

SUGGESTED GUIDELINES FOR THE ANALYSIS AND INTERPRETATION OF ENVIRONMENTAL EFFECTS OF TRANSPORTATION FACILITIES

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ABSTRACT

The universe of environmental "elements" and "impacting factors" is identified, categorized, and defined for consistent utility in environmental impact assessment. "Primary" elements and "secondary" elements are identified. *Significance* of environmental elements affected is also discussed on various bases, i.e., *exposure*, *effect*, and *stage of (project) development*.

The ambiguities surrounding current nomenclature and analytical approaches are clarified by systematizing the analysis and interpretation framework of environmental impact assessment for transportation facilities.

The upsurge in interest in attempting to regularize impact-evaluation procedures dates back only a few years. A requirement for "a detailed statement . . . on . . . the environmental impact of the proposed action" begins with the National Environmental Policy Act of 1969, and methods for quantifying such "unquantifiables" as aesthetics, for instance, are presented by *Leopold*.

Environmental Elements and Impacting Factors

Since the federal requirement, however, impact statements have been presented as descriptive, subjective discussions of possible and probable effects, with broad categories of environmental elements considered, and only the more obvious impacting factors discussed, such as noise, air pollution, and community disruption.

In connection with a study¹ recently completed by the authors, the universe of "environmental" descriptive material was searched and summarized, as was the equally universal (but inconsistent) material on impact. A review of this literature resulted in information from which one could identify a *limited* number of cases of cause/effect relationship between *impacting factors* and the *environmental elements* which are impacted. However, most documents dealt with controlled laboratory experimentation, which when evaluated for use in this research effort, plays a limited role in adding to the knowledge-base necessary in the area of environmental analysis.

Lack of information, however, is more serious in the "social" area than in the "ecological" one. This lack of information on environmental impacts is indeed a serious problem. To quote from a recent study, "Despite an explosion of environmental literature, hard information on criteria and thresholds for measuring impacts is in exceedingly short supply".²

IDENTIFICATION AND CATEGORIZATION

A second need that was identified in the environmental literature refers to the practice of mixing the terms "environmental elements" and "environmental impact factors" into the same bag. This lack of rigor in terminology tends to create confusion for the transportation engineer or planner when he attempts to evaluate, and present to the public, the findings of an environmental analysis; and if the analyst is not confident with the methodology he uses, the public is not likely to appreciate or even to understand the issues being presented.

In this connection, the environmental elements and impacting factors have been first *identified* and then *categorized* using a framework which permits the analyst and the public to trace the

¹ NCHRP 20-11, Toward Environmental Benefit/Cost: Measurement Methodology.

² Arthur D. Little, Inc., "Transportation and Environment: Synthesis for Action" a study prepared for the U.S. Department of Transportation, Office of the Secretary, July 1971.

chain of environmental events generated by a change in the impacting factors.

The identification and categorization of environmental elements that are affected by the provision and operation of transportation facilities, and the determination of the significant elements and relationships among them, requiring the confrontation of certain semantic errors and obfuscations common in the general field of environmental impacts. It was found from a review of the literature that the terms "elements", "impacts", "factors", and "effects" are used interchangeably. It is necessary therefore to define *environment*, *environmental element*, *impacting factor*, and *environmental effect*, as they are used in this report.

Environment—This is considered to be the *whole of the terrestrial universe*, including all natural and man-made objects and phenomena, and all humans, flora, and fauna.

Environmental element—This is an aspect, or portion, or process, in the general *environment* which can be named and thereby described or defined.

Impacting factor—This is a characteristic, or emission, or a by-product of (in this case) a land transportation facility *which can have an impact on an environmental element*.

Environmental effect—This is, then, the resulting change in state or behavior of an *environmental element* as a result of an *impacting factor*.

Further, if the term "ecology" is accepted in its biological definition as dealing with the relations between living organisms and their environment, and restricted to the *physical* environment, the term "environment" as used may be divided between "ecological" and "non-ecological" considerations, or between "physical" relationships and "social" relationships.

The "ecological" or "physical" sphere must deal with all those aspects having to do with disturbance or disruption of the "cycle of life", the basic cycle of birth, death, and regeneration of which all living things, including man, take part (see Figure 1). This includes all of the effects of land transportation *construction*, in disturbing plants and animals, changing wind and water patterns, and affecting drainage and erosion; *presence*, in making permanent these effects; *operation*, in emitting gases, vapors, liquids, solids, and noise; *maintenance*, in use of salts, pesticides, and other chemicals.

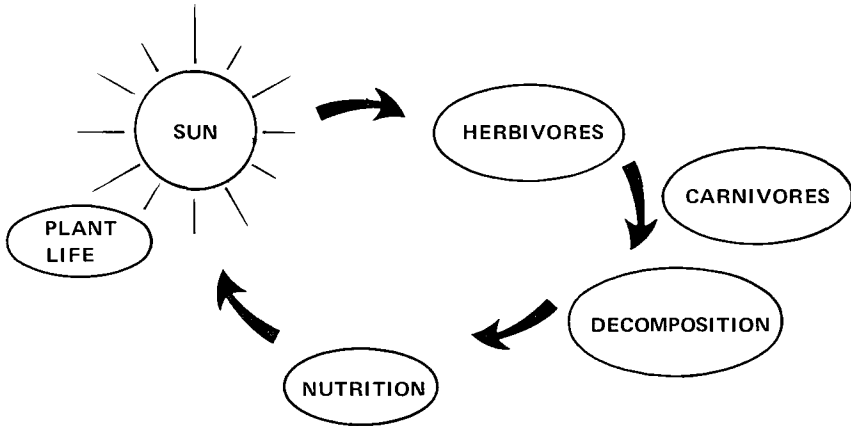


Figure 1. Cycle of life.

The “non-ecological”, or “social” sphere concerns disruptions of the social structure of man from a *physical* standpoint (relocation, separation of community facilities); a *sociological* standpoint (disruption of community “cohesion”, reduction in community “spirit”); and a *psychological* standpoint (increase in “residential mobility”, “aesthetics”). This area may also consider questions of *economic* effects as a measure of social effects.

There are areas of overlap, in that man is involved in the purely ecological (his health, safety, or life can be affected by the transportation facility; physical structures are also attacked by emissions), and these very considerations are also social in nature (see Figure 2).

In considering the process by which Impacting Factors affect Environmental Elements, it is apparent that emissions from engines, noise from vehicles, and the physical presence of a facility do not have a direct effect upon man, animals, plants, or structures. The effects of these impacting factors are transmitted through a medium. Direct effects are on Air (including Meteorology), Water and Soil, and elements of the Man-Made Environment. In polluting air, gases affect respiration, particulates affect lungs, leaf surfaces, human eyes; in polluting water, liquids, gases and solids affect plants and fish and humans; in removing houses, a facility affects economics and social cohesion. Figure 3 identifies the environmental elements as Primary (media through which impacts are transmitted), and Secondary (receptors of positive or negative effects).

Detailed descriptions of the terms used above (and in Figure 2) follow Figure 3.

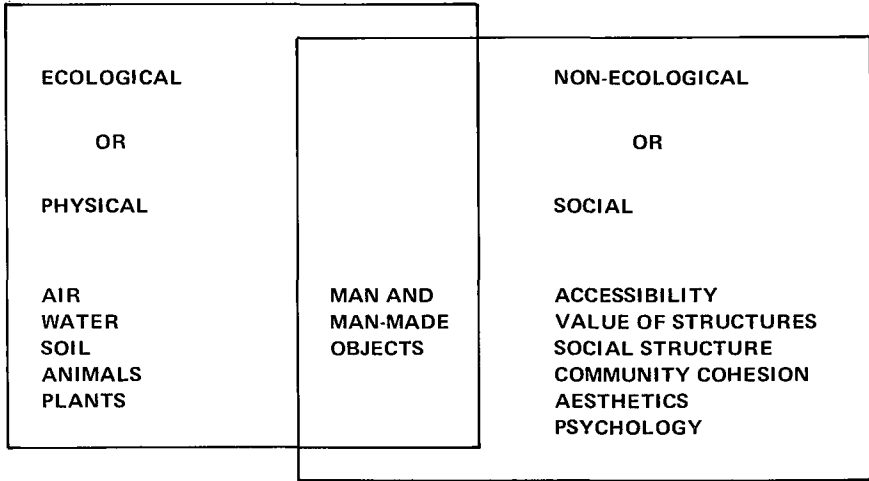


Figure 2. Classification of environmental elements.

Primary Elements

AIR AND METEOROLOGY includes

- Air Composition
- Air Density
- Visibility
- Wind Direction
- Wind Velocity
- Rainfall
- Temperature
- Light

WATER AND SOIL includes

- Topological Features
- Surface and Ground Water, including
 - current direction
 - current velocity
 - water quality
- Drainage Pattern
- Soil or Sediment *Type*
- Soil or Sediment *Texture*
- Soil or Sediment *Transport*, including
 - material type
 - quantity
 - rate
- Dissolved Solids, both
 - inorganic, and
 - organic

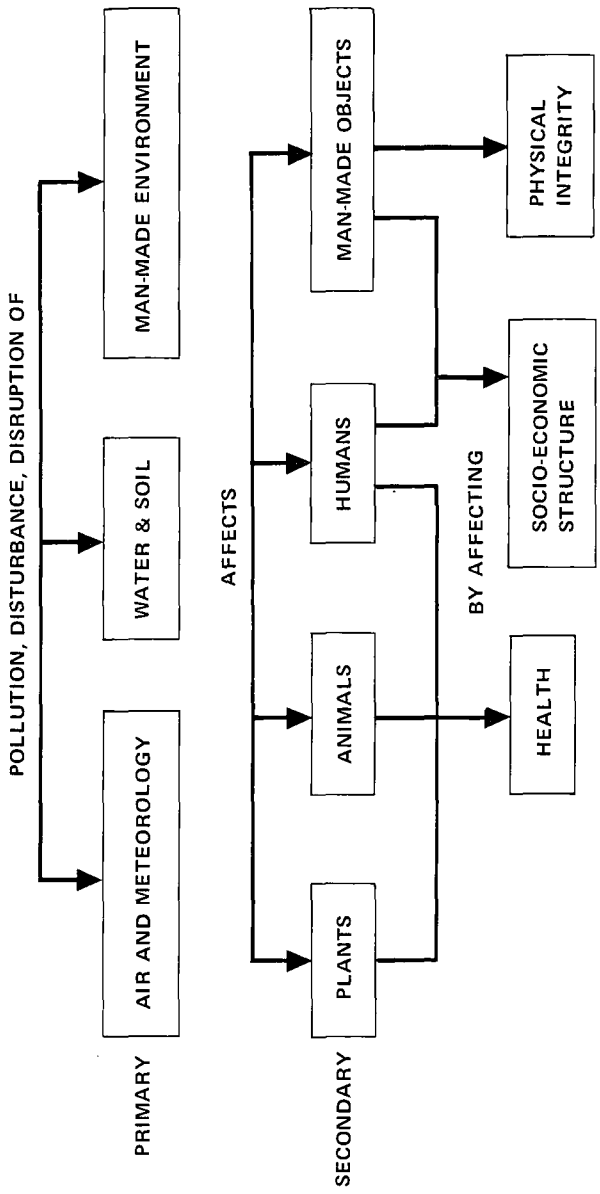


Figure 3. Environmental elements affected by land transportation facilities.

Interstitial Dissolved Solids, including

- inorganic
- organic, and
- pH, Redox, and alkalinity

MAN-MADE ENVIRONMENT covers all of the works of man, both

Physical, including

- structures
- devices
- parks and recreational areas, and

Social, including

- communities
- economies
- social relationships

Secondary Elements

PLANTS or AUTOTROPHS are classified as

Bacteria

Algae, both

- Micro- and
- Macro-

Mosses

Lichens

Ferns

Herbs

Grasses

Shrubs

Trees

ANIMALS or HETEROTROPHS are classified as

Bacteria

Fungi

Protozoans

Invertebrates

Fish

Amphibians

Reptiles

Birds

Mammals

HUMANS can be said to properly belong among "Mammals", above, but since all aspects of human existence must be considered, a separate classification is developed.

The HEALTH of Plants (Autotrophs), Animals (Heterotrophs), and Humans is affected by the Primary Elements. In

addition, however, effects on the Primary Elements are transmitted to the *SOCIO-ECONOMIC STRUCTURE* of Humans. *MAN-MADE OBJECTS* make up the physical aspects of the Primary Element of *MAN-MADE ENVIRONMENT*; therefore, disruption of a *community* destroys individual *houses* or *facilities*; acids in the *air* can corrode *metal* and *stone*.

Component Characteristics of Secondary Elements

Effects on the *HEALTH* of Plants (Autotrophs), Animals (Heterotrophs), and Humans has been noted by effects on the following component parts or systems:

Plants (Autotrophs)

Studies have shown effects on

- leaves
- stems
- roots
- transpiration
- photosynthesis

Animals (Heterotrophs) and Humans

Studies have shown effects on

- throat and nose
- lungs
- eyes
- teeth
- blood
- heart
- kidneys
- bone tissue
- gastro-intestinal system
- nervous system
- resistance to infection
- skin
- mental health
- birth defects
- growth

Effects on *SOCIO-ECONOMIC STRUCTURE* can be divided into three groupings:

Physical Aspects, Community Aspects, and Individual and Family Aspects.

The *Physical Aspects* of Human Socio-Economic Structure include

- Housing*
- Business, Industry and Farms*
- Services and Utilities*, including police, fire, water, electricity, sewage, etc.
- Institutions*, such as churches, hospitals, libraries, schools, museums, scientific services, etc.
- Amenities*, such as conservation, open space, recreation facilities, aesthetics, architecture, historic considerations, cultural considerations, etc.
- Safety*
- Land Use*, including community growth or stability, economics, population, residential/commercial mix, etc.
- Access to Land Use* includes distance, time, cost, public safety, national defense.
- Topography*
- Property Values*
- Tax Base*

The *Community Aspects* of Human Socio-Economic Structure include

- Population Density* and
- Population Change*,
- Socio-Economic Status*, including economic, educational, recreational, and social opportunities
- Cultural and Ethnic Homogeneity*
- Living Patterns*
- Community Pride*,
- Spirit*,
- Identity*
- Cohesion*
- Activities*, and
- Stability*

Tax Base

The *Individual and Family Aspects* of Human Socio-Economic Structure include

- Socio-Economic Status*, in terms of economic, educational, recreational and social
- Physical Mobility and Accessibility*
- Living Patterns*
- Interpersonal Relationships and Functional Integration*, in terms of neighboring, privacy, friendliness, territoriality,

belongingness, orientation, personalization, mutual support, social participation, sharing, self-actualization, personal worth, motivation, familiarity

Property Values

Effects on the *PHYSICAL INTEGRITY* of MAN-MADE OBJECTS include effects on

stone
masonry
metal
synthetics
rubber
glass
wood
cellulose
dyes

IDENTIFICATION OF IMPACTING FACTORS

Factors emanating from the planning, design, construction, operation, and simple presence of a land transportation facility can be classified as “*emissions*”, *other by-products*, *salt*, *noise* and *vibration*, and *physical presence*. In considering the consequences of the introduction of a facility into a given location, the major *deleterious* effects of such introduction are in the form of air pollution, noise, erosion, and dislocation of houses and businesses. The major *positive* effects are in terms of accessibility, “progress”, and economic effects.

Emissions—Generally considered to be gaseous emanations from motor vehicles, but the following physical emission types are included here:

gases
vapors
aerosols
particulate matter

From a review of the literature, the following emission categories have been developed, based upon relative importance in quantity, effect, or nature:

- carbon monoxide (CO)
- organic compounds, or hydrocarbons, and nitrogen oxides (HC and NO_x)

- particulates
- sulfur oxides (SO_x)

Other by-products—Includes those resultants of transportation which are currently considered minor in effect as a result of a dearth of knowledge as to their extent and effects:

oil drippings
 gasoline drippings
 rubber particles from tire wear
 asphalt and concrete particles from tire wear
 asbestos from brake lining wear

However, this category must also include other resultants of transportation which can be quantified, and which have a body of literature as to effect:

pesticides
 herbicides
 fertilizers
 trash
 abandoned vehicles

Salt—Sodium chloride or calcium chloride, is a major Impacting Factor because of the large quantities used in ice and snow removal in northern regions of the country.

Noise and vibration—Constitutes a special Impacting Factor which is not physical but is borne upon the air (and through solids) and results in a physical (and psychological) impact.

Physical presence—That Impacting Factor which results in changes in drainage patterns, obliteration of natural and man-made elements, and disruption of natural and human systems. It also offers the most *positive* effects: accessibility, economic improvement, communication.

Significance of Environmental Elements

BY EXPOSURE

Review of available literature affords current knowledge on the known impingements of Impacting Factors on Environmental Elements. In the first case, the *Primary Elements*: Air and

Table 1. Effect of Impacting Factors on Primary Environmental Elements

Primary Elements Affected By	Impacting factors							
	CO	HC & NO _x	Particu- lates	SO _x	Other By-products	Salt	Noise & Vibration	Physical Presence
Air and Meteorology:								
Air Composition	x	x	x	x				
Density	x	x		x				
Visibility	x		x	x				
Wind Direction								x
Velocity								x
Rainfall	x	x	x	x	x			
Temperature	x	x	x	x	x			
Light	x	x	x	x	x			x
Water and Soil:								
Topological Features								x
Surface and Ground Water								
Quality		x	x	x	x	x		x
Current Direction								x
Current Velocity								x
Drainage Pattern								x
Soil or Sediment Type							x	
Texture		x					x	x
Transport								x
Dissolved Solids			x	x	x	x		
Interstitial Dissolved Solids		x			x	x		
Man-Made Environment:								
Physical Aspects			x	x		x	x	x
Social Aspects	x	x	x	x	x	x	x	x

Meteorology, Water and Soil, and Man-Made Environment, are affected as shown in Table 1.

The gases, vapors, and aerosols, which constitute the "emissions", can be seen to affect *air* and aspects of *meteorology*, excepting wind direction and velocity. Air "pollution", of course, includes changes in air "quality", or *composition of gases*, *density*, and *visibility* conditions. In addition, *rainfall* "quality", if not quantity and pattern, is affected; as are *temperatures* and *light transmission* quality. Only *wind direction* and *velocity* cannot be said to be affected by gases; the physical presence of the facility, its conformation and orientation, can have an effect on these elemental variables.

The *Secondary Elements*: Plants (Autotrophs), Animals (Heterotrophs), Humans, and Man-Made Objects, are affected as shown in Table 2, through the medium of the *Primary Environmental Elements*. As noted, research has shown effects of gases on the higher plants (autotrophs) to a greater degree than effects on bacteria and algae. Similarly, effects are recorded to a greater

Table 2. Effect of Impacting Factors on Secondary Environmental Elements

<i>Secondary elements affected by</i>	<i>HC & CO</i>	<i>Particulates</i>	<i>NO_x</i>	<i>SO_x</i>	<i>Other by-products</i>	<i>Salt</i>	<i>Noise & vibration</i>	<i>Physical presence</i>
Plants or Autotrophs:								
Bacteria, Micro-Algae, and Macro-Algae		x		x	x	x		x
Mosses, Lichens, Ferns, Herbs, Grasses, Shrubs, and Trees	x	x	x	x	x	x		x
Animals or Heterotrophs:								
Bacteria, Fungi, Protozoans						x		x
Invertebrates	x	x		x	x	x		x
Fish				x	x	x		x
Amphibians	x	x	x	x	x	x		x
Reptiles, Birds, Mammals	x	x	x	x	x	x	x	x
Humans	x	x	x	x	x	x	x	x
Man-Made Objects		x	x	x	x	x	x	x

degree for the higher animals (heterotrophs). Highway salts have a deleterious effect on all living creatures. Noise effects are well documented on the higher animals and man.

Finally, the constituent aspects of the Secondary Elements: Health of Plants (Autotrophs) and Animals (Heterotrophs), including Man, in the natural environment; Physical, Community, and Individual/Family Aspects of the Human Socio-economic Structure, and Physical Integrity of Man-Made Objects, in the Man-Made Environment, are developed in Tables 3 and 4.

Research has shown the damaging effects of gases, aerosols, vapors, and particulate matter on such plant anatomy as leaves, stems, and roots, and also on such processes as transpiration and photosynthesis. Again, there are more clearly noted effects on the higher plants.

As to the health effects on animals (heterotrophs) and man, most effects have been noted either in the laboratory (on higher animals) or on man in situations of air pollution. Long-term effects have rarely been studied. Most available information concerns short-term effects.

As noted, the gases and particulate matter have effects on the throat, nose, lungs, eyes, teeth, blood, heart and skin, and can also affect the gastro-intestinal system, the nervous system, resistance to infection, mental health, birth defects, and growth. Factors such as salt and noise have observed effects on the eyes, the heart, the kidneys, the nerves, infection, mental health, and the possibility of birth defects.

Table 3.

<i>Constituents of secondary elements affected by (natural environment)</i>	<i>HC &</i>		<i>Particu- lates</i>	<i>SO_x</i>	<i>Other by-products</i>	<i>Salt</i>	<i>Noise & vibration</i>	<i>Physical presence</i>
	<i>CO</i>	<i>NO_x</i>						
Health of Plants (Autotrophs):								
Leaves	x	x	x	x	x	x		x
Stems, Roots, Transpiration						x		
Photosynthesis	x	x	x	x	x			x
Health of Animals (Heterotrophs) and Man:								
Throat, Nose, Lungs		x	x	x	x			
Eyes		x	x	x	x		x	
Teeth			x	x	x			
Blood	x	x						
Heart	x	x					x	x
Kidneys							x	
Gastro-Intestinal System					x		x	x
Nervous System	x	x					x	x
Resistance to Infection		x						x
Skin		x						
Mental Health	x	x	x					x
Birth Defects	x				x			x
Growth		x	x					

Considering constituents of the Man-Made Environment, Human Socio-Economic Structure is divided among Physical, Community, and Individual/Family Aspects, as noted earlier. Of the Physical Aspects, the major disruption is due to Noise and the Physical Presence of a transportation facility, in severing access, changing topography, and disrupting or obliterating houses, businesses, institutions, and farms. At the same time, the greatest *positive* aspects emerge for similar reasons: the presence of the new facility *increases* certain aspects of accessibility, and amenity, and land use, and safety, and property value and tax base.

Similarly with Community and Individual/Family Aspects, construction and operation of a transportation facility in or near a community will have positive and/or negative effects on the various component aspects of these groupings.

Finally, it has been noted that emissions, and salts, noise and vibration, and even physical removal or destruction will have effects on the man-made structure of human society in varying degrees, from "acid rain" to bulldozing of existing structures.

A review of the foregoing relationships among Impacting Factors and Environmental Elements can indicate *significance* in terms of how many different categories of impacting factors impinge upon a

Table 4.

<i>Constituents of secondary (man-made environment) affected by</i>	<i>CO</i>	<i>HC & NO_x</i>	<i>Particu- lates</i>	<i>SO_x</i>	<i>Other by-products</i>	<i>Salt</i>	<i>Noise & vibration</i>	<i>Physical presence</i>
Human Socio-Economic								
Structure Physical Aspects:								
Housing, Business, Industry								
Institutions, Farms			x	x	x		x	x
Services and Utilities							x	x
Amenities		x	x	x	x	x	x	x
Safety						x		x
Land Use	x	x	x	x	x		x	x
Access to Land Use							x	x
Topography								x
Property Values and Tax Base	x	x	x	x	x	x	x	x
Community Aspects:								
Population Density and								
Population Change							x	x
Socio-Economic Status and								
Cultural and Ethnic								
Homogeneity								x
Living Patterns		x	x	x	x	x	x	x
Community Pride, Spirit,								
Identity, Cohesion			x	x	x		x	x
Community Activities						x	x	x
Community Stability, Amenity								
and Character			x	x	x	x	x	x
Tax Base	x	x	x	x	x	x	x	x
Individual and Family Aspects:								
Socio-Economic Status								x
Physical Mobility,								
Accessibility, Living Patterns,								
Interpersonal Relationships,								
Functional Integration							x	x
Safety			x	x	x	x	x	x
Property Values	x	x	x	x	x	x	x	x
Physical Integrity of Man-Made								
Objects:								
Stone, Masonry, Metal			x	x	x	x	x	x
Synthetics		x	x	x	x			x
Rubber		x	x	x	x			
Glass, Wood			x	x	x		x	x
Cellulose		x	x	x	x			
Dyes		x						

specific environmental element. This ignores, of course, relative *extent* or *importance* of different impacts, or *degree of effect*. At

any rate, on this basis, the Primary Elements would be ranked as follows in relative significance:

Within Category:

Air and Meteorology

1. Rainfall, Temperature, Light
2. Air Composition
3. Air Density, Visibility
4. Wind Direction, Velocity

Water and Soil

1. Surface and Ground Water Quality
2. Dissolved Solids
3. Soil or Sediment Texture, Interstitial Dissolved Solids
4. Surface and Ground Water Current Direction and Velocity, Drainage, Soil or Sediment Type, Soil or Sediment Transport.

Man-Made Environment

1. Social Aspects
2. Physical Aspects

By Element:

1. Social Aspects of the Man-Made Environment
2. Surface and Ground Water Quality
3. Rainfall, Temperature, Light, Physical Aspects of the Man-Made Environment
4. Air Composition, Dissolved Solids
5. Air Density, Visibility, Soil or Sediment Texture, Interstitial Dissolved Solids
6. Wind Direction and Velocity, Topological Features, Surface and Ground Water Current Direction and Velocity, Drainage, Soil or Sediment Type and Transport

BY EFFECT

Further review of the impacting factor-environmental element relationship, in terms of whether effects are long- or short-range, positive or negative, local or regional, can result in still another approach to the identification of *significance*.

From the aspect of *Local* or *Regional* effects, the gases (CO, HC and NO_x SO_x) can have local or regional effects. *Particulates* can also have local or regional effects. *Other by-products* will generally be local in effect. *Salt* has immediate local effects, with long-range regional effects. *Noise and vibration* is generally local in effect, but local in relation to the facility, which may be in a major corridor

in a region. In addition, airports can be considered to affect a region with the noise problem. Similarly, the *physical presence* of a facility will have local effects within range of its immediate physical effects, but long-range regional effects can be expected in terms of accessibility, economic gain, and progress.

All of the impacting factors can have either *long-term* or *short-term* effects.

Considering whether effects are *positive* or *negative*, only the physical presence of the facility, its existence or introduction into a given context, has any positive aspects. All of the gases, particulates, other by-products, salts, and noise, are intrusions into a previous situation which can only become more negative, or less positive, than it was before. In no case can any of these impacting factors be said to redress a chemical imbalance in the atmosphere or ground water, or add desirable noise to an area previously devoid of such a background.

Only in the consideration of the social, ecological, and economic effects of a given transportation facility, or its size or other characteristics, or in the choices between one transportation mode and the other, does the question of positive effects versus negative effects arise.

In this sense, the ultimate objective of this line of research, the concept of benefit-cost in environmental impact assessment, is served by a recognition that all of the Impacting Factors as identified, except for Physical Presence, will stand in the *cost* column. *Benefits* must be recognized in the socio-economic aspects of the facility's *existence*, its *capacity*, its *modal character*, and its *design and operating features*.

BY STAGE OF DEVELOPMENT

Of greater immediate utility is an approach which considers the categories of environmental elements from the viewpoint of stage of facility development. If such stages of development are set as:

1. Regional planning: corridor selection
2. Modal Choice
3. Route Selection
4. Design
5. Construction
6. Operation and Maintenance

then certain considerations must take precedence at each stage.

Regional Planning considerations from the standpoint of corridor

selection require consideration of the three Primary Element categories on a general basis: identification of existing areas of substandard *air quality*, and the general areas related to prevailing *wind patterns* which would aggravate such air quality conditions given a specific land transportation facility; identification of unusual or critical *topology*, and *water* conditions which would preclude the introduction of a land transportation facility, or a specific *mode* of land transportation facility, into a given corridor; and identification of urbanized areas, isolated communities and structures and other works of man or man-related natural resources, which might be critical to corridor selection.

This stage may be summarized as requiring inventory, on a regional (macro) basis, of situations of *social, economic, air quality*, and *topology-water quality*, at or near a *critical condition* ("critical" remains to be defined).

Modal Choice must be made at this stage based largely on existing transportation planning principles and regional development policy goals. Travel patterns, desires, accessibility requirements, etc. will determine a choice among highway, rail, rapid transit (rail or rubber), busway, truckway, or some new or novel mode. If that choice agrees with policy for the region affected, in terms of economic justification, development of underdeveloped regions, availability of specific types of propulsive energy; *then* broad principles of environmental impact can be considered, *unless* the existing environmental balance (whether social or ecological) is so critical that the choice is predetermined at some point, i.e., between highway and busway, or between gasoline motor vehicle and electric propulsion. The choice of *size* of any given mode can also be considered in this manner.

Route Selection must include consideration of modal choice, since somewhat differing criteria of right-of-way width, topography, and impacting factor-environmental element relationships, must be met for each land transportation mode.

At this stage, knowledge of existing conditions of *Air and Meteorology, Water and Soil*, and *Man-Made Environment*, must be developed at a more detailed level *within the chosen corridor* to permit route selection. The final choice of a route within the previously chosen corridor must be made to minimize effects in each of these environmental categories. Route selection must go beyond the socio-economic considerations which have characterized land transportation planning methods of the past. While such considerations can be shown to be extremely important and possibly of greatest significance within any given context, natural and

ecological considerations must now be introduced into the planning process. Indeed, effects of Impacting Factors on natural environmental elements are seen to affect the socio-economic sphere and thereby enter into that aspect of human activity.

Design constitutes the level at which not only *Primary* Environmental Elements, but *Secondary* Elements as well, must be considered. Compromises will have been made in selecting a route, which may pass a railroad through a suburban development. Design considerations must be used to mitigate the effects of the compromise, i.e.:

- remove as few houses as possible
- affect remaining property as little as possible
- decide upon at-grade or separated crossing on basis of traffic volumes, safety, etc.
- introduce design features to minimize noise to surrounding neighborhood
- provide as little divisive influence on area (many crossings versus elevated or subterranean structure)
- introduce design features to insure safety along right-of-way (fences, etc.)
- design for aesthetic values

If a motor vehicle facility has been decided upon, questions include effects on local air quality; dissipation patterns of fumes, gases, odors, and runoff; and drainage patterns and effects; effects of Other By-Products and Salts on ground water and soils; etc.

The *Construction* stage represents a few special problems in that often temporary effects may have long-term carryover. *Air quality* problems will generally be temporary, in that emissions from construction vehicles and temporary asphalt plants will not carry over into the operation stage (for highways, the construction vehicles will be replaced by traffic). *Wind direction and velocity* will be permanently affected where cuts and fills are substantial. But if more area of a natural or man-made environment is taken than will be required for the ultimate facility, special questions arise:

- If it was determined that the portion of a given forest which will be taken out by the finished facility will not have a major effect on the ecological system of which it is a part, is it still true that the portion taken by the finished facility, *plus* the portion taken temporarily for construction (and replaced by grass seeding) will not have a major effect on the ecosystem?

What is the replacement value of grass to a forest? To its watershed capability? To adjacent aquifers?

- If the disruption to an established community caused by introduction of a facility can be predicted (and accepted), what of the greater disruption caused during the construction process? Will it have permanent effects on the social structure not foreseen for the finished, operating facility?

These questions suggest that the *extent* of all changes to an established situation must be described and, where possible, measured, whether temporary or permanent. Effects can then be predicted, and design decisions (and planning decisions for that matter) can be taken to mitigate the worst, or longest-lasting, effects. If, for instance, it is intended, in design, to provide an “adequate” number of points of access across a given transportation facility within a community, and such a number of access points has been determined as adequate to preserve the cohesion of the community, will lack of that number of access points *during construction* (say six months, or a year) destroy, or damage that community cohesion?

Finally, *Operation and Maintenance* affect all environmental elements in predictable degree. What may not be predicted, however, is change in either the nature, quantity, or character of the *impacting factors*, or change in the nature or character of the *environmental elements*. Changes in fuel, for instance, will affect emissions and thereby affect the expectation of air quality. Change in method for snow and ice removal, or in appearance of the facility, may not be foreseen in predicting effects. Changes in neighborhood character, density, and appearance may occur independently of the facility and thereby negate previous (design) predictions. The introduction of trucks or buses, for instance, on previously passenger-car-only facilities has impacts which must be considered in the *Operation and Maintenance* phase.

A summary, then, of *Significance by Stage of Development* should include:

1. Regional Planning: corridor selection
 - consider regional patterns of Primary Elements—
 - Air and Meteorology
 - Water and Soil
 - Man-Made Environment
2. Modal Choice
 - consider gross effects within potential corridors on
 - Air and Meteorology

Water and Soil
 Man-Made Environment

3. Route Selection

- consider more detailed effects on Secondary Elements
 - Plants (Autotrophs)
 - Animals (Heterotrophs)
 - Humans (Physiological and Social)
 - Man-Made Objects

4. Design

- consider effects on individual elements
 - Plants (Autotrophs)
 - Animals (Heterotrophs)
 - Humans (Physiological and Social)
 - Man-Made Objects
- consider constituents of Secondary Elements
 - Health
 - Human Socio-Economic Structure
 - Physical Integrity of Man-Made Objects

5. Operation and Maintenance

- consider Primary and Secondary Elements
at levels of operation and maintenance designed for
- consider Primary and Secondary Elements
at every change in operation or maintenance procedure

Conclusions

In this paper we have addressed the central issues of environmental analysis. We have attempted to clarify some ambiguities which are found in the literature by proposing a methodology which offers a logical view of the ecological process. The focus of this paper is the development of a systematic approach in the analysis of the relationships between environmental elements and their impacting factors. In this connection, a novel definition of environmental elements has been introduced. This has been accomplished through separating the *primary* from the *secondary* elements, thus making it easier for the transportation analyst to understand the numerous and complex linkages which exist within and between ecosystems.

The role of the impacting factors has also been clarified and the results of this task consist of a set of impact matrices which are useful to the practicing transportation engineer or planner.

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