detailed networks are visually complicated, time-consuming, and difficult to produce unless a computer program is used for the task. However, they can be a useful aid for establishing "impact hypothesis" and other structured science-based approaches to EIA.

4.6 Overlays and geographic information systems

Overlays can be used to map impacts spatially and display them pictorially. The original overlay technique, popularized by McHarg, is an environmental suitability analysis in which data on topographic features, ecological values, and resource constraints are mapped onto individual transparencies and then aggregated into a composite representation of potential impacts. This approach is useful for comparing site and planning alternatives and for routing linear developments to avoid environmentally

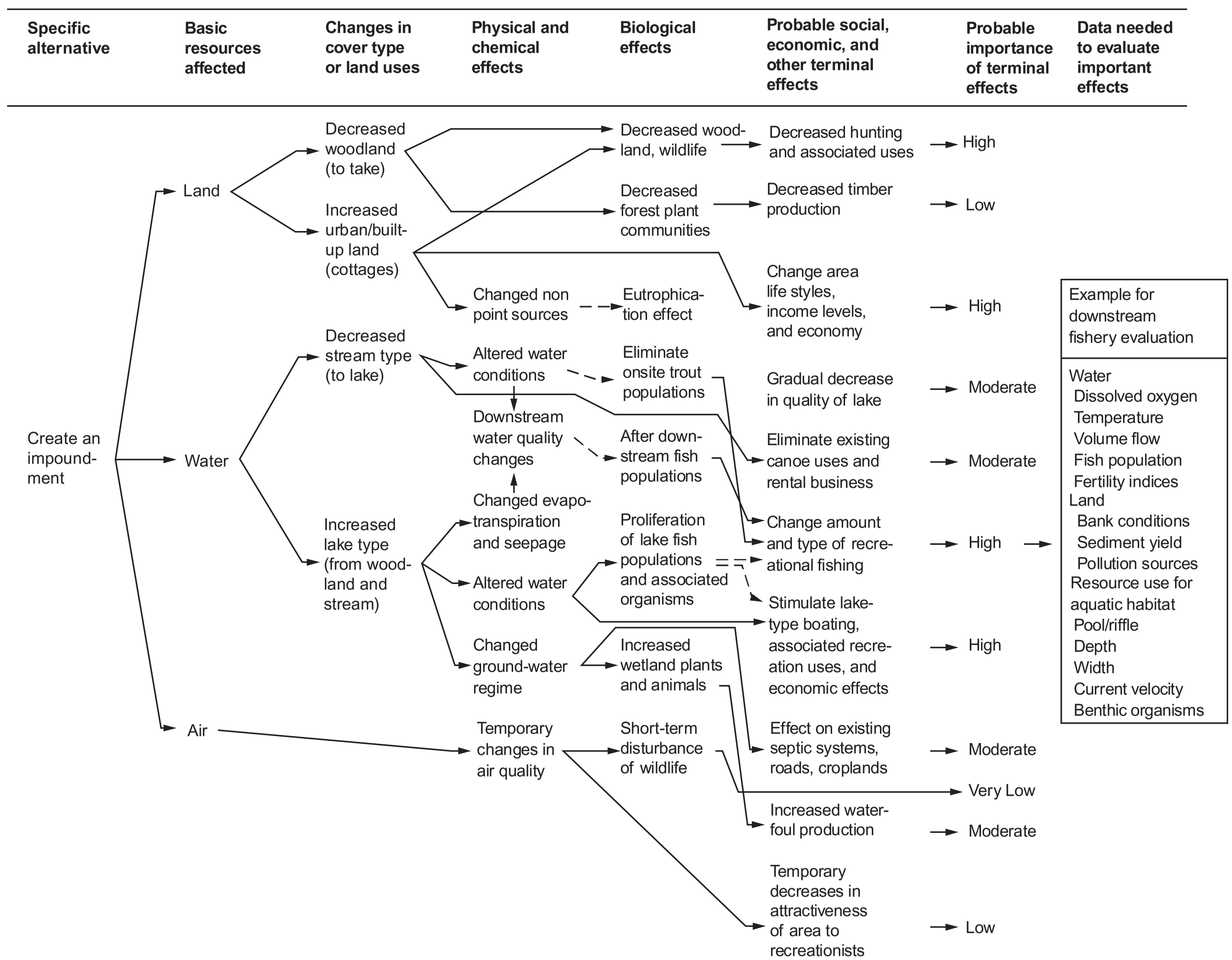

Fig. 4.3 An example of a network diagram for analyzing probable environmental impacts.

sensitive areas and landscape and habitat zoning at the regional level. Disadvantages of this approach relate to the lack of precision in differentiating the likelihood and magnitude of impacts and relating them to project actions. Also, the overlay process can become cumbersome in its original form.

A modern version of the overlay method is the computer-based GIS. In simple terms, a GIS stores, retrieves, manipulates, and displays environmental data in a spatial format. A set of maps or overlays of given area provide different types of information and scales of resolution. The user of GIS for EIA purposes is not as widespread as commonly imagined. The main drawbacks are the lack of appropriate data and the expense of creating a usable system. However, the potential application of GIS to EIA is widely acknowledged, and its use is expected to increase in the future, particularly to address cumulative effects. A classical example of this method is presented in the following sections.

Problems with the overlay method as seen by Munn (1975) include the following:

- There is restriction on the number of factors that can be considered.
- Objectivity is low; except with respect to the spatial positioning of effects and impacts (e.g., flooded land), interactions are not displayed.
- Extreme impacts with small probabilities of occurrence are not considered.
- Each alternative would require a separate set of overlays to be produced, and less than gross differences between alternatives may be difficult for the decision-maker to detect.

The overlay method cannot be considered ideal. Despite its limitations, however, it is useful for illuminating complex spatial relations (in a greatly simplified fashion). It is relevant to large regional developments and corridor selection problems, but the assessor still view the analysis with at least a degree of caution.

4.6.1 Expert systems

Expert or knowledge-based systems are used to assist diagnosis, problem solving, and decision-making. A number of such computerized systems have been developed for use in EIA, primarily at the early stages of the process. For example, screening and scoping procedures, expert knowledge, and judgment. The user has to answer a series of questions that have been systematically developed to identify impacts and determine their “mitigability” and significance. Based on the answer given in each question, the expert system moves to the next appropriate questions. This can be used along with query-based GIS on ArcGIS platform.

Like GIS system, expert systems are an information-intensive, high-investment method of analysis. As such, they are limited in their current use and application, especially by many developing countries. However, they also have the potential to be a powerful aid to systematic EIA in the future, not least because they can provide an efficient means of impact. Computer programs can be written to perform the task of aggregating the predicted impacts. This is done by coding the geographic area in terms of small zones, assigning a numerical weighting to each zone to represent the impact for each environmental effect, and summing all the numbers allocated to each particular zone. This is the basis of GIS as discussed by Sadar (1994), who sees that they have the potential for storing and accessing very large data sets assembled from diverse sources. Such systems are efficient at performing multiple map overlays, allowing a number of different scenarios to be investigated quickly, by varying the parameters for successive analysis runs. The generation of descriptive statistics may also be useful for some assessments.

4.6.2 Advantages and disadvantages of impact identification methods

Table 4.6 shows the advantages and disadvantages of impact identification methods.

4.7 Significance of identified impacts

Evaluating the significance of environmental impacts is perhaps the most critical component of impact analysis. More than other components, however, the interpretation of significance is also a contentious process. The interpretation of significance bears directly on the subsequent EIA process and also during environmental clearance on project approvals and condition setting. At an early stage, it also enters into screening

Table 4.6 **Advantages and disadvantages of impact identification methods**

	Advantages	Disadvantages
Checklists	• Simple to understand and use • Good for site selection and priority setting • Simple ranking and weighting	• Do not distinguish between direct and indirect impacts • Do not link action and impact • The process of incorporating values can be controversial
Matrices	• Link action to impact • Good method for displaying EIA results	• Difficult to distinguish direct and indirect impacts • Significant potential for double counting of impacts
Networks	• Link action to impact • Useful in simplified form for checking for second-order impacts • Handles direct and indirect impacts	• Can become very complex if used beyond simplified version
Overlays	• Easy to understand • Good to display method • Good siting tool	• Address only direct impacts • Do not address impact duration or probability
GIS and computer expert	• Excellent for impact identification and analysis • Good for "experimenting"	• Heavy reliance on knowledge and data • Often complex and expensive

and scoping decisions on what level of assessment is required and which impacts and issues will be addressed. Impact significance is also a key to choosing among alternatives. The attribution of significance continues throughout the EIA process, from scoping to EIS review, in a gradually narrowing "cone of resolution" in which one stage sets up the next. But at this stage, it is the most important as better understanding and quantification of impact significance is required.

One common approach is based on the determination of the significance of predicted changes in the baseline environmental characteristics and compares these with reference to regulatory standards, objective criteria, and similar thresholds as eco-sensitively, cultural/religious values. The practice of formally evaluating significance of residual impacts, that is, after predicting the nature and magnitude of impacts based on before-versus-after-project comparisons and identifying measures to mitigate these effects is not being followed in a systematic way.

Step 1 Are the environmental impacts adverse?

Criteria for determining of effects that are "adverse" include

- effects on biota health,
- effects on rare or endangered species,
- reductions in species diversity,
- habitat loss,
- transformation of natural landscapes,
- effects on human health,
- effects on current use of lands and resources for traditional purposes by aboriginal persons,
- foreclosure of future resource use or production.

Step 2 Are the adverse environmental impacts significant?

Criteria for determining "significance" are to judge that the impacts

- are extensive over space or time,
- are intensive in concentration or proportion to assimilative capacity,
- exceed environmental standards or thresholds,
- do not comply with environmental policies, land use plans, and sustainability strategy,
- adversely and seriously affect ecologically sensitive areas,
- adversely and seriously affect heritage resources, other land uses, community lifestyle, and/or indigenous people traditions and values.

Step 3 Are the significant adverse environmental impacts likely?

Criteria for determining "likelihood" include

- probability of occurrence and
- scientific uncertainty.

4.7.1 Impact prediction tools

The credibility of EIA relies on the ability of the EIA practitioners to estimate the nature, extent, and magnitude of change in environmental components that may result from different project activities under different phases of the project implementation specifically during construction and operational phase. Information about predicted changes is needed for assigning impact significance, delineating mitigation measures, and designing and developing environmental management plans and also postproject monitoring programs. The more accurate the predictions, the more confident the EIA practitioner will be prescribing specific measures to eliminate or minimize the adverse impacts of development projects.

The scientific and technical credibility of an EIA relies on the ability of the EIA practitioners to estimate the nature, extent, and magnitude of change in environmental components that may result from project activities. Information about predicted changes is needed for assigning impact significance, prescribing mitigation measures, and designing and developing environmental management plans and monitoring programs. The more accurate the predictions, the more confident the EIA practitioner will be in feasibility done. Consider the example of filling in swamp lands. Such filling could be described in several ways:

- Volume of swamp filled as a proportion of the swamp system
- Number of species lost
- Reduction in the area of mosquito breeding habitat
- Changes in peak water flows

Selection of units requires yet another judgment by the analyst. In many cases, it will not matter which units are used. The important thing is to be consistent. The impact prediction tools used in EIA study are presented in Table 4.7a–4.7f. The impact prediction tools are listed in Table 4.7a–4.7f for all important-valued environmental parameters.

4.7.2 Models for predicting impacts

Prediction is of concern because once the important environmental factors and effects have been identified, the next step is to decide how much change would occur if the proposal (or an alternative) was undertaken. Prediction involves a number of steps, as illustrated by Sadar (1994):

- Make the understanding of environmental factors focused and as precise as possible.
- Identify links between the proposal’s components and these environmental factors.
- Identify direct impacts, where the proposal’s elements interact with the social and biophysical environments, and there is an immediate cause-effect consequence from an activity of the proposal.
- Identify indirect impacts that are at least one step removed from the project activity in terms of cause-effect links (e.g., reduced employment opportunities resulting from the acquisition of shops for a road proposal).
- Identify cumulative impacts that come from the interaction of elements of the proposal or other activities occurring simultaneously or subsequently.
- Predict residual impacts, if any, that may result from impacts that cannot be avoided or mitigated.
- Predict the probability, magnitude, distribution, and timing of expected impacts.
- Forecast what will happen to the affected components of the environment if the proposal goes ahead.

Table 4.7a Impact prediction models on air environment

Model	Application	Remarks
ISCST 3	• Appropriate for point, area, and line sources • Application for flat or rolling terrain • Transport distance up to 50 km valid • Computes for 1 h to annual averaging periods	• Can take up to 99 sources • Computes concentration on 600 receptors in Cartesian on polar coordinate system • Can take receptor elevation • Requires source data, meteorological data, and receptor data as input
AERMOD with AERMET	• Settling and dry deposition of particles • Building wake effects (excluding cavity region impacts) • Point, area, line, and volume sources • Plume rise as a function of downwind distance • Multiple point, area, line, or volume sources • Limited terrain adjustment • Long-term and short-term averaging modes • Rural or urban modes • Variable receptor grid density • Actual hourly meteorology data	• Can take up to 99 sources • Computes concentration on 600 receptors in Cartesian on polar coordinate system • Can take receptor elevation • Requires source data, meteorological data, and receptor data as input
PTMAX	• Screening model applicable for a single-point source • Computes maximum concentration and distance of maximum concentration occurrence as a function of wind speed and stability class	• Requires source characteristics • No meteorological data required • Used mainly for ambient air monitoring network design
PTDIS	• Screening model applicable for a single-point source • Computes maximum pollutant concentration and its occurrences for the prevailing meteorologic conditions	• Requires source characteristics • Average meteorological data (wind speed, temperature, stability class, etc.) required • Used mainly to see likely impact of a single source
MPTER	• Appropriate for point, area, and line sources applicable for flat or rolling terrain	• Can take 250 sources • Computes concentration at 180 receptors up to 10 km

Continued

Table 4.7a Continued

Model	Application	Remarks
	• Transport distance up to 50 km valid • Computes for 1 h to annual averaging periods • Terrain adjustment is possible	• Requires source data, meteorological data, and receptor coordinates
Complex terrain dispersion model (CTDM PLUS)	• Point-source steady-state model can estimate hourly average concentration in isolated hills/array of hills	• Can take maximum 40 stacks and computes concentration at maximum 400 receptors • Does not simulate calm met conditions • Hill slopes are assumed not to exceed 15 degrees • Requires sources, met and terrain characteristics, and receptor details
Urban airshed model (UAM)	• 3-D grid-type numerical simulation model • Computes O_3 concentration short-term episodic conditions lasting for 1 or 2 days resulting from NO_x and VOCs • Appropriate for single urban area having significant O_3 problems	
Rural airshed model (RAM)	• Steady-state Gaussian plume model for computing the concentration of relatively stable pollutants for 1 h to 1 day averaging time • Application for point and area sources in rural and urban setting	• Suitable for flat terrains • Transport distance less than 50 km
CRESTER	• Applicable for single-point source either in rural or in urban setting • Computes highest and second-highest concentration for 1, 3, 24 h, and annual averaging times • Tabulates 50 highest concentration for entire year for each averaging times	• Can take up to 19 stacks simultaneously at a common site • Unsuitable for cool- and high-velocity emissions • Do not account for tall buildings or topographic features • Computes concentration at 180 receptor, circular wing at five downwind ring distance 36 radials

Table 4.7a Continued

Model	Application	Remarks
		• Requires sources and meteorological data
Offshore and coastal dispersion (OCD) model	• It determines the impact of offshore emissions from point sources on the air quality of coastal regions • It incorporates overwater plum transport and dispersion and changes that occur as the plume crosses the shoreline • Most suitable for overwater sources shore onshore receptors are below the lowest shore height	• Requires source emission data • Requires hourly meteorological data at offshore and onshore locations like water surface temperature, overwater air temperature, relative humidity, etc.
Fugitive dust model (FDM)	• Suitable for emissions from fugitive dust sources • Source may be point, area, or line (up to 121 sources) • Requires particle size classification max up to 20 sizes • Computes concentrations for 1, 3, 8, 24 h, or annual average periods	• Requires dust source particle sizes • Source coordinates for area sources, source height, and geographic details • Can compute concentration at max 1200 receptors • Requires meteorological data (wind direction, speed, temperature, mixing height, and stability class) • Model does not include buoyant point sources, hence no plume rise algorithm
Rough terrain diffusion model (RTDM)	• Estimates GLC is complex/ rough (or flat) terrain in the vicinity of one or more collocated point sources • Transport distance max up to 15–50 km • Computes for 1–24 h or annual average concentrations	• Can take up to 35 colocated point sources • Requires source data and hourly meteorological data • Computes concentration at maximum 400 receptors • Suitable only for nonreactive gases • Does not include gravitational effects or depletion mechanism such as rain/washout, dry deposition
Climatological dispersion model (CDM)	• It is a climatologically steady-state GPM for determining long term (seasonal or annual)	• Suitable for point and area sources in urban region and flat terrain

Continued

Table 4.7a Continued

Model	Application	Remarks
	• Arithmetic average pollutant concentration at any ground-level receptor in an urban area	• Valid for transport distance less than 50 km • Long-term averages, 1 month to 1 year or longer
Plume visibility model (PLUVUE-II)	• Applicable to assess visibility impairment due to pollutants emitted from well-defined point sources • It is used to calculate visual range reduction and atmospheric discoloration caused by plumes • It predicts transport, atmospheric diffusion, chemical, conversion, optical effects, and surface deposition of point source emissions	• Requires source characteristics, meteorological data, and receptor coordinates and elevation • Requires atmospheric aerosols (back ground and emitted) characteristics, like density and particle size • Requires background pollutant concentration of SO_4, NO_3, NO_x, NO_2, O_3, and SO_2 and deposition velocities of SO_2, NO_2, and aerosols
Meso-scale puff model (MESO-PUFF II)	• It is a Gaussian, variable trajectory, puff superposition model designed to account for spatial and temporal variations in transport, diffusion, chemical transformation, and removal mechanism encountered on regional scale • Plume is modeled as a series of discrete puffs, and each puff is transported independently • Appropriate for point and area sources in urban areas	• Can model five pollutants simultaneously (SO_2, SO_4, NO_x, HNO_3, and NO_3) • Requires source characteristics • Can take 20 point sources or 5 area source for area source—location, effective height, initial puff size, emission is required • Computes pollutant concentration at max 180 discrete receptors and 1600 (40×40) grided receptors
	• Regional-scale model	• Requires hourly surface data including cloud cover and twice-a-day upper-air data (pressure, temp, height, wind speed, and direction) • Does not include gravitational effects or depletion mechanism such as rain/washout, dry deposition

Table 4.7b Choice of models for impact modeling—noise environment[a]

Model	Application
Federal Highway Administration (FHWA)	Noise impact due to vehicular movement on highways
Dhwani	For predictions of impact due to the group of noise sources in the industrial complex (multiple sound sources)
Hemispheric sound wave propagation	For predictive impact due to single noise source
Airport	For predictive impact of traffic on airport and railroad

[a]*Note*: (i) If a project proponent prefers to use any model other than listed can do so with prior concurrence of concerned appraisal committee. (ii) Project-specific proposed prediction tools need to be identified by the project proponent and shall be incorporated in the draft ToR to be submitted to the authority for the consideration and approval by the concerned EAC/SEAC.

Table 4.7c Choice of model for impact modeling—land environment

Model	Application	Remarks
Digital analysis techniques	Provides land use/land cover distribution	
Ranking analysis for soil suitability criteria	Provides suitability criteria for developmental conversation activities	Various parameters, namely, depth, texture, slope, erosion status, geomorphology, flooding hazards, GW potential, and land use, are used

Direct impacts, Sadar suggests, can be identified from the assessment of which components of the proposal will interact with the range of environmental factors. Also, networks of ecosystems and social interconnections can be used to identify indirect impacts, which may be as important at direct impacts. Identification of cumulative impacts is likely to be more difficult as these are the potential additive or combined effects of past, existing, and proposed activities, including the proposal under assessment. Cumulative impacts may have to be examined under a full cumulative impact assessment (CIA).

Looking at a variety of environmental factors in the physical and social environments and some issues of special concern (such as chemical hazards), Erikson (1994) discusses predictive approaches appropriate to each factor. In this review, he considers direct and indirect impacts and how quantitative or qualitative methods may be available for the assessment. Sadar (1994) also comments on the use of quantitative methods (such as models, "worst-case" calculations where the results of modeling are limited, laboratory or field experiments, and case studies). He suggests that case studies could be used for identifying qualitative thresholds, and the trend extrapolation and scenario development may be useful in some situations.

Table 4.7d Choice of models for impact modeling—water environment[a]

Model	Application	Remarks
QUAL-II E	Wind effect is insignificant, vertical dispersive effects insignificant applicable to streams Data required Deoxygenation coefficients, reaeration coefficients for carbonaceous, nitrogenous and benthic substances, and dissolved oxygen deficit The model is found excellent to generate water quality parameters Photosynthetic and respiration rate of suspended and attached algae Parameters measured up to 15 components can be simulated in any combination, for example, ammonia, nitrite, nitrate, phosphorous, carbonaceous BOD, benthic oxygen demand, DO, coliforms, conservative substances, and temperature	Steady-state or dynamic model
DOSAG-3, USEPA, (1-D)	Water quality simulation model for streams and canal	Steady-state
RECEIV-II, USEPA	A general water quality model	
Explore-I, USEPA	A river basin water quality model	Dynamic, simple hydrodynamics
HSPE, USEPA	Hydrologic simulation model	Dynamic, simple hydrodynamics
RECEIVE-II, USEPA	A general dynamic planning model for water quality management	
Stanford watershed model	This model simulates stream flows once historic precipitation data are supplied The major components of the hydrologic cycle are modeled including interception, surface detention, overland inflow, groundwater, evapotranspiration and routing of channel flows, temperature, TDS, DO, carbonaceous BOD coliforms, algae, zooplanktons,	

Table 4.7d Continued

Model	Application	Remarks
	nitrite, nitrate, ammonia, phosphate, and conservative substances can be simulated	
Hydrocomp model	Long-term meteorologic and wastewater characterization data are used to simulate stream flows and stream water quality	Time-dependent (dynamic)
Stormwater management model (SWMM)	Runoff is modeled from overland flow, through surface channels and through sewer network both combined and separate sewers can be modeled This model also enables to simulate water quality effects to stormwater or combined sewer discharges. This model simulates runoff resulting from individual rainfall events	Time-dependent
Battelle reservoir model	Water body is divided into segments along the direction of the flow, and each segment is divided into number of horizontal layers. The model is found to generate excellent simulation of temperature and good prediction of water quality parameters The model simulates temperature, DO, total and benthic BOD, phytoplankton, zooplankton, organic and inorganic nitrogen, phosphorous, coliform bacteria, toxic substances, and hydrodynamic conditions	Two-dimensional multisegment model
Turbulent diffusion temperature model reservoirs (TIDEP)	Horizontal temperature homogeneity coefficient of vertical turbulent diffusion constant for charge of area with depth negligible coefficient of thermal exchange constant data required wind speed, air temperature, air humidity, net incoming radiation, surface water temperature, heat exchange coefficients, and vertical turbulent diffusion coefficients	Steady-state model
Biolake	Model estimates potential fish harvest from a lake	Steady-state model

Continued

Table 4.7d Continued

Model	Application	Remarks
Estuary models/ estuarial dynamic model	It simulates tides, currents, and discharge in shallow, vertically mixed estuaries excited by ocean tides and hydrologic influx, and wind action tides and currents in estuary are simulated	Dynamic model
Dynamic water quality model	It simulates the mass transport of either conservative or nonconservative quality constituents utilizing information derived from the hydrodynamic model Bay-Delta model is the program generally used Up to 10 independent quality parameters of either conservative or nonconservative type and the BODDO coupled relationship can be handled	Dynamic model
HEC-2	To compute water surface profiles for steady, gradually varying flow in both prismatic and nonprismatic channels	
SMS	Lake circulation, salt water intrusion, and surface water profile simulation model	Surface water modeling system hydrodynamic model
RMA2	To compute flow velocities and water surface elevations	Hydrodynamic analysis model
RMA4	Solves advective-diffusion equations to model up to six noninteracting constituents	Constituent transport model
SED2D-WES	Model simulates transport of sediment	Sediment transport model
HIVEL2D	Model supports subcritical and supercritical flow analysis	A two-dimensional hydrodynamic model
MIKE-II, DHI	Model supports, simulations of flows, water quality, and sediment transport in estuaries, rivers, irrigation systems, channels, and other water bodies	Professional engineering software package

[a]*Note*: (i) If a project proponent prefers to use any model other than listed can do so with prior concurrence of concerned appraisal committee. (ii) Project-specific proposed prediction tools need to be identified by the project proponent and shall be incorporated in the draft ToR to be submitted to the authority for the consideration and approval by the concerned EAC/SEAC.

Table 4.7e Choice of models for impact modeling—biological environment

Name	Relevance	Applications	Remarks
Flora			
Sample plot methods	Density and relative density Density and relative dominance	Average number of individuals species per unit area Relative degree to which a species predominates a community by its sheer numbers, size bulk, or biomass	The quadrant sampling technique is applicable in all types of plant communities and for the study of submerged, sessile (attached at the base) or sedentary plants
	Frequency and relative frequency importance value	Plant dispersion over an area or within a community	Commonly accepted plot size, 0.1 m^2 mosses, lichens, and other mat-like plants
		Average of relative density, relative dominance, and relative frequency	0.1 m^2—herbaceous vegetation including grasses
			10.20 m^2—for shrubs and saplings up to 3 m tall and 100 m^2—for tree communities
Transects and line-intercept methods	Cover	Ratio of the total amount of line intercepted by each species and total length of the line intercept given its cover	This method allows for rapid assessment of vegetation transition zones and requires minimum time or equipment establish
	Relative dominance	It is the ratio of total individuals of a species and total individuals of all species	Two or more vegetation strata can be sampled simultaneously
Plotless sampling methods	Mean point plant Mean area per plant	Mean point-plant distance Mean area per plant	Vegetation measurements are determined from points rather than being determined in an area with boundaries
	Density and relative density		Method is used in grassland and open shrub and tree communities
	Dominance and relative dominance		It allows more rapid and extensive sampling than the plot method

Continued

Table 4.7e Continued

Name	Relevance	Applications	Remarks
	Importance value		Point-quarter method is commonly used in woods and forests
Fauna			
Species list methods	Animal species list	List of animal communities observed directly	Animal species lists present common and scientific names of the species involved so that the faunal resources of the area are cataloged
Direct-contact methods	Animal species list	List of animal communities observed directly	This method involves the collection, study, and release of animals
Count-index methods (roadside and aerial count methods)	Drive counts temporal counts	Observation of animals by driving them past trained observers	Count indexes provide estimates of animal populations and are obtained from signs, calls, or trailside counts or roadside counts
	Call counts	Count of all animals passing a fixed point during some stated interval of time	These estimates, though they do not provide absolute population numbers, provide an index of the various species in an area Such indexes allow comparisons through the seasons or between sites or habitats
Removal methods	Population size	Number of species captured	Removal methods are used to obtain population estimates of small mammals, such as rodents through baited snap traps
Market capture methods	Population size estimate (M)	Number of species originally marked (T) Number of marked animals recaptured (t) and total number of animals captured during census (n) $N = nT/t$	It involves capturing a portion of the population and at some later date sampling the ratio of marked to total animals caught in the population

Table 4.7f Choice of models for impact prediction—socioeconomic environment[a]

Relevance		
Name	**Application**	**Remarks**
Extrapolative methods	Prediction is made that is consistent with past and present socioeconomic data, for example, a prediction based on the linear extrapolation of current trends	
Intuitive forecasting (Delphi techniques)	Delphi technique is used to determine environmental priorities and also to make intuitive predictions through the process of achieving group consensus	Conjecture Brainstorming Heuristic programming Delphi consensus
Trend extrapolation and correlation	Predictions may be obtained by extrapolating present trends not an accurate method of making socioeconomic forecasts, because a time series cannot be interpreted or extrapolated very far into the future without some knowledge of the underlying physical, biological, and social factors	Trend breakthrough precursor event correlation and regression
Metaphors and analogies	The experience gained elsewhere is used to predict the socioeconomic impacts	Growth historical simulation commonsense forecasts
Scenarios	Scenarios are commonsense forecasts of data Each scenario is logically constructed on the model of a potential future for which the degrees of "confidence" as to progression and outcome remain undefined	Common sense
Dynamic modeling (input-output model)	Model predicts net economic gain to the society after considering all inputs required for the conversion of raw materials along with cost of finished product	
Normative methods	Desired socioeconomic goals are specified, and an attempt is made to project the social environment backward in time to the present to examine whether existing or planned resources and environmental programs are adequate to meet the goals	Morphological analysis technology scanning contextual mapping - functional array - graphic method Mission networks and functional arrays decision trees and relevance trees matrix methods scenarios

[a]*Note*: (i) If a project proponent prefers to use any model other than listed can do so with prior concurrence of concerned appraisal committee. (ii) Project-specific proposed prediction tools need to be identified by the project proponent and shall be incorporated in the draft ToR to be submitted to the authority for the consideration and approval by the concerned EAC/SEAC.

More generally, Leopold et al. (1971) suggest that predictive methods can be classified in many ways. In terms of the scope of the methods, they can be divided into holistic and partial methods. Partial methods are subdivided into type of project (e.g., retail impact assessment) and the type of impact (e.g., wider economic impacts). Some methods are extrapolative, where predictions are made on the basis of past and present data (e.g., trend analysis, scenario generation, analogies, and intuitive forecasting). Otherwise, there are normative methods, which work backwards from the desired final state of the project to assess whether the project can be achieved without causing environmental problems.

4.7.3 Mathematical models

Mathematical and mechanic models can be used for prediction. These describe cause and effect relationships that are assumed to be correct, and therefore, the output of the model is taken as being correct; these issues have been discussed previously. Glasson et al. (1994) note that the general range of flowcharts and mathematical functions used in EIA work can be classified as mass balance models; statistical models; physical, image, or architectural models; field and laboratory experimental models; and analog models.

However, in practice, they comment, there has been a tendency to use less formal predictive methods, especially expert opinion, and even where the more formal approaches have been used, they have generally been of a simple form. Munn (1975) has also discussed the use of the formal mathematical models, particularly identifying some of the difficulties in their use.

As discussed by Duncan (2008), the use of computer modeling in impact assessment is quite common and allows "an analyst to experiment with a mode to test a system's behavior under varying conditions and with alternative interventions" (2008, p. 54), although the author acknowledges the issues of values assigned to the models, as decisions always have to be made as to what data go into the model.

This pessimism is not to say that these types of predictive approaches should not be used. Rather, the point is that they may be very useful in helping to identify differences between alternatives, including the "do-nothing" alternative. However, when they are used, the uncertainty in the model and the data has to be recognized. One way of doing this is to use sensitivity analysis in conjunction with the prediction. In this analysis, a comparison is made between the results of the model using the data that are thought to be correct and the results when a small difference or possible error is inserted into the data. If there is a substantial difference in the two results coming from, the model should be considered with caution.

4.7.4 Assessment criteria

An indication of the issues that should be considered in assessments can be gained from the following list of criteria suggested by Canter (1986). He considers that a methodology should aim to include the following:

- *Comprehensiveness*: The environment contains intricate systems of living and nonliving elements bound together by complex interrelationships. An adequate methodology must consider effects on all these systems.

- *Flexibility*: Sufficient flexibility must be contained in the methodology, as proposals of different sizes and scales result in different types of impact.
- *Detect true effects*: The actual effects are the changes in environmental conditions resulting from a proposal, as opposed to the changes that would naturally occur from existing conditions. Moreover, both short- and long-term changes must be reported.
- *Objectivity*: The methodology must provide impersonal, unbiased and constant measurements, immune to outside tampering by political, and other outside forces. An objective and consistent procedure provides a firm foundation, which can be periodically updated, refined, and modified, thereby incorporating the experience gained through practical application. To be effective as an aid to decision-making, environmental assessments should be repeatable by different analysis and able to withstand scrutiny by various interest groups.
- *Ensure input of required expertise*: Sound, experienced, professional judgments must be assured by a methodology, especially as subjectivity remains inherent in many aspects of environmental evaluation. Input of the necessary expertise can be achieved either through the design of the methodology itself or through the rules governing its use.
- *Utilize the state of the art*: Maximum possible use of the state of the art should be made, drawing on the best available techniques.
- *Employ explicitly defined criteria*: Evaluation criteria, especially any quantified values, employed to assess the magnitude or importance of environmental effects should not be arbitrarily assigned. The methodology should provide explicitly defined criteria and explicitly stated procedures regarding the use of these criteria, with the rationale behind such criteria being documented.
- *Assess actual magnitude of effects*: Means must be provided for an assessment based on specific levels of effects for each environmental factor, in the terms established for describing that factor. Assessment of magnitude based on generalities or relatives (qualitative comparisons between alternatives) is usually considered to be inadequate.
- *Provide for overall assessment of total effect*: A means for aggregating multiple individual effects is necessary to provide an evaluation of overall total environment impact.
- *Pinpoint critical effects*: The methodology should provide a warning system to pinpoint and emphasize particularly "bad" effects. In some cases, the sheer intensity or magnitude of effect may justify special attention in the planning process, regardless of how narrowly the effect may be noticed.

Shopley and Fuggle (1984) in their comprehensive review of evaluation methods also comment on evaluation and adaptive techniques, which combine aspects of the major groupings. The demise of checklists and numerical data manipulation methods, according the Bisset (1988), has been predicted for years, but they continue to fulfill a role in the technocratic "objective" decision-making processes used by most proponents.

Whether for the investigation of direct or indirect effects, when choosing a method, it is important to remember what the evaluation is for. The final product you are hoping to achieve is the presentation of information that will help decision-maker come to an informed decision about the proposal. Consequently, it is necessary to present the effects in a meaningful way so that the trade-offs between positive and negative effects can be made and so that these environmental effects can be considered alongside the economic and technical information. This usually means that the assessments present the effects in one of these ways: simple display of information, tabular comparison, and aggregation of effects. The output from the following types of methods falls into one of these groupings.

Ad hoc methods typically present the environmental effects in descriptive form. As there is usually a large amount of information on a varied nature associated with an EIS, such lists of information may become rambling catalogs of environmental concern.

An improvement on this is where a summary is provided of the key issues. The result of this is a list or table composed of numerical data and descriptions such as "good," "bad," "dangerous," "polluting," or "minimal environmental impact." The terms might not be defined or put into context, so it is then up to the decision-maker to interpret the effects relative to each other and relative to the other information.