

Texas Coastal Management Program  
Technical Paper No. 13

ECOLOGICAL ATTRIBUTE ALTERATION  
MEASUREMENT AND EVALUATION

ACTIVITY ASSESSMENT ROUTINE  
ECOLOGICAL SYSTEMS COMPONENT



The General Land Office of Texas  
Bob Armstrong, Commissioner

RPC, Inc.  
Austin, Texas

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This is one of a series of technical papers, which cover a variety of topics. For information concerning other technical papers in this series, or to order more copies of this paper, contact:

Elizabeth Christian Wilds  
RPC, Inc.  
1705 Guadalupe  
Austin, Texas 78701

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## FOREWORD

This technical paper is one of a series of papers in which the background material, models, and data used to develop the ecological systems component (ESC) of the activity assessment routine (AAR) are discussed. Together, the papers are reference sources for the ESC user's manual and form a basis for further system development.

Staff members of the Environmental Management Division, Texas General Land Office, in Austin are available to assist interested parties in learning to use the system, and they welcome any questions, comments, and suggestions concerning the ESC.

Many individuals assisted in the production of these technical papers. The principal-in-charge was Ron Luke. Project manager was Andrew Reed. Author of this paper was Chris Caran. James Kimmel managed final production of these technical papers. The technical editor was Nancy Grona. Production assistance was provided by Denise Girard, Lori Snyder, Kim Frazier, and Margaret Wells.



Bob Armstrong, Commissioner  
General Land Office of Texas

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## ABBREVIATIONS

- AAR - activity assessment routine
- BOD - biochemical oxygen demand
- COD - chemical oxygen demand
- D - decrease of consumers in an ecosystem
- ESC - ecological systems component of the activity assessment routine
- ESD - ecological system diagram
- I - increase of consumers in an ecosystem
- ICNRE - Interagency Council on Natural Resources and the Environment
- L - long-term ecological alteration
- mg/l - milligrams per liter, approximately equivalent to parts per million
- mm - millimeters
- PEA - primary ecological alteration
- ppm - parts per million
- Sh - short-term ecological alteration
- TL<sub>m</sub> - median tolerance limits

## 1. INTRODUCTION

This technical paper is intended to provide a more complete treatment of implicit principles and assumptions contained in the user's manual for the ecological systems component of the activity assessment routine. The ecological systems component (ESC) defines a method for evaluating changes in an ecosystem which may result from resource use and consumption.

An ecological system, or ecosystem, represents the stable sum of a unique combination of biological and environmental interactions. Interdependent biotic and abiotic components, or attributes, comprise the ecosystem. Ecological change is thus understood to consist of the collective changes in attributes. These attribute alterations, then, are the primary elements of environmental impact.

Three fundamental assumptions concerning attribute alterations are made in the ESC system of impact analysis:

1. Ecosystems are internally homogeneous.
2. All changes in an ecosystem may be defined as altered energy or material flows.
3. Environmental change is time-dependent, so that effects must be described as net change over a finite time interval.

The ESC builds upon these assumptions to derive meaningful estimates of potential change in an ecosystem.

The concept of attribute alteration is a pivotal part of the ESC process. For this reason, some of the conventions for alteration assessment are elaborated here. The arrangement of topics in this technical paper differs from that in the ESC user's manual. Tasks in Chapter 2, Part III of the manual trace the sequence of steps by which the analyst is likely to evaluate an attribute alteration. This technical paper, however, expands on assumptions inherent in the ESC by providing information about those tasks which are most complex or to which exceptions may apply.

This paper begins by characterizing an ecosystem as an organized collection of attributes mutually dependent on energy exchange. The magnitude matrix with which altered energy flows are scaled is described in Chapter 4. The magnitude of an alteration is assessed somewhat differently for the two

categories of attributes; discussion of conventions relevant to this distinction is provided in Chapter 5. However, effects on attributes are variable through time, and additional remarks concerning duration are included in Chapter 6. Finally, possible exceptions to the general guidelines for designating the direction of an effect are introduced in Chapter 7.



## 2. EFFECTS ON CONTIGUOUS ECOSYSTEMS

The natural environment is usually seen as a collection of ecological systems, or ecosystems (E.P. Odum, 1971). Schwarz et al. (1976) define an ecosystem as "any complex of living organisms taken together with all the other biotic and abiotic factors which affect them, that are mentally isolated for purposes of study." (p. 67) This definition is consistent with the designation of coastal ecosystems in the ESC user's manual.

Ecosystems are somewhat artificial divisions, separated along conceptualized boundaries. Materials, energy, and organisms move through the environment unrestrained by barriers imposed for the convenience of assessments. The ESC accounts for such movements of flows by defining pathways of interaction among contiguous ecosystems (see Figure 1). Exchanges of materials and energy between ecosystems are called imports and exports. The movement of organisms across ecosystem boundaries is called immigration and emigration.

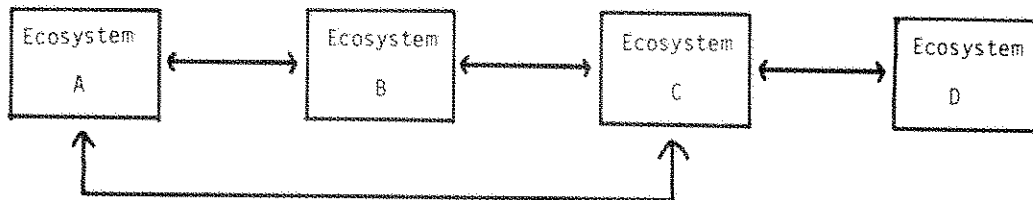
Ecological system diagrams (ESDs) are used in the ESC methodology as ecosystem models. The pathways of exchange shown on a diagram provide access from one ecosystem to another during an impact assessment. If, in the analysis of a single ecosystem, exchange with one or more contiguous ecosystems is anticipated, the consequences of the flow must be evaluated in the contiguous or participant ecosystems, as well. The exchange would serve as a primary ecological alteration (PEA) in the participant ecosystem(s). The first-degree attribute alteration which results from that PEA thus directly corresponds to the attribute alteration in the ecosystem which initiated the exchange. The duration, magnitude, and probability (see ESC user's manual) of such corresponding alterations would be identical. However, the direction of the alterations would be opposite.

For example, dredging activity in the medium salinity bay ecosystem may affect top consumers, an attribute (see medium salinity bay ecosystem diagram, ESC user's manual). An assessment of this effect could indicate probable displacement of top consumers from the alteration site and possible emigration from the medium salinity bay ecosystem. The consumers would then immigrate to the contiguous ecosystem, the bay transitional area in this example. (See Figure 2.)

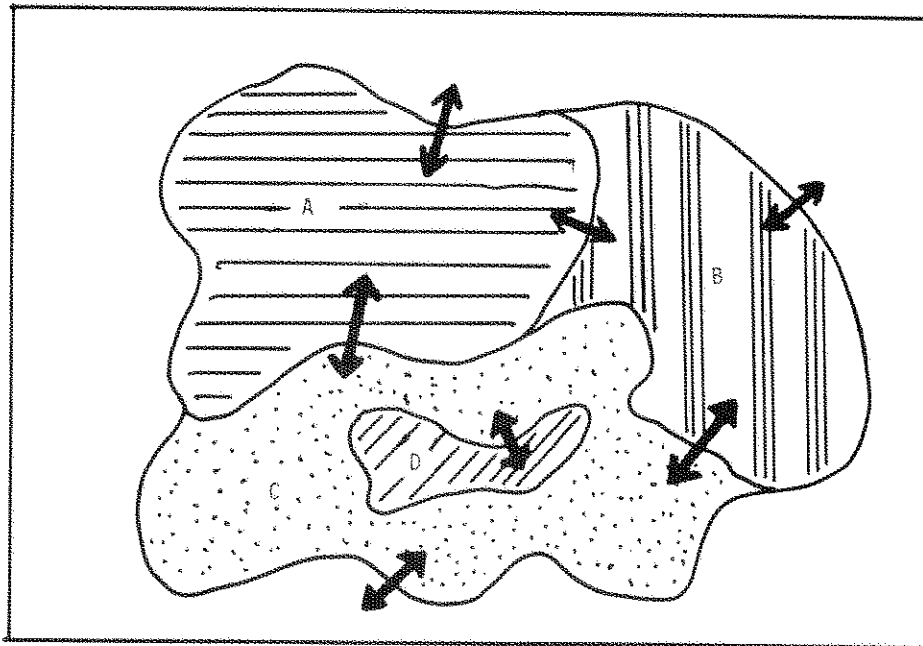
The duration, magnitude, and probability of the emigration of top consumers from the medium salinity bay would be identical to those of immigration of top consumers into the bay transitional area. However, by conven-

Figure 1

PATHWAYS BETWEEN CONTIGUOUS ECOSYSTEMS

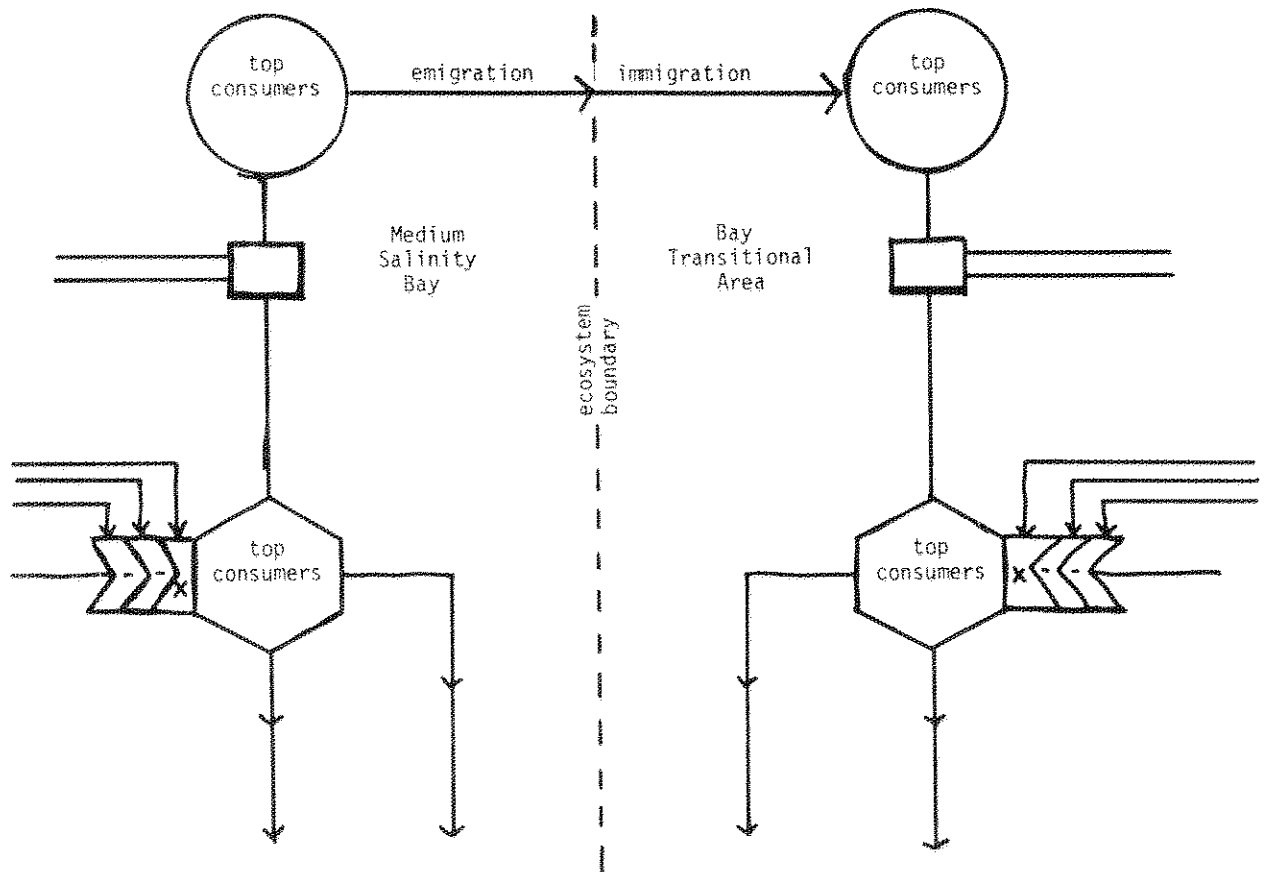


- (a) Diagram of exchange between contiguous ecosystems. Pathways of exchange: import-export (materials, energy) and immigration-emigration (organisms)



- (b) Plan view of contiguous ecosystems representing pathways of exchange

Figure 2  
EFFECTS ON CONTIGUOUS ECOSYSTEMS



In this example, the displacement of top consumers from the medium salinity bay ecosystem is a primary ecological alteration (PEA) in the bay transitional area ecosystem.

tion, the direction of an emigration is designated a decrease (D) while an immigration is reported as an increase (I). (See Chapter 7 of this technical paper). The directions of the two corresponding alterations would be opposite.

### 3. ENERGY AND MATERIAL FLOW

As previously stated, the ESC relies on the ecological system diagram (ESD) as the primary model with which changes in the environment are predicted. (For a more complete discussion of ESDs, see Technical Paper No. 12.) An ESD is a graphic representation of the major components or attributes of the ecosystem and their interaction pathways.

Evaluation of change in an entire ecosystem requires integration of changes in its parts. To understand both incremental and net change throughout an ecosystem, a common denominator must be found which can be used to compatibly express all flows and processes.

In the ESC methodology, expected changes in an ecosystem, or attribute alterations, are generally described as percentage equivalent energy flow. Energy is often defined as "the ability or capacity to do work," and is measured in such units as ergs, calories, and British thermal units. These units and the definition are outgrowths of classical thermodynamics, which has only recently been applied to studies of the environment.

However, the fundamental energy basis of environmental maintenance has long been recognized (Lotka, 1925; Schrodinger, 1944). Ecosystems process energy, converting sunlight and other primary energy sources into the kinetic energy of biotic activity and the potential energy of protoplasm. Theoretically organisms and organic matter could, therefore, be described in energy equivalents.

More recently, H.T. Odum (1957, 1971) and others have refined the theoretical concept of ecosystem energetics to account for energy flow in thermodynamic units. This advanced technique has been used successfully in several studies of environmental impact (Boynton, 1975; California State Polytechnic University, 1972; Gilliland and Riser, 1977; H.T. Odum, 1957, 1971, 1972; H.T. Odum et al., 1974, 1977; and U.S. Department of Commerce, 1975).

In each of these studies, however, the cost in terms of original data collection was enormous. The cost was so great, in fact, that the study area in each case was, by design or necessity, quite small. At the present state of the art, a comparable effort could not be practicably undertaken for an area as large as the Texas coastal region. Despite advantages of assessments based on energy flow, the cost of a coastal zone energetics analysis would be prohibitive.

The absence of definitive measurements of an ecosystem's energy budget requires consideration of alternatives. One such alternative is to express energy flow in dimensionless (i.e., unitless) percentages. In this way, change in an attribute can be readily estimated as a proportional variation from that attribute's baseline energy condition. The baseline energy condition is usually assumed to be unity, or one. For example, an estimate of a 20 percent change in energy processing by attribute A is as useful and very likely nearly as accurate as a prediction of a 5,000 kilocalories reduction in A's normal energy processing rate of 25,000 kilocalories per unit time. By establishing reasonable conventions for evaluating energy flow in terms of percent change, the ESC has incorporated many of the advantages of energetics analysis in a practical procedure for environmental impact assessment.

#### 4. THE MAGNITUDE MATRIX

The relative magnitude of a change in energy flow to or from an attribute is estimated as the percentage deviation from the attribute's normal energy condition. Such a change is, however, localized. Effects at the alteration site must be related to the size of the ecosystem.

The magnitude matrix is designed to illustrate the interdependence of percentage change and the areal extent of an effect. In the form shown in Figure 3, the magnitude matrix is plotted on log-log Cartesian coordinates with percentage change indicated along the ordinate (vertical) axis and area shown on the abscissa (horizontal) axis.

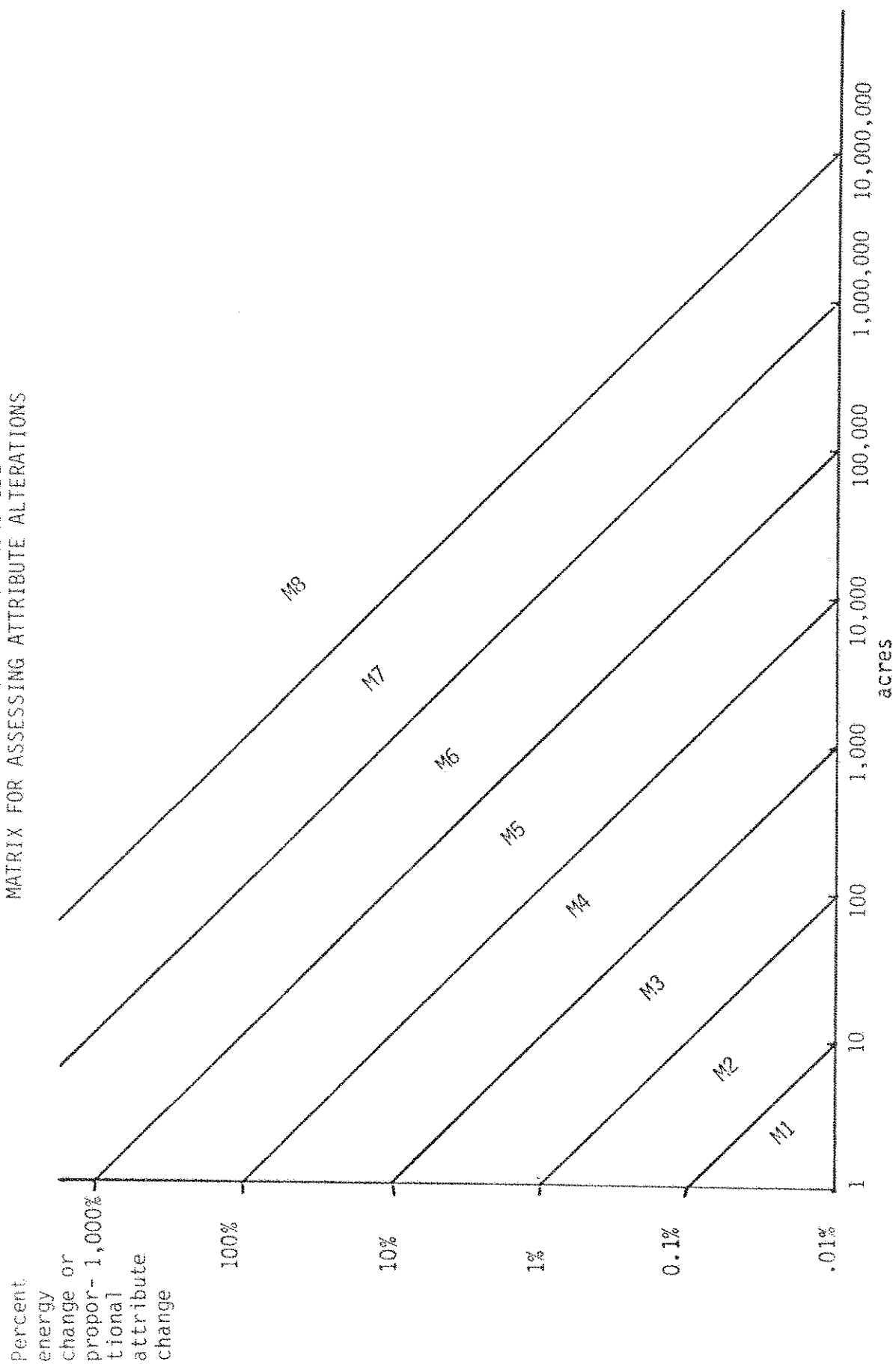
When change in energy flow is plotted against area on this matrix such that a constant product of percentage and area is defined, the resulting diagonal lines divide the matrix into equally spaced zones. These zones are numbered for identification. The numbers then become useful code designations with which to describe the magnitude of attribute alterations.

While it is convenient to define magnitude zones at intervals of order of magnitude (powers of ten), the analyst may choose an entirely different method for designating magnitude. In practice, however, estimates of attribute change are often accurate only to the nearest order of magnitude, so the analyst should consider the certainty with which alterations can normally be predicted.

The principle on which the magnitude matrix is based is theoretical but simple. If each ecosystem is assumed to be internally homogeneous, minor effects over a large area are comparable to major effects over a smaller area. In Figure 3, for example, a one percent change over 1,000 acres is identical to 10 percent change over 100 acres and to a 100 percent change over 10 acres, in terms of implied energy flow.

Of course, such an assumption is incompatible with the realization that within even the most uniform ecosystem, spatial variation is enormous. However, when preparing an assessment, if provision is made for consideration of effects on nonuniformly distributed attributes, effects on the ecosystem as a whole may be reasonably approximated. Because the ESC is primarily intended to be used to predict effects (i.e., before an alteration is imposed), approximations accurate to the nearest order of magnitude are extremely useful and may represent a significant improvement over estimates attainable by any other method of impact assessment with comparable data requirements.

Figure 3  
MAGNITUDE MATRIX: LOG-LOG COORDINATE  
REPRESENTATION OF THE MAGNITUDE  
MATRIX FOR ASSESSING ATTRIBUTE ALTERATIONS





## 5. TYPE A AND TYPE B ATTRIBUTES

Two classes of ecosystem attributes can be distinguished on the basis of energy processing. (See Appendix A.)

### TYPE A ATTRIBUTES

Type A attributes are those which process energy directly. Organisms and primary energy sources in the environment are the most important Type A attributes. Generally, energy sources are not directly affected by activities in the ecosystem. Instead, the rates of flow along pathways connecting energy sources to other attributes may be altered to varying degrees.

Effects on organisms are more complex. For example, a reduction in energy processing by a consumer group can mean that (1) the consumers eat less and therefore grow and reproduce less readily; (2) the consumers modify their diet and/or behavior in terms of energy expenditure per unit intake, loosely implying reduced growth rate; (3) the consumers are displaced to unaffected or less affected areas which may be able to sustain an immigrant population; or (4) the consumers sustain lethal effects. Percentage change in energy flow thus cannot always be directly equated with numbers of organisms or even with population density. This is particularly true when the change is much smaller than 100 percent. A complete description of the method of evaluating Type A attribute alterations is included in Chapter 2, Part III of the user's manual.

### TYPE B ATTRIBUTES

Type B attributes are those abiotic components of an ecosystem which affect energy processing by Type A attributes, but which do not themselves constitute primary energy processors.

Changes in Type B attributes can have marked effects on organisms and other Type A attributes in the ecosystem. A change in a Type B attribute which is sufficient to kill or displace a major producer or consumer group, or to seriously impair the energy flow from some other Type A attribute to the affected portion of the ecosystem, represents an obvious threshold against which to gauge lesser effects. Similarly, changes in Type B attributes which are so minute as to approach the analytical limit of detection may have negligible

effects on Type A attributes. Least certain is the extent to which moderate changes in Type B attributes may alter energy transfer. Sublethal effects on organisms and partial impairment of energy flows occur over a broad range of variation in any Type B attribute. Effects within this range are complex and, in some cases, synergistic or mutually compensating. Professional judgment is required to establish the approximate intermediate thresholds which correspond to changes in equivalent energy flow.

A change in a Type B attribute is restricted in time and space; that is, the effect generally persists for a finite time period and encompasses a finite area. The duration of the effect is discussed in Chapter 6 of this technical paper. The areal extent of the expected effect must be approximated by the analyst. In the ESC procedure, the area over which a change may occur is important in describing the magnitude of an attribute alteration.

#### CORRELATION OF TYPE B ATTRIBUTES WITH TYPE A ATTRIBUTES

An example of the manner in which actual, or absolute, changes in Type B attributes may be correlated with effects on Type A attributes is shown in Table 1. The extent to which Type B attributes may exert such influence is subject to interpretation, and must be viewed in the context of a particular ecosystem. The analyst must generate a comparable correlation table for each ecosystem for which an assessment is conducted. These tables should be stored for reuse and reviewed periodically to ensure consistency with current knowledge of the interactions described.

Not all of the changes observed in Type B attributes can be readily related to changes in energy flow. In particular, small changes in some Type B attributes may not clearly correspond to demonstrable effects on Type A attributes. In such cases, the analyst may designate categories of proportional change in material flow within which the absolute change may be expressed. The proportional change is given as a percentage of ambient values or of some other standard against which deviation may be measured. Table 1 is organized such that the percentage change in the attribute is numerically equal to the corresponding change in energy flow in instances where a clear relationship exists. Therefore, the figure which appears at the head of each column may be used to designate either the proportional change in the attribute or the equivalent change in energy flow, when given. This figure is used in classifying the magnitude of attribute alterations when plotted on the magnitude matrix.

For each Type B attribute, the analyst must provide a reasonable estimate of the expected absolute change in that attribute. Information from many sources may be used by the analyst in making this estimate, including the following pertinent portions of the project description; the environmental report; site inspections and surveys; technical literature used in defining relationships among attributes; descriptions of engineering techniques to be employed during the project, and applicable performance specifications; environmental monitoring and life history data; detailed analog models of natural

Table 1

## SAMPLE CORRELATION OF TYPE B ATTRIBUTES\*

Project _____ Date _____ Ecosystem _____ Activity _____ Prepared by _____ Approved by _____			
Attribute	Direction	Change on the Order of 1%	Change on the Order of 10%
Dissolved oxygen	Decrease	Decrease of approximately 0.5 ppm	Decrease to concen- tration of 5 ppm
	Increase	Increase of approximately 0.5 ppm	Not defined
Salinity	Decrease	Decrease of approximately 1 ppt	Decrease to a concentra- tion of 1 ppt or higher if lethal limit of major species is reached or major species are excluded
	Increase	Increase of approximately 1 ppt	Maximum concentration of 55 ppt or lower concen- tration if lethal limit of major species is reached or major species are excluded

\*This is a sample correlation of Type B attributes with percent change in equivalent energy or material flow. A comparable table should be constructed for each ecosystem directly or indirectly affected by a subactivity.

processes in the ecosystem; geologic, pedologic, hydrographic, topographic, and biotic assemblage or ecosystem maps; and aerial photographs.

The ecological system diagram (see Technical Paper No. 12) of the ecosystem under consideration provides a logical framework in which to view a sequence of changes in attributes. The number of considerations which arise at each point in the analysis is thus limited. Cause and effect can be isolated so that the analyst is usually able, with confidence, to make a reasonable approximation of the change without an exhaustive data search. Ordinarily, this approximation must be accurate only to the nearest order of magnitude (factor of ten), thereby permitting a considerable margin of error. The analysis is generally not hampered by imprecision of less than one order of magnitude.

The change will, in most cases, be estimated initially as an actual or absolute value (e.g. one part per million) or as a percentage of an absolute value (e.g., 10% of the ambient value). A table such as Table 1 will be used to correlate such values with the proportional change in the attribute given as a percentage or with the percentage change in equivalent energy flow. The analyst must prepare such a table before beginning the assessment. Appendix B of this technical paper provides information which the analyst may find useful in constructing the table and in developing an understanding of its meaning.

The figures appearing at the head of each column in the correlation table will be used to determine the magnitude of the alteration sustained by the attribute. The "percentage equivalent change" is expressed as either a change in equivalent energy flow or material flow. In the ESC analysis changes in Type B attributes are not described in terms of energy flow directly, but rather as changes in equivalent energy flow (when changes in the attributes correspond closely to effects on organisms or other energy processors) or as a proportional change in the attribute. The proportional changes serve to categorize the spectrum of detectable variation in the attribute.

Absolute values shown in the three columns in Table 1 define approximate thresholds beyond which change in the Type B attribute and the effect that change may have on Type A attributes is markedly increased or decreased. Because the ESC system of analysis is primarily intended to distinguish effects which differ by an order of magnitude (factor of ten) or more, use of a table of relationships such as Table 1 does not require data (i.e., estimates of absolute change) with accuracy greater than to the nearest order of magnitude. Most effects in nature cannot be reliably predicted with greater precision. Therefore, an order of magnitude estimate of potential effects is both adequate and reasonable. However, the level of detail attainable in the analyst's estimate of absolute changes in Type B attributes matches precisely the degree of accuracy attainable in an impact assessment which employs the ESC methodology.

## 6. DURATION

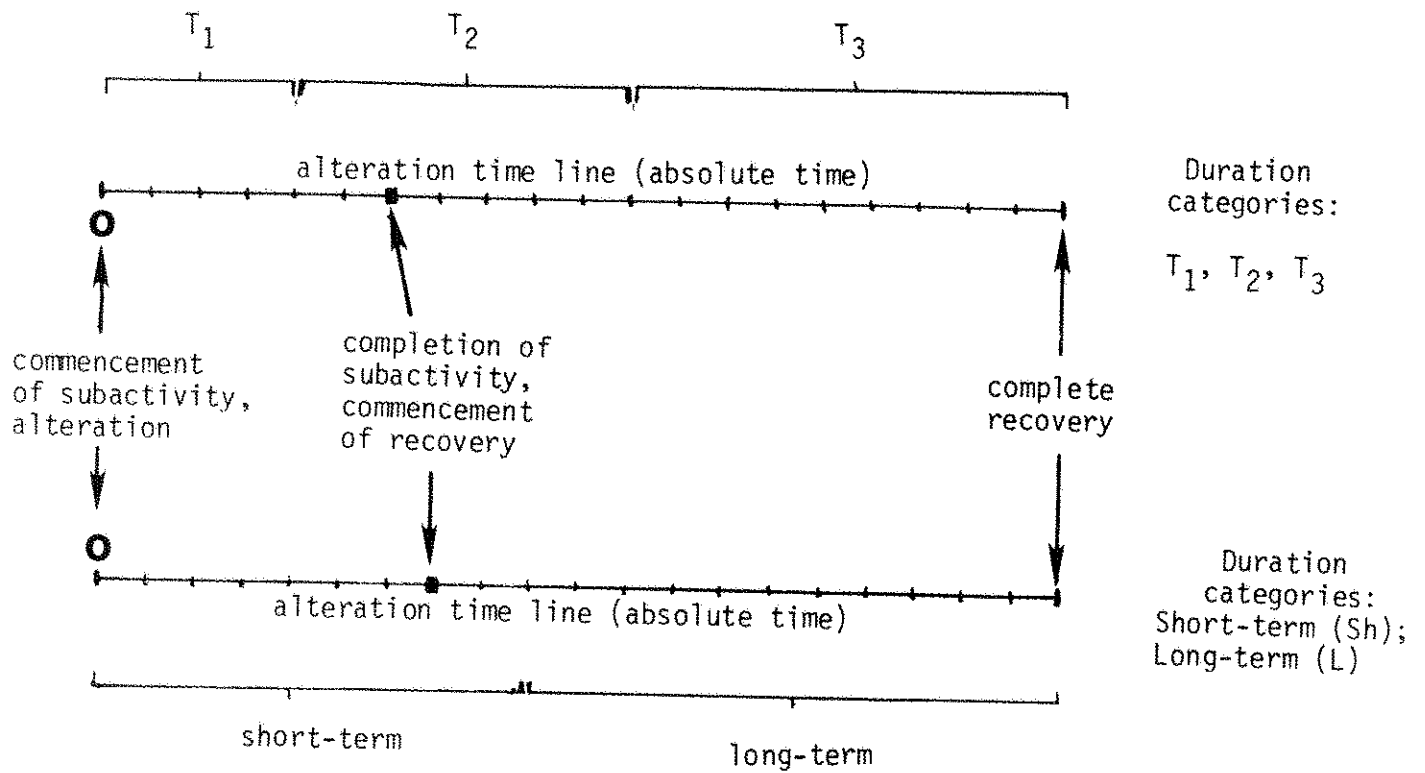
A fundamental assumption in the ESC methodology is that the net result of time-varying effects in an ecosystem can be approximated over a finite time interval. The process of estimating net effects is facilitated if categories of duration are selected as the functional time intervals over which effects are evaluated. A predetermination of the needed duration categories is not provided in the ESC methodology. For each assessment, the analyst must establish an appropriately divided time line and must apply these duration categories uniformly. Because duration actually represents the third dimension of the magnitude matrix, it is important to select a rational basis for dividing the time axis that is consistent with the attainable accuracy and level of treatment of other axes. Considerations which may assist the analyst in establishing duration categories are provided in the ESC user's manual (see also Figure 4).

To illustrate the rationale for selecting duration categories, the following discussion relevant to the pilot study of the ESC (Technical Papers No. 2 and 3) may be of help to the reader. In the pilot study, a useful division of the time line was provided by clearly discriminating among instantaneous, short-term, and long-term effects. Instantaneous alterations are those which are effected within hours or days and which persist for comparable periods. Short-term alterations include those effected within and persistent for two years or less, but which could not reasonably be characterized as instantaneous. Long-term effects occur over a period in excess of two years from commencement of the subactivity and/or persist longer than two years. Duration codes designating short-term (Sh) and long-term (L) alterations appear on the worksheets prepared for the pilot study. Instantaneous effects were accounted for by adopting the convention that, where appropriate, instantaneous first-degree attribute alterations would be designated short-term. Elsewhere on the worksheets, short-term effects were defined as above.

Selection of the two-year time interval as the basis for distinguishing short- from long-term alterations was based on consideration of the importance of seasonal events in nature. These include reproduction, migration, cyclical productivity, and weather-influenced environmental variations. Fluctuating tidal range, water temperature, and flooding potential are other phenologic or season-dependent phenomena. Ecosystems may be intrinsically tied to and defined by seasonal events. Execution of a subactivity in such an ecosystem may interrupt one or more of these seasonal processes or may directly or indirectly alter attributes with marked periodicity. The ability of altered ecosystem attributes to fully recover, or of environmental processes to resume presubactivity conditions, may depend on the season of the year in which the impact is sustained to

Figure 4

ESTABLISHING DURATION CATEGORIES:  
ALTERNATE MEANS OF REPRESENTING CATEGORIES OF DURATION



a greater extent than on the passage of an arbitrary period of calendar time. By evaluating the magnitude of impacts over a two-year time span, the analyst ensures that at least one full annual cycle of phenologic events is completed regardless of the season in which the initial impact was sustained.

In many cases, the relative recovery of an attribute cannot be estimated unless the impact is envisioned after one full seasonal cycle has ensued following cessation of the disturbance. Longer-lived changes are those which resist restoration despite passage of the time required for a full cycle. Therefore, division of the time line into short-term (two calendar years or less) and long-term (longer than two calendar years) intervals was both necessary and sufficient for the analytical detail attainable in the trial assessment. In addition to ensuring passage of at least one full annual cycle during the short-term time interval, two calendar years is a period of adequate length to permit confident discrimination of effects which are rapidly compensated (i.e., instantaneous) by normal environmental processes from gradually modified and permanent changes in the affected portion of the ecosystem.

Within the power of resolution which can be defensibly attributed to the ESC, distinction of short-term, long-term, and by convention, instantaneous effects as here defined may represent the limit of user confidence in dividing the impact time line. However, other applications of the analytical method may require more refined time considerations or division of the time line on an entirely different basis. The user is free to select the method of describing impact persistence that is most suitable to his needs as long as that method can be consistently and meaningfully applied.





## 7. DIRECTION

In the ESC methodology, direction is the designation of the nature of the alteration (i.e., whether the net effect of a change is to increase or decrease the energy or material flow to and/or from an attribute).

However, effects on some attributes, particularly Type B attributes, may be difficult to describe as an increase or decrease. For this reason, the analyst may wish to establish conventions governing the designation of direction codes for such attributes on the assessment worksheets. Generally, a simple definition, recorded in the "Comments" section of the worksheets and elsewhere as advisable, will suffice in permitting the analyst to apply the same code ("I" or "D") to alterations not otherwise readily conceivable as an increase or decrease.

For example, the storage "bacteria-suspended organic matter" which appears on the medium salinity bay ecosystem diagram is linked to, and thus affects, two mutually exclusive processes: production of toxic substances (such as sulfates and ammonia) under conditions of oxygen depletion, and nutrient cycling (organic matter decomposition) under conditions of higher dissolved oxygen tensions. Yet in neither case is the amount of organic matter or the gross energy processing rate by bacteria necessarily altered (increased or decreased). To facilitate and simplify the assignment of direction and to avoid loss of information and/or confusion, a simple definition is established: with respect to the action of bacteria on organic matter, oxidizing activity is designated an increase, while reducing activity is said to be a decrease. Such a definition is also useful in describing the direction of imports and exports (suggest increase and decrease, respectively), immigration and emigration (same convention), and substrate texture (reduction in substrate coarseness implies decrease). In such cases, the actual definition can be arbitrary, but it should be followed throughout the analysis, and it must be recorded on the assessment worksheets.



APPENDIX A  
LISTS OF TYPE A AND  
TYPE B ATTRIBUTES

## TYPE A ATTRIBUTES

### Coastal Prairie

1. Macroplant detritus
2. Microplant detritus and microbes
3. Perennial grasses
4. Brush
5. Annuals
6. Perennial herbs
7. Small mammals
8. Granivorous birds
9. Predatory mammals and raptors
10. Insectivorous songbirds
11. Invertebrate consumers

### Salt Marsh

1. Water head for ebb tide
2. Spartina alterniflora
3. Epiphytes
4. Phytoplankton
5. Detritus
6. Detritus export/import
7. Muskrats
8. Oysters
9. Meiofauna
10. Snails

11. Insects
12. Water fowl
13. Wading and shorebirds
14. Crabs and shrimp
15. Small fish
16. Raccoons
17. Large fish

### Brackish Marsh

1. Phytoplankton
2. Scirpus
3. Spartina patens
4. Detritus and microbes
5. Rough mat
6. Aquatic invertebrates
7. Waterfowl
8. Fish
9. Furbearers
10. Small mammals
11. Insects
12. Alligators
13. Red wolves
14. Predatory mammals and raptors
15. Wading and shorebirds

## TYPE A ATTRIBUTES

### Medium Salinity Bay

- |  |   |
|--|---|
| 1. Birds   | 4. Phytoplankton import/export                      |
| 2. Bacteria/dissolved and suspended organic matter import/export | 5. Herbivores and detritivores migration            |
| 3. Current energy  | 6. Intermediate consumers migration                 |
| 4. Turbulent energy  | 7. Top consumers migration                          |
| 5. Phytoplankton   | 8. Birds  |
| 6. Herbivores and detritivores migration                         | 9. Phytoplankton                                    |
| 7. Intermediate consumers migration                              | 10. Macrophytes (seagrass)                          |
| 8. Top consumers migration                                       | 11. Bacteria/dissolved and suspended organic matter |
| 9. Phytoplankton import/export                                   | 12. Bacteria/sediment organic matter                |
| 10. Bacteria/dissolved and suspended inorganic matter            | 13. Microalgae, diatoms, blue-greens                |
| 11. Bacteria/sediment organic matter                             | 14. Benthic community                               |
| 12. Benthic community  | 15. Herbivores and detritivores                     |
| 13. Herbivores and detritivores (zooplankton, mullet, shrimp)    | 16. Intermediate consumers                          |
| 14. Intermediate consumers                                       | 17. Top consumers                                   |
| 15. Top consumers  |   |

### Wind Tidal Flats

1. Current energy
2. Turbulent energy
3. Organic matter import/export
4. Phytoplankton import/export
5. Herbivores and detritivores migration
6. Intermediate consumers migration

### Bay Transitional Area

1. Current energy
2. Turbulent energy
3. Bacteria/dissolved and suspended organic matter import/export

(continued)

## TYPE A ATTRIBUTES

(Wind Tidal Flats, cont.)

7. Top consumers migration
8. Bacteria/suspended organic matter
9. Bacteria/sediment organic matter
10. Phytoplankton
11. Herbivores and detritivores
12. Microalgae, diatoms, blue-greens
13. Benthic community
14. Intermediate consumers
15. Top consumers
16. Birds

### Tidal Stream Reach

1. Dissolved nutrients (inorganic and organic)
2. Turbulent energy
3. Wind or wave action
4. Macrophytes and periphyton (Ruppia)
5. Phytoplankton
6. Estuarine bay (phytoplankton import/export)
7. Zooplankton
8. Macrobenthic invertebrates (Rangia, Penaeus)
9. Benthic invertebrates
10. Aquatic invertebrates
11. Top carnivores (alligator gar and Cynoscion)
12. Estuarine bay consumer migration

## TYPE B ATTRIBUTES

### Coastal Prairie

1. Salt spray
2. Land slope
3. Land elevation
4. Groundwater
5. Sediments import
6. Surface water
7. Macropore water
8. Micropore water
9. Soil heat
10. Heat export
11. Sediments in system
12. Sediment export
13. Soil air
14. Fire frequency
15. Fire
16. Soil toxicants
17. Soil structure
18. Soil texture
19. Available nutrients
20. Unavailable nutrients
21. Plant surface salts
22. Soil salt content
23. Nutrients and salt export

24. Runoff (except that detritus in runoff may be a major energy source (Type A) in downstream system)

### Salt Marsh

1. Heat (fresh water)
2. Nutrients (fresh water)
3. Sediments (fresh water)
4. Sediments (saltwater)
5. Nutrients (saltwater)
6. Heat (saltwater)
7. Available nutrients
8. Unavailable nutrients
9. Frequency of inundation
10. Gas exchange
11. Heat storage
12. Salt storage
13. Suspended solids
14. Bottom sediments
15. Nutrients export
16. Salt export
17. Heat export
18. Suspended solids export
19. Waterborne pollutants

(continued)

## TYPE B ATTRIBUTES

(Salt Marsh, cont.)

20. Water heat
21. Dissolved oxygen
22. Oxidizable materials
23. Water salinity

### Brackish Marsh

1. Inundation frequency
2. Sediment import
3. Land elevation
4. Standing water
5. Macropore water
6. Micropore water
7. Suspended solids
8. Bottom sediments
9. Sediment export
10. Duration of submergence
11. Average depth
12. Frequency of submergence-emergence
13. Gaseous exchange
14. Heat
15. Soil salinity
16. Available nutrients
17. Unavailable nutrients

18. Fire frequency
19. Fire
20. Dissolved oxygen
21. Water heat
22. Water salinity
23. Oxidizable material
24. Waterborne toxic substances
25. Total suspended solids
26. Runoff (standing water export)

### Medium Salinity Bay

1. Water depth
2. Water heat storage
3. Sediment heat storage
4. Heat import/export
5. Salinity import/export
6. Salinity storage
7. Suspended solids storage
8. Sediment solids storage
9. Substrate texture/structure
10. Suspended solids import/export
11. Dissolved and suspended inorganic nutrients import/export
12. Dissolved and suspended toxics import/export

(continued)



## TYPE B ATTRIBUTES

### (Medium Salinity Bay, cont.)

13. Dissolved oxygen import/export
14. Dissolved and suspended inorganic nutrients
15. Inorganic sediment nutrients
16. Dissolved and suspended toxics storage
17. Sediment toxics
18. Dissolved oxygen in water
19. Dissolved oxygen in sediment

13. Suspended solids
14. Bacteria/dissolved and suspended organic matter import/export
15. Dissolved and suspended toxics
16. Dissolved oxygen
17. Sediment dissolved oxygen
18. Sediment toxics
19. Inorganic sediment nutrients

### Bay Transitional Area

1. Heat import/export
2. Salinity import/export
3. Suspended solids import/export
4. Dissolved and suspended inorganic nutrients import/export
5. Dissolved and suspended toxics import/export
6. Dissolved oxygen import/export
7. Salinity storage
8. Heat storage
9. Water depth
10. Sediment solids
11. Sediment heat
12. Substrate texture/structure

### Wind Tidal Flats

1. Sediment heat
2. Water depth
3. Sediment solids
4. Substrate texture
5. Suspended solids
6. Dissolved/suspended nutrients
7. Water heat
8. Sediment nutrients
9. Sediment toxics
10. Dissolved oxygen, surface only
11. Dissolved oxygen
12. Dissolved/suspended toxics
13. Salinity
14. Heat import/export

(continued)

## TYPE B ATTRIBUTES

(Wind Tidal Flats, cont.)

15. Inorganic solids import/export
16. Nutrients import/export
17. Waterborne toxics import/export

### Tidal Stream Reach

1. Land slope
2. Stream morphology
3. Stream gradient
4. Stream form ratio
5. Stream velocity
6. waterborne toxins
7. Heat

8. Dissolved oxygen
9. Fresh water
10. Saltwater
11. Substrate
12. Suspended sediments
13. Bottom sediments
14. Substrate texture (grain size)
15. Exported sediments
16. Average water depth
17. Dissolved toxins
18. Sediment toxins
19. Estuarine bay (water discharge)
20. Toxins export

APPENDIX B  
THRESHOLDS IMPORTANT IN CORRELATING  
TYPE B ATTRIBUTES

## ALKALINITY

"Alkalinity is the capacity of a water to react with hydrogen ions to (a minimum of) pH 4.5. Alkalinity in water is caused primarily by bicarbonates, carbonates, and hydroxides.<sup>1</sup> Their relative concentrations are a function of the temperature, pH, and concentration of other dissolved solids." (Brown et al., 1970, p. 41) "Alkalinity is (functionally) defined as the capacity of the (aqueous) solution to neutralize acid." (Hem, 1970, p. 152) "Alkalinity, therefore, is a measure of the (acidity-) buffering capacity of the water, and since pH has a direct effect on organisms as well as an indirect effect on the toxicity of certain other pollutants in the water, the buffering capacity is important to water quality." (U.S. EPA, 1976, p. 7) See also "pH."

"Like acidity, alkalinity is related to pH but high alkalinities should not be confused with high pH values. Thus, a relatively pure water with a pH value of 7.0 (neutral) will have a low total alkalinity whereas a buffered (against acidity) water at pH 6.0 will have a high total alkalinity. . . . None of the strong alkalies, such as calcium, potassium, and sodium hydroxide, has been shown clearly to be lethal to fully developed fish in natural waters when its concentration is insufficient to raise the pH well above 9.0. Interference with normal development and other damage to fish life sometimes may occur, however, at lower pH values. When caused almost entirely by bicarbonates, alkalinity does not seem to have any harmful effect upon plankton and other aquatic life. . . . It is generally recognized that the best (fresh) waters for the support of diversified aquatic life are those with pH values between 7 and 8, having a total alkalinity of 100 to 120 mg/l or more. . . . This alkalinity serves as a buffer to help prevent any sudden change in pH value (that might otherwise result from an influx of acidic solution), which might cause death to fish or other aquatic life." (McKee and Wolf, 1963, pp. 128, 129) "Alkalinity is important for fish and other aquatic life in freshwater systems because it buffers pH changes that occur naturally as a result of photosynthetic activity of the chlorophyll-bearing vegetation.<sup>2</sup> Components of alkalinity such as carbonate and bicarbonate will complex (effectively, to remove from interaction) some toxic heavy metals and reduce their toxicity markedly.

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<sup>1</sup>"Direct contribution to alkalinity by hydroxides is rare in nature, and their presence can usually be attributed to water treatment or to contamination." (Brown et al., 1970, p. 42)

<sup>2</sup>"Where photosynthesis by aquatic organisms (plants and photosynthesizing protists) takes up dissolved carbon dioxide (which in solution forms carbonic acid) during the daylight hours, a diurnal pH fluctuation may occur and the maximum pH value may sometimes reach as high as 9.0." (Hem, 1970, p. 93)

For these reasons, . . . a minimum alkalinity of 20 mg/l (is recommended, but) natural alkalinity (should) not be reduced by more than 25 percent (regardless). The use of the 25 percent reduction avoids the problem of establishing standards on waters where natural alkalinity is at or below 20 mg/l. For such waters, alkalinity should not be further reduced . . . Adequate alkalinity (should) be maintained to buffer the pH with tolerable limits (see "pH") for marine waters (as well)." (U.S. EPA, 1976, pp. 7-8)

A related water quality parameter is "hardness." "Hardness of water is a physical-chemical characteristic that is . . . attributable to the presence of alkaline earths (principally calcium and magnesium bicarbonates and carbonates)." (U.S. Geological Survey, 1977, p. 8) "The concept of hardness comes from water supply practice. It (hardness) is measured by soap requirements for adequate lather formation and as an indicator of the rate of scale formation in hot water heaters and low pressure boilers. . . . Hardness . . . frequently is distinguished as carbonate and bicarbonate fractions. The carbonate fraction is chemically equivalent to the bicarbonates present in water. Since bicarbonates generally are measured as alkalinity, the carbonate hardness usually is considered equal to the alkalinity." (U.S. EPA, 1976, p. 75)

#### AMMONIA (TOTAL AMMONIA NITROGEN, $\text{NH}_3 + \text{NH}_4^+$ , EXPRESSED AS N)

"Ammonia ( $\text{NH}_3$ ) is a pungent, colorless, gaseous, alkaline compound of nitrogen and hydrogen that is highly soluble in water. It is a biologically active compound present in most waters as a normal biological degradation product of nitrogenous organic matter."<sup>3</sup> (U.S. EPA, 1976, p. 10) "It (ammonia) may also result from the discharge of industrial wastes from chemical or gas plants, from ice plants, or from scouring and cleaning operations where 'ammonia water' is used. Rivers known to be unpolluted have very low ammonia concentrations, generally less than 0.2 mg/l as N." (McKee and Wolf, 1963, p. 132)

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<sup>3</sup>"Ammonia nitrogen includes nitrogen in the forms of  $\text{NH}_3$  and  $\text{NH}_4^+$ . As a component of the nitrogen cycle, (ammonia) is often present in water, but usually in small amounts." (Goerlitz and Brown, 1972, p. 13)

"When ammonia dissolves in water, some of the ammonia reacts with the water to form ammonium ions. A chemical equilibrium is established which contains un-ionized ammonia ( $\text{NH}_3$ ), ionized ammonia ( $\text{NH}_4^+$ , the ammonium radical), and hydroxide ions ( $\text{OH}^-$ ) . . . . The toxicity of aqueous solutions of ammonia is attributed (largely) to the  $\text{NH}_3$  species.<sup>4</sup> Because of the equilibrium relationship among  $\text{NH}_3$ ,  $\text{NH}_4^+$ , and  $\text{OH}^-$  (nontoxic), the toxicity of ammonia is very much dependent upon pH as well as the concentration of total ammonia.<sup>5</sup> . . . . In most natural waters, the pH range is such that the  $\text{NH}_4^+$  fraction of ammonia predominates; however, in highly alkaline waters (well above the typical range of values encountered in freshwater, estuarine, and marine systems), the  $\text{NH}_3$  fraction can reach toxic levels. . . . Other factors also affect the concentration of  $\text{NH}_3$  in water solutions, the most important of which are temperature and ionic strength. The concentration of  $\text{NH}_3$  increases with increasing temperature, and decreases with increasing ionic strength. In aqueous solutions of dilute saline concentrations, the  $\text{NH}_3$  concentration decreases with increasing salinity." (U.S. EPA, 1976, pp. 10-11)

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<sup>4</sup>Although early studies "concluded that the  $\text{NH}_4^+$  fraction had little or no toxicity, (more recent work) has attributed some degree of toxicity to fishes and invertebrates by the  $\text{NH}_4^+$  species (less than 1/50th that of  $\text{NH}_3$ )." (U.S. EPA, 1976, p. 11)

<sup>5</sup>"The difference in sensitivity among fish species to prolonged exposure (to ammonia in water) is probably small." (U.S. EPA, 1976, p. 11)

Chemical species linked to ammonia are also important in the environment. Under aerobic conditions, ammonia and many organic substances are converted to oxides of nitrogen of which nitrites ( $\text{NO}_2^-$ ) and nitrates ( $\text{NO}_3^-$ ) are the most important. "In water, nitrites are generally formed by the action of bacteria upon ammonia and organic nitrogen.<sup>6</sup> Owing to the fact that they (nitrites) are quickly oxidized to nitrate (under favorable conditions), they are seldom present in surface waters in significant concentrations. In conjunction with (excessive quantities of) ammonia and nitrate, nitrites in water are (therefore) indicative of pollution (or other disruptions of the nitrification process)<sup>7</sup> . . . . Nitrites are poisonous compounds . . . . Tests with (fresh water fish) showed that a concentration of 50 mg/l of sodium nitrite could be fatal in 14 days, while 10,000 mg/l destroyed the (fish) in 1.5 hours. . . . (Fresh water snails) were killed in 24 hours by 10,000 mg/l of sodium nitrite or potassium nitrite." (McKee and Wolf, 1963, pp. 225-226)

"Nitrates are the end product of the aerobic stabilization of organic nitrogen." (McKee and Wolf, 1963, p. 224) "In general, the oxidation of organic nitrogen . . . can be expected to produce nitrite and finally nitrate. Some mediating organisms reduce nitrate nitrogen and can produce nitrogen gas instead of, or in addition to, ammonia . . . . The oxidation and reduction of aqueous nitrogen species are closely tied to biological activity, and both the paths followed and the end products of such reactions depend very strongly on kinds and numbers of biota present. . . . Nitrogen in the form of dissolved nitrate is a major nutrient for vegetation, and the element is essential to all life." (Hem, 1970, pp. 180, 181) "Photosynthetic action is constantly utilizing nitrates and converting them to organic nitrogen in plant cells . . . : (therefore), nitrates are seldom abundant in natural surface waters." (McKee and Wolf, 1963, p. 224) Despite the importance of nitrates as mandatory nutrients for producers, "nitrates are rated among the poisonous ingredients of mineralized waters, with potassium nitrate being more poisonous than sodium nitrate." (McKee and Wolf, 1963, p. 224) With regard to nitrate and nitrite toxicity, U.S. EPA (1976) made the following observations: "(1) levels of nitrate nitrogen at or below 90 mg/l would have no adverse effects on warm water fish . . . ; (2) nitrite nitrogen at or below 5 mg/l should be protective of most warm water fish . . . ; and (3) nitrite nitrogen at or below 0.06 mg/l should be protective of salmonid fishes. . . . These levels either are not known to occur or would be unlikely to occur in natural surface waters." (p. 109)

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<sup>6</sup>Nitrites are also produced by nitrate denitrification, a process whereby nitrates, under anaerobic conditions, are altered to form nitrite.

<sup>7</sup>The action of anaerobic bacteria upon ammonia to form, by a sequence of oxidations, ionic nitrate.

## OXYGEN (DISSOLVED)

"Oxygen dissolved in water is derived from the air and from the oxygen given off in the process of photosynthesis by aquatic plants." (Brown et al., 1970, p. 126) "The content of dissolved oxygen in water at equilibrium with a normal atmosphere is a function of the temperature and salinity (dissolved solids content) of the water, the ability of water to hold oxygen decreasing with increases in temperature or dissolved solids. . . . Natural waters, however, are seldom at equilibrium and seldom exactly saturated with dissolved oxygen, for temperatures are changing and physical, chemical, bio-chemical, or biological activities are utilizing or liberating oxygen. . . . Temperature affects not only the amount of available dissolved oxygen in water but also the rate at which fish utilize such oxygen." (McKee and Wolf, 1963, p. 180) "Water bodies in which there is much organic productivity often display wide fluctuations of dissolved oxygen in response to the biological activity." (Hem, 1970, p. 221)

"No general statement can be made to give the minimum dissolved-oxygen concentration required to support fish life, owing to the fact that the oxygen requirements of fish vary with the species and age of the fish, with prior acclimatization, with temperature, with the concentration of other substances in the water, and with several other factors. . . . The lethal effect of low concentrations of dissolved oxygen appears to be increased by the presence of toxic substances, such as excessive dissolved carbon dioxide, ammonia, cyanides, zinc, lead, copper, or cresols. . . . With so many factors influencing the effect of oxygen deficiency, it is difficult to estimate the minimum safe concentration at which fish will be unharmed under natural conditions." (McKee and Wolf, 1963, p. 180)

"Water should contain sufficient dissolved oxygen to maintain aerobic conditions in the water column and, except as affected by natural phenomena, at the sediment-water interface. . . . Dissolved oxygen concentrations are an important gauge of existing water quality and the ability of a water body to support a well-balanced aquatic fauna. . . . The dissolved oxygen criteria (given in Table B1 on page 49) are based on the concentration that will support a well-rounded population of fish . . . as it would occur under natural conditions. . . . Fish embryonic and larval stages are especially vulnerable to reduced oxygen concentrations because their ability to extract oxygen from the water is not fully developed and they cannot move away from adverse conditions. Although many species can develop at oxygen concentrations as low as 2.5 to 3.0 mg/l, the effects of a reduced oxygen concentration even as high as 5 or 6 mg/l can cause a partial mortality or at the least retard development . . . . For most fish, maintaining a minimum 5 mg/l in the water mass in the vicinity of the embryos and larvae should suffice. . . . (Also,) as long as dissolved oxygen concentrations remain entirely satisfactory for fish, no material impairment of the food resources (invertebrates and smaller vertebrates) for fish ascribable to dissolved oxygen insufficiency will occur." (U.S. EPA, 1976, pp. 123-126)

A related and frequently reported property of natural waters is biochemical oxygen demand, "a measure of the quantity of dissolved oxygen, in milligrams per liter, necessary for the decomposition of organic matter by microorganisms,



such as bacteria." (U.S. Geological Survey, 1977, p. 5) This property is also related to the total organic carbon content of the waters.

"As in tests for alkalinity, acidity, color, turbidity, and specific conductance the determination of biochemical oxygen demand (B.O.D.) does not reveal the concentration of a specific substance. Instead it measures the effect of a combination of substances and conditions.

As a parameter of the detrimental effects of organic matter upon a surface water, the (often reported) 5-day B.O.D. value alone means very little. In itself, B.O.D. is not a pollutant and exercises no direct harm. Only by depressing the dissolved-oxygen content to levels that are inimical to fish life and other beneficial uses does B.O.D. exert an indirect effect. Where reaeration, dilution, and/or photosynthetic action offset or minimize this depletion, B.O.D. does not interfere with the reasonable uses of the water . . . .

B.O.D. is important only insofar as it produces septicity or decreased dissolved oxygen, or subsequent growth of saprophytic bacteria which increase the turbidity or other undesirable characteristics of the streams. In a slow, sluggish stream, a 5-day B.O.D. of 5 mg/l might be sufficient to produce de-oxygenation resulting in anaerobic conditions, whereas a swift mountain stream can easily handle 50 mg/l of 5-day B.O.D. without appreciable depletion of dissolved oxygen. Each stream must be considered in its own right, and until the reaeration characteristic of the stream is known the limiting values of B.O.D. cannot be set." (McKee and Wolf, 1963. p. 147)

"Many (waste) effluents (and other inflows) . . . contain substances that are oxidized by the dissolved oxygen in the water either directly or after partial disintegration by bacterial action. These compounds, collectively, at times reduce the dissolved oxygen to critically low levels and can produce sudden, serious, oxygen crises if the water temperature is raised or if stream flow is decreased. Silt and (other suspended sediments) often complicate the problems produced by the oxygen-consuming materials by flocculating them in layers on the bottom of the stream where they constitute severe hazards to bottom fauna. It is necessary, therefore, to measure the oxygen-consuming power of most effluents containing oxidizable materials. However, it is difficult to make accurate determinations of the oxygen consumed by (most) effluents, as these wastes are variable mixtures of many substances that are oxidized at different rates and have different oxygen demands." (Ellis et al., 1946, p. 25) These effects may in part be expressed by the term chemical oxygen demand (COD), "a measure of the chemically oxidizable material in the water, (furnishing) an approximation of the amount of organic and reducing material present." (U.S. Geological Survey, 1977, p. 6) COD is less frequently reported than is BOD. The two terms may not be correlative and cannot be used interchangeably.

## pH (MEASURE OF HYDROGEN ION ACTIVITY)

"The effective concentration (activity) of hydrogen ions could be expressed in the same kinds of units as other dissolved (chemical) species, but  $H^+$  concentrations in milligrams per liter or moles per liter are very low for water solutions that are not strongly acid. The activity of hydrogen ions can be most conveniently expressed in logarithmic units, and the abbreviation 'pH' represents the negative base-10 log of the hydrogen-ion activity in moles per liter."<sup>8</sup> (Hem, 1970, p. 88) The "pH is an important factor in the chemical and biological systems of natural waters. The degree of dissociation of weak acids or bases is affected by changes in pH. This affect is important because the toxicity of many compounds is affected by the degree of dissociation." (U.S. EPA, 1976, p. 178)

"Conversely, the concentration of weakly dissociated acids and bases markedly affects the pH value and the ease with which it can be altered. For this reason, pH should not be confused with acidity and alkalinity."<sup>9</sup> The presence of carbonates, phosphates, borates, and similar ions give water a buffering power so that addition of an acid or base is less likely to be deleterious." (McKee and Wolf, 1963, p. 235) "A solution is said to be buffered if its pH is not greatly changed by the addition of moderate quantities of acid or base. Buffering effects occur in systems where equilibria involving hydrogen ions occur, and the range of pH over which buffering is effective depends on the nature of the solute species. Most natural waters are buffered to some extent by reactions which involve dissolved carbon dioxide species. The most effective buffering action by these species is within the pH range of most natural waters, from near 6.0 to about 8.5." (Hem, 1970, p. 92) Note: "The pH of a water does not (by itself) indicate ability to neutralize additions of acids or bases without appreciable change. This characteristic, termed 'buffering capacity,' is controlled by the amounts of alkalinity and acidity present." (U.S. EPA, 1976, p. 178)

"The permissible range of pH for fish depends upon many other factors such as temperature, dissolved oxygen, prior acclimatization, and the content of various anions and cations." (McKee and Wolf, 1963, p. 236) "The susceptibility of (some fish) to changes in temperature and dissolved oxygen is markedly increased by shifting the hydrogen-ion concentration (activity) from pH 8 to pH 6. . . . It is neither accurate to state that any given (normal) pH is

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<sup>8</sup>  $pH = -\log_{10}[H^+]$ , where  $H^+$  is the hydrogen ion activity.

<sup>9</sup> Underscored here for emphasis. Popular and some technical accounts of pH incorrectly use the term interchangeably with acidity and alkalinity.

or is not (by itself) harmful to fish life, nor sound to dismiss the pH determination as of no consequence merely because it falls in the range of hydrogen-ion concentrations commonly accepted as harmless to fishes . . . . There are<sup>10</sup> (however) certain gross limits to the hydrogen-ion concentrations beyond which rapidly lethal effects are almost inevitable if fishes are exposed to such waters for even a short time; namely, acidity in excess of pH 4.0 (pH values lower than 4.0) and alkalinity greater than pH 9.5 (pH values higher than 9.5). Many acids and their acidic salts, however, kill at hydrogen-ion concentrations much less acidic (at higher pH values) than pH 4.0 and various alkalis and alkaline salts are lethal in waters less alkaline (at lower pH values than pH 9.0. . . . Considering the various possibilities, pH determinations lying outside the range pH 6.0 to pH 8.7 (in most natural waters) indicate that the usual balance of carbon dioxide and the carbonates and sulfates of calcium and magnesium had been disturbed either by the presence of too large a quantity of one or more of these compounds or by the addition of other substances to the physico-chemical complex of the water. Generally such deviations point to conditions at least unfavorable to fish life." (Ellis et al., 1946, p. 44)

#### TOTAL DISSOLVED SOLIDS AND SALINITY

"Total dissolved solids, (a term) generally associated with fresh water systems, . . . consist of inorganic salts, small amounts of organic matter, and (other) dissolved materials. . . . Salinity is an oceanographic term, and although not precisely equivalent to the total dissolved salt (solids) content it is related to it. . . . For most purposes, the terms total dissolved salt content (total dissolved solids) and salinity are equivalent."<sup>11</sup> The principal

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<sup>10</sup>Underscored here for emphasis.

<sup>11</sup>Total dissolved solids are usually measured in mg/l (milligrams per liter, approximately equivalent to parts per million) while salinity is generally measured in 0/00 (parts per thousand) which is three orders of magnitude greater than parts per million. To convert parts per million to parts per thousand, multiply by 1,000 ( $10^3$ ); to convert parts per million to parts per thousand, multiply by 1/1,000 ( $10^{-3}$ ).

inorganic anions<sup>12</sup> dissolved in water include the carbonates, chlorides, sulfates, and nitrates (principally in ground waters); the principal cations<sup>12</sup> are sodium, potassium, calcium, and magnesium." (U.S. EPA, 1976, p. 205)

"All salts (solids) in solution change the physical and chemical nature of the water and exert osmotic pressure (on organisms). Some (salts) have (direct) physiological or toxic effects as well."<sup>13</sup> (McKee and Wolf, 1963, p. 182) "All species of fish or other aquatic life must tolerate a range of dissolved solids concentrations to survive under natural conditions. . . . Marine fishes . . . exhibit variance in (their) ability to tolerate salinity changes (with adverse effects resulting either from too rapid increases or decreases in salinity). . . . Estuarine species of fish are tolerant of salinity changes ranging from fresh to brackish to seawater. Anadromous (and catadromous) species likewise are tolerant although evidence indicates that the young cannot tolerate the change until the normal time of migration. . . . Other aquatic species are more dependent on salinity for protection from predators or require certain minimal salinities for successful hatching of eggs." (U.S. EPA, 1976, p. 207) "Dissolved solids may (also) influence the toxicity of heavy metals and organic compounds to fish or other aquatic life, primarily because of the antagonistic effect of hardness metals. Chromates, copper, cyanides, detergents, phenolic compounds, zinc and several other substances are generally more toxic in distilled water than in hard water (such as seawater) of high dissolved solids." (McKee and Wolf, 1963, p. 182) "Indirect effects (on wildlife) of excess dissolved solids are primarily the elimination of desirable food plants and other habitat-forming plants. Rapid salinity changes cause plasmolysis of tender leaves and stems (of vascular plants) because of changes in osmotic pressure." (U.S. EPA, p. 207)

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<sup>12</sup>Many inorganic substances are ionized by dissolution in water, forming anions (negatively-charged ions) and cations (positively-charged ions).

<sup>13</sup>The effects on biota of dissolved solids as discussed here are those attributable solely to total concentration or to osmotic pressure rather than the toxic effects of individual solutes. "It should be pointed out, however, that possible synergistic or antagonistic interactions between mixed salts (solids) in solution may cause the effects of salts in combination to be different from those of salts separately, and that the presence of poisonous salts (such as nitrates, sulfides, and fluorides) can render dangerous . . . waters whose total solids concentration is apparently within acceptable limits." (McKee and Wolf, 1963, p. 182)

A frequently measured and reported property of natural waters is "specific (electrical) conductance, . . . a measure of the ability of a water to conduct an electrical current. . . . Specific conductance is related to the type and concentration of ions in solution and can be used for approximately (or determining accurately) the dissolved solids content in the water. Commonly, the concentration of dissolved solids (in milligrams per liter) is about 65 percent of the specific conductance (in micromhos per centimeter at 25°C, adjusted to field conditions). This relation is not constant from stream to stream (site to site), and it may vary in the same source with changes in the composition of the water." (U.S. Geological Survey, 1977, p. 12) "To conduct a current, solute ions actually must move through the solution to transfer charges, and the effectiveness of a particular ion in this process depends upon its charge, size, the way it interacts with the solvent, and other factors. . . . It is apparent that even in relatively simple solutions the relationships that affect conductance may be complicated. . . . Natural waters are not simple solutions. They contain a variety of both ionic and undissociated (chemical) species, and the amounts and proportions of each may range widely. When applied to natural waters, therefore, the conductance determination cannot be expected to be simply related to ion concentrations or to total dissolved solids. . . .

A reasonably well-defined relationship is<sup>14</sup> indicated for the range (of conductance values commonly recorded); so for any given conductance value a dissolved-solids value can be estimated with an uncertainty of only about  $\pm 100$  mg/l (dissolved solids). . . . The regression line (which results from a linear plot of specific conductance against dissolved solids concentration) has some curvature; hence, the straight-line formula  $KA=S$ , where K is conductance in micromhos (per centimeter at 25°C, as adjusted), S is dissolved solids in milligrams per liter, and A the conversion factor, does not fix exactly. This kind of formula is often used, however, in calculating approximate dissolved-solids values from conductance determinations. For the analyses of (most) natural waters, . . . the range of A is about from 0.54 to 0.96, which represents nearly the full range to be expected. Usually A is between 0.55 and 0.75, the higher values generally being associated with waters high in sulfate concentration." (Hem, 1970, pp. 98, 99)

#### SULFATE, SULFIDE, AND HYDROGEN SULFIDE

"The element sulfur when dissolved in water generally occurs in the fully oxidized ( $S^{+6}$ ) state complexed with oxygen as the anion sulfate  $SO_4^{2-}$ . The . . . form  $S^{-2}$  (sulfide) is sometimes found as the  $HS^-$  ion (hydrosulfide, in alkaline solutions) or as dissolved undissociated  $H_2S$  (hydrogen sulfide, in reducing environments). Conversion of oxidized to reduced species or vice

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<sup>14</sup>Underscored here for emphasis.

versa often is associated with biochemical processes, and in fact, some reactions of sulfur such as the reduction of sulfate hardly can be made to take place in natural systems unless certain species of bacteria, along with a suitable food or energy supply, are present. . . . The sulfate ion is chemically stable in aerated water and forms salts of low solubility." (Hem, 1970, pp. 161-162, 164) "Sulfates are found in most natural (waters). . . . Sulfates, particularly magnesium, calcium and sodium sulfates can be listed, therefore, as one of the expected groups of compounds tolerated by fishes in concentrations up to 300 p.p.m. (approximately equivalent to 300 mg/l) or more without marked effects." (Ellis et al., 1946, p.77)

"The degree of hazard exhibited by sulfide to aquatic animal life is dependent on the temperature, pH, and dissolved oxygen. At lower pH values a greater proportion is in the form of the toxic undissociated  $H_2S$ . In winter when the pH is neutral or below (in many fresh water systems) or when dissolved oxygen levels are low but not lethal to fish, the hazard from sulfides is exacerbated." (U.S. EPA, 1976, pp. 213-214) "Hydrogen sulfide is a (flammable,) soluble, highly poisonous, gaseous compound having the characteristic odor of rotten eggs. . . . (It) biologically is an active compound that is found primarily as an anaerobic degradation product of both organic sulfur compounds and inorganic sulfates. The anaerobic decomposition of (wastes and) naturally deposited organic material is a major source of hydrogen sulfide. . . . Many past data on the toxicity of hydrogen sulfide to fish and other aquatic life have been based on extremely short exposure periods. . . . Recent long term data, both in field situations and under controlled laboratory conditions, demonstrate hydrogen sulfide toxicity at lower concentrations." (U.S. EPA, 1976, pp. 214-215)

#### SUSPENDED SEDIMENT CONCENTRATION AND TURBIDITY

"Sediment is solid material that originates mostly from disintegrated rocks and is transported by, suspended in, or deposited from water; it includes chemical and biochemical precipitates and decomposed organic material, such as humus. The quantity, characteristics, and cause of the occurrence of sediment in streams are influenced by environmental factors. Some major factors are degree of slope, length of slope, soil characteristics, land usage, and quantity and intensity of precipitation. . . . Suspended Sediment is the sediment that at any given time is maintained in suspension by the upward components of turbulent currents or that exists in (more permanent) suspension as a colloid. . . . The velocity-weighted concentration of suspended sediment in the (standard U.S. Geological Survey) sampled zone (from the water surface to a point approximately 0.3 ft. above the bed) is expressed as milligrams of dry sediment per liter of water-sediment mixture (mg/l)."<sup>15</sup> (U.S. Geological Survey, 1977, p. 11)

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<sup>15</sup>Two other expressions of water-transported sediment are occasionally recorded. These are: (1) "Suspended - sediment discharge, . . . the rate (in tons per day) at which dry weight of sediment passes a (given) section of a

Turbidity is an expression of "the reduction of transparency (of water) due to the presence of suspended particulate matter (and other coloring agents). Such material may consist of clay or silt, finely divided organic matter, plankton, or other microscopic organisms which cause light to be scattered and absorbed rather than transmitted in straight lines through the sample. . . . Attempts to correlate turbidity with the weight concentration of suspended matter are impractical, as the size, shape, and refractive index of the particulate materials are of great importance optically (for turbidity measurements,) but bear little direct relationship to the concentration and specific gravity of the suspended matter." (Brown et al., 1970, p. 156) However, suspended sediment concentration and turbidity are related, although not interchangeably. The threshold values provided by Table B1 on page 49 reflect the correlation but independence of these two expressions whose detrimental effects may be quite distinct.

"Natural waters, particularly if they are moving rapidly or are subject to strong wind, wave, or current action, carry varying quantities of suspended matter. This material is often of importance . . . as bottom conditions, light penetration, bacterial content, and various other features of the aquatic complex can be modified seriously by suspended matter." (Ellis et al., 1946, p. 51) "The impact of man's activities . . . alter and augment the suspended solids in surface waters by the discharge of liquid (and solid) wastes . . . , by increased erosion . . . , (by excavation, filling, and other bottom disturbance), and by dusts that are blown into streams (and marine habitats). . . . To differentiate between suspended solids and settleable solids is often difficult, because the two are often confused in the (scientific) literature, although the method of determination of each is (established;<sup>16</sup> see Brown et al., 1970 and U.S. Geological Survey, 1977). Strictly speaking, until they have

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stream or is the quantity of sediment, as measured by dry weight..., that passes (the) section in a given time. It is computed by multiplying (stream) discharge (in cubic feet per second) times mg/l (of suspended sediment) times 0.0027. (2) Total Sediment Discharge, . . . the sum (in tons per day) of the suspended-sediment discharge and the bed-load discharge (not often recorded). It is the total quantity of sediment, as measured by dry weight . . . , that passes (the) section during a given (interval of) time. (U.S. Geological Survey, 1977, p. 11) These expressions are generally applied only to the sediment in rivers and lesser streams.

<sup>16</sup>The U.S. Geological Survey routinely measures and reports the "percentage (of suspended sediment sampled) finer than 0.062 mm (the size of silt, normally the largest particles which will remain in suspension under nonturbulent conditions).

settled to the bottom of a water course (or a laboratory sample bottle), all settleable solids are suspended solids. On the other hand, only a fraction of the suspended solids are settleable and this fraction is dependent upon (water) quiescence, temperature, density, flocculation (enhancement), and many other factors." (McKee and Wolf, 1963, pp. 279-280)

"Disregarding any possible toxic effects attributable to substances leached out (of the suspended sediment) by water, suspended solids (sediment) may kill fish and shellfish by causing abrasive injuries; by clogging the gills and respiratory passages of various aquatic fauna; and by blanketing the stream bottom, killing eggs, young, and food organisms, and destroying spawning beds. . . . Indirectly, suspended solids are inimical to aquatic life because they screen out light (turbidity) and because, by carrying down and trapping bacteria and decomposing organic wastes on the bottom, they promote and maintain the development of noxious conditions and oxygen depletion, killing fish, shellfish and fish food organisms. . . . It has been pointed out that healthy fish may swim through heavy suspensions of solids without significant injury . . . , yet, in the presence of even low concentrations of toxic substances, fish may be so weakened that the abrasive and clogging actions of suspended solids become more effective and dangerous, and even lethal." (McKee and Wolf, 1963, p. 280)

"Settleable materials which blanket the bottom of water bodies damage the invertebrate populations, block gravel spawning beds, and if organic, remove dissolved oxygen from overlying waters. . . . When settleable solids block gravel spawning beds which contain eggs, high mortalities result although there is evidence that some species of (fish) will not spawn in such areas. . . . It has been postulated that silt attached to the eggs prevents sufficient exchange of oxygen and carbon dioxide between the egg and the overlying water. The important variables are particle size, stream velocity, and degree of turbulence. . . . Deposition of organic materials to the bottom sediments can cause imbalances in stream biota by increasing bottom animal density, principally worm populations, and diversity is reduced as pollution-sensitive forms disappear. . . . Algae likewise flourish in such nutrient-rich areas although forms may become less desirable. . . . The near surface waters are heated because of the greater heat absorbency of the particulate material (in suspension) which tends to stabilize the water column and prevents vertical mixing. . . . Such mixing reductions decrease the dispersion of dissolved oxygen and nutrients to lower portions of the water body. . . . One partially offsetting benefit of suspended inorganic material in water is the sorption of organic materials such as pesticides. Following this sorption process subsequent sedimentation may remove these materials from the water column into the sediments." (U.S. EPA, 1976, pp. 211-212)

#### WATER TEMPERATURE

"Temperature changes in bodies (of water) or streams . . . may result from natural climatic phenomena, . . . from the introduction of (waste effluents, and from other activities). The temperature is important, and sometimes



critical, for many uses of water. . . . Heat may contribute to undesirable (water) conditions such as decreased oxygen capacity, increased oxygen demand, anaerobic zones, putrefication of sludge deposits, and the growth of sewage fungus. . . . Stream temperatures may also be increased by irrigation practices and the return of agricultural drainage. Temperature rises of 10 to 20°C have been reported. . . . Flocculation and sedimentation rates are increased as the temperature is increased. It was found that at 2°C the settling period was 73 percent longer than at 20°C . . . . The exchange capacity of base-exchange materials . . . varies with temperature, but not in a uniform direction; for some substances rising temperatures increase the exchange capacity, for others they reduce it. . . . The bactericidal effects of disinfectants are generally increased by an increase in the temperature of the water. . . . Changes in water temperature as a result of human activity are generally upward. An exception is the release of cold bottom water from stratified artificial impoundments, which may alter the flora and fauna for many miles downstream from the dam.

Other activities of man such as the discharge of cooling water, warm industrial wastes, and return irrigation water generally raise the temperature of receiving waters, with the following concomitant effects: (a) higher temperatures diminish the solubility of dissolved oxygen and thus decrease the availability of this essential gas, (b) elevated temperatures increase the metabolism, respiration, and oxygen demand of fish and other aquatic life, approximately doubling the respiration for a 10°C rise in temperature; hence the demand for oxygen is increased under conditions where the supply is lowered, (c) the toxicity of many substances is intensified as the temperature rises, (d) higher temperatures militate against desirable fish life by favoring the growth of sewage fungus and the putrefaction of sludge deposits, and finally (e) even with adequate dissolved oxygen and the absence of any toxic substances, there is a maximum temperature that each species of fish or other organism can tolerate; higher temperatures produce death in 24 hours or less.

The maximum temperatures that adult fish can tolerate vary with the species of fish, prior acclimatization, oxygen availability, and the synergistic effects of other pollutants. Median tolerance limits ( $TL_m$ ) have been reported (for many species). . . . For spawning and hatching of eggs, much lower temperatures are (generally) required. . . . It is apparent . . . that many fish are unable to complete their life cycles unless the temperatures at the time of spawning and hatching are 10 to 15°C below the median tolerance limits. . . . Fish have optimum temperatures for rate of growth and reproduction. Given a choice, they also show a preference for water of a definite temperature range. . . . If the temperature of a reach of stream is raised by 5-10°C, it is probable that (some) fish will avoid this reach and that they will be replaced by (warmer-) water fish. Thus, without any direct mortality, the character of the fish life will change. It will also change because of effects upon spawning and hatching of eggs. . . . Sudden changes in temperature (from acclimatization temperatures) deleterious to fish life, with abrupt changes of 5°C or greater likely to be harmful. . . . Increased temperature is also an important consideration when toxic substances are present in a stream. Many substances (e.g., cyanides, phenol, xylene, zinc) exhibit increased toxicity at elevated temperatures. . . . This synergistic effect is aggravated at low tensions of dissolved oxygen. . . . Changes in temperature also affect lower aquatic and marine

life. For each organism there is a thermal death point and also a range of temperature of optimum growth. Temperature is one of the environmental factors that determines which organisms will thrive and which will diminish in numbers and size. There is relatively little information in the literature about optimum temperatures for aquatic flora and fauna. Diatoms appear to grow best at 15-25°C, green algae at 25-35°C, and blue-green algae at 30-40°C." (McKee and Wolf, 1963, pp. 283-285)

"The life associated with the aquatic environment in any location has its species composition and activity regulated by water temperature. Since essentially all of these organisms are so-called 'coldblooded' or poikilothermous, the temperature of the water regulates their metabolism and ability to survive and reproduce effectively. Industrial uses for process water and for cooling are likewise regulated by the water's temperature. Temperature, therefore, is an important physical parameter which to some extent regulates many of the beneficial uses of water. To quote from the FWPCA (1967), 'Temperature, a catalyst, a depressant, an activator, a restrictor, a stimulator, a controller, a killer, is one of the most important and most influential water quality characteristics to life in water.' . . .

Temperature also affects the self-purification phenomenon in water bodies and therefore the aesthetic and sanitary qualities that exist. Increased temperatures accelerate the biodegradation of organic material both in the overlying water and in bottom deposits, thus increasing demands on the dissolved oxygen resources of a given system. The typical situation is exacerbated by the fact that oxygen becomes less soluble as water temperature increases. Thus, greater demands are exerted on an increasingly scarce resource which may lead to total oxygen depletion and obnoxious septic conditions.

Indicator enteric bacteria, and presumably enteric pathogens, are likewise affected by temperature. It has been shown that both total and fecal coliform bacteria die away more rapidly in the environment with increasing temperatures. . . . Temperature changes in water bodies can alter the existing aquatic community. The dominance of various phytoplankton groups in specific temperature ranges has been shown. Likewise, changes from a cold water fishery to a warm water fishery can occur because temperature may be directly lethal to adults or fry, cause a reduction of activity, or limit reproduction. . . .

Factors such as diet, activity, age, general health, osmotic stress, and even weather contribute to the lethality of temperature. The aquatic species, thermal acclimation state, and exposure time are considered the critical factors. . . . The effects of sublethal temperatures on metabolism; respiration, behavior, distribution, migration, feeding rate, growth, and reproduction (are also significant). . . . Inside the tolerance zone there is encompassed a more restrictive temperature range in which normal activity and growth occur; and yet an even more restrictive zone inside that in which normal reproduction will occur. . . . Toxicity (of many substances) generally increases with increased temperature and that organisms subjected to stress from toxic materials are less tolerant of temperature extremes. . . .

The tolerance of organisms to extremes of temperature is a function of their genetic ability to adapt to thermal changes within their characteristic temperature range, the acclimation temperature prior to exposure, and the

time of exposure to the elevated temperature (Coutant, 1972). The upper incipient lethal temperature or the highest temperature that 50 percent of a sample of organisms can survive is determined on the organism at the highest sustainable acclimation temperature. The lowest temperature in which 50 percent of the warm-acclimated organisms can survive is the ultimate lower incipient lethal temperature. True acclimation to changing temperatures requires several days. . . . The lower end of the temperature accommodation range for aquatic life is 0°C in fresh water and somewhat lower for saline waters. However, organisms acclimated to relatively warm water may suffer a significant mortality due to thermal shock when subjected to reduced temperatures which would not be detrimental under other conditions of acclimation. . . .

Through the natural changes in climatic conditions, the temperatures of water bodies fluctuate daily as well as seasonally. These changes do not eliminate indigenous aquatic populations, but affect the existing community structure and the geographical distribution of species. Such temperature changes are necessary to induce the reproductive cycles of aquatic organisms and to regulate other life factors. . . .

Artificially induced changes such as the return of cooling water or the release of cool hypolimnetic waters from impoundments may alter indigenous aquatic ecosystems. . . .

In open waters elevated temperatures may affect periphyton, benthic invertebrates, and fish in addition to causing shifts in algal predominance. . . . The number and distribution of bottom organisms decrease as water temperatures increase. The upper tolerance limit for a balanced benthic population structure is approximately 32°C. Many of these invertebrate species are able to tolerate higher temperatures than those required for reproduction. . . .

In marine and estuarine waters, the limiting effects of thermal addition are not as conspicuous in the fall, winter, and spring as during the summer season of maximum heat stress. Nonetheless, crucial thermal limitations do exist. Hence, it is important that the thermal additions to the receiving waters (or other temperature-affecting activities) be minimized during all seasons of the year. Size of harvestable stocks of commercial fish and shellfish, particularly near geographic limits of the fishery, appear to be markedly influenced by slight changes in the long term temperature regime. . . .

Community balance can be influenced strongly by such temperature dependent factors as rates of reproduction, recruitment, mortality and growth of each component population. A few degrees elevation in average monthly temperature can appreciably alter a community through changes in inter-species relationships. . . .

Temperature is a primary factor controlling reproduction and can influence many events of the reproductive cycle from gametogenesis to spawning. Among marine invertebrates, initiation of reproduction (gametogenesis) is often triggered during late winter by attainment of a minimum environmental threshold temperature. In some species, availability of adequate food is also a requisite. . . . Elevated temperature can limit gametogenesis by preventing accumulation of nutrients in the gonads. This problem could be acute during the winter if food availability and feeding activity are reduced. Most marine organisms spawn during the spring and summer; gametogenesis is usually initiated during the previous fall. It should also be noted that some species spawn during the winter and the very early spring. . . . It is clear that adaptations for reproduction exist which are dependent on temperature conditions close to the natural cycle. . . .

Juvenile and adult fish usually thermoregulate behaviorally by moving to water having temperatures closest to their thermal preference. This provides a thermal environment which approximates the optimal temperature for many physiological functions, including growth (Neill and Magnuson, 1974). As a consequence, fishes usually are attracted to heated water during the fall, winter, and spring. Avoidance will occur as water temperature exceeds the preferred temperature by 1° to 3°C (Coutant, 1975). This response precludes problems of heat stress for juvenile and adult fishes during the summer, but several potential problems exist during the other seasons. The possibility of cold shock and death of plume-entrained fish due to winter plant shutdown is well recognized. Also, increased incidence of disease and a deterioration of physiological condition have been observed among plume-entrained fishes, perhaps due to insufficient food (Massengill, 1973). A weight loss of approximately 10 percent for each 1°C rise in water temperature has been observed in fish when food is absent (Phillips, et al. 1960). There also may be indirect adverse effects on the indigenous community due to increased predation; thermal addition may lead to increases in fish populations which are dependent on this community for their food.

Fish migration is often linked to natural environmental temperature cycles. In early spring, fish employ temperature as their environmental cue to migrate northward (e.g., menhaden, bluefish) or to move inshore (winter flounder). Likewise, water temperature strongly influences timing of spawning runs on anadromous fish into rivers (Leggett and Whitney, 1972). In the autumn, a number of juvenile marine fishes and shrimp are dependent on a drop in temperature to trigger their migration from estuarine nursery grounds for oceanic dispersal or southward migration (Lund and Maltezos, 1970; Talbot, 1966).

Thermal discharges should not alter diurnal and tidal temperature variations normally experienced by marine communities. Laboratory studies show thermal tolerance to be enhanced when animals are maintained under a diurnally fluctuating temperature regime rather than at a constant temperature (Costlow and Bookhout, 1971; Furch, 1972; Hoss, et al. 1975). A daily cyclic regime can be protective additionally as it reduces duration of exposure to extreme temperatures (Pearce, 1969; Gonzalez, 1972).

Summer thermal maxima should be established to protect the various marine communities within each biogeographic region. During the summer, naturally elevated temperatures may be of sufficient magnitude to cause death or emigration (Chin, 1961; Glynn, 1968; Vaughn, 1918). This more commonly occurs in tropical and warm temperate zone waters, but has been reported for enclosed bays and shallow waters in other regions as well. . . . Summer heat stress also can contribute to increased incidence of disease or parasitism; reduce or block sexual maturation; . . . inhibit or block embryonic cleavage of larval development . . . reduce feeding and growth of juveniles and adults . . . result in increased predation . . . and reduce productivity of microalgae and sea grasses. . . ." (U.S. EPA, 1976, pp. 220-229)

Table B1

## SUMMARY OF THRESHOLD VALUES

<u>Parameter</u>	<u>Value</u>	<u>Threshold</u>	<u>Reference</u>	<u>Comments</u>
Alkalinity <sup>1</sup>	25 mg/l minimum <sup>2</sup>		USEPA (1976), p. 8	"Productive waterfowl habitats are above 25 mg/l (alkalinity) with higher alkalinities resulting in better waterfowl habitats." (USEPA, 1976, p.8) Water quality criterion: "20 mg/l or more (alkalinity, expressed as an equivalent concentration of CaCO <sub>3</sub> ) for freshwater aquatic life except where natural concentrations are less." (USEPA, 1976, p. 7)
Ammonia (total ammonia nitrogen, NH <sub>3</sub> + NH <sub>4</sub> <sup>+</sup> , expressed as N)	2.5 mg/l <sup>3</sup> maximum 0.02 mg/l (as un-ionized ammonia, NH <sub>3</sub> ) maximum (for fresh water life)		Goerlitz and Brown (1976), p. 13; Ellis et al. (1946), pp. 65-66  USEPA (1976), p. 10	"Fish . . . cannot tolerate large quantities (of ammonia nitrogen in water). The toxicity to fish is directly related to the amount of free ammonia in solution; hence, the toxicity is dependent on the pH (and, to a lesser extent, the temperature) of the water. Ammonia decreases the ability of hemoglobin to combine with oxygen, and the fish suffocate. Although the tolerances of fish differ, 2.5 (mg/l) <sup>3</sup> of ammonia nitrogen is considered harmful in the 7.4 to 8.5 pH range." <sup>4</sup> (Goerlitz and Brown, 1972, p. 13) "Detrimental effects may be expected if 2.5 ppm (parts per million, equivalent to 2.5 mg/l (Hem, 1970, p. 80) or more ammonia are present in the water." (Ellis et al., 1946, p. 65) "Ammonia has been shown to be 10 times as toxic at pH 8.0 as at pH 7.0." (USEPA, 1976, p.178)
Oxygen (dissolved)	2.5 mg/l <sup>5</sup> minimum (Texas estuaries) 5.0 mg/l minimum (fresh water and		ICNRE (1972), Table B-8 USEPA (1976), p. 123	"The lethal limit (minimum concentration of dissolved oxygen which will support life) for freshwater fishes is subject to some individual and species variation and to the modifying action of numerous physical and

(continued)

(Table B1, continued)

Parameter	Threshold		Comments
	Value	Reference	
Oxygen (dissolved) (continued)	interstitial waters of benthic sediment)		chemical factors . . . in general 3 ppm (parts per million equivalent to 3 mg/l: Hem, 1970, p. 93) of dissolved oxygen in water at 25°C is the upper limit of dissolved oxygen at which asphyxia from low oxygen can be expected." (Ellis et al., 1946, pp. 23-24) It should be noted, however, that "temperature affects not only the amount of available dissolved oxygen in water (solubility of oxygen in water) but also the rate at which fish utilize such oxygen." (McKee and Wolf, 1963, p. 180); at higher temperatures, dissolved oxygen is more rapidly utilized. "Decreased dissolved oxygen levels, if sufficiently severe, can adversely affect aquatic insects and other animals" (USEPA, 1976, p. 126), as well.
pH	6.5 to 9.0 (fresh water aquatic life) 6.5 to 8.5 (marine aquatic life)	USEPA (1976), p. 178	"Based on present evidence, a pH range of 6.5 to 9.0 appears to provide adequate protection for the life of freshwater fish and bottom dwelling invertebrate fish organisms. Outside of this range, fish suffer adverse physiological effects increasing in severity as the degree of deviation increases until lethal levels are reached.  The chemistry of marine waters differs from that of fresh water because of the large concentration of salts present. In addition to alkalinity based on the carbonate system, there is also alkalinity from other weak acid salts such as borate. Because of the buffering system present in seawater, the naturally occurring variability of pH is less than in fresh water. Some marine communities are more sensitive to pH change than others . . . Normal pH values in seawater are 8.0 to 8.2 at the surface, decreasing to 7.7 to 7.8.

(continued)

(Table B1, continued)

Parameter	Threshold	
	Value	Reference

pH (continued)

Comments

with increasing depth. . . Plankton and benthic invertebrates are probably more sensitive than fish to changes in pH. . . . Mature forms and larvae of oysters are adversely affected at the extremes of the pH range of 6.5 to 9.0. However, in the shallow, biologically active waters in tropical or subtropical areas, large diurnal pH changes occur naturally because of photosynthesis. pH values may range from 9.5 in the daytime to 7.3 in the early morning before dawn. Apparently these communities are adapted to such variations or intolerant species are able to avoid extremes by moving out of the area (or by other measures).

For open ocean waters where the depth is substantially greater than the euphotic zone, the pH should not be changed more than 0.2 units from the naturally occurring variation or in any case outside the range of 6.5 to 8.5. For shallow, highly productive coastal and estuarine areas where naturally occurring pH variations approach the lethal limits for some species, changes in pH should be avoided but in any case should not exceed the limits established for fresh water, i.e., pH of 6.5 to 9.0. As with the freshwater criterion, rapid pH fluctuations that are due to waste discharges (or other causes) should be avoided. . . . The effects of variable pH on copper, zinc, cadmium, and lead (have been demonstrated), small changes in pH cause large shifts in these metallic complexes. Such changes may affect toxicity of these metals." (USEPA, 1976, pp. 180-181)

(continued)

Parameter	Threshold		Comments
	Value	Reference	
Total dissolved solids and salinity <sup>7</sup>	5,000 to 10,00 mg/l maximum (fresh water fish)	McKee and Wolf (1963), p. 183	"Limiting concentrations of dissolved solids (or salinity) for freshwater fish are not definitely known, but may range from 5,000 to 10,000 mg/l (maximum), according to species and prior acclimating. . . ." (McKee and Wolf, 1963, p. 183) "The blood of freshwater fish has an osmotic pressure equal to approximately 6 atmospheres, or about 7,000 mg/l (concentration) of sodium chloride. Although some freshwater fish are adapted to live in more saline waters, for practical purposes any (fresh) water that has an osmotic pressure greater than 6 atmospheres can be expected to be lethal." (Brown et al., 1970, p. 145) "Fishkills in Laguna Madre off the Texas coast have occurred with salinities in the range of 75 to 100 percent (75,000 to 100,000 mg/l)." (USEPA, 1976, p. 207)
	"To protect (estuarine) fish and other marine animals no changes in hydrography or stream flow (or introduction of effluents) should be allowed that permanently change isohaline patterns in the estuary by more than 10 percent from natural variation." <sup>8</sup>	USEPA (1976), p. 207	
	550 mg/l <sup>8</sup> maximum (most birds)	USEPA (1976), p. 207	
	3,000 mg/l to 15,000 mg/l maximum (live-stock and wildlife)	USEPA (1976), p. 207	
	12,500 mg/l minimum (oyster drills, a major oyster predator)	USEPA (1976), p. 207	
	5,000 mg/l minimum for as long as 20 days (oysters)	USEPA (1976), p. 207	

(continued)



(Table B1, continued)

Parameter	Threshold		Comments
	Value	Reference	
Suspended sediment concentration and turbidity	"Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life." <sup>9</sup>	USEPA (1976), p. 210	<p>"Means by which suspended solids adversely affect fish and fish food populations: (1) by acting directly on the fish swimming in water in which solids are suspended, and either killing them or reducing their growth rate, resistance to disease, et cetera; (2) by preventing the successful development of fish eggs and larvae; (3) by modifying natural movements and migrations of fish; (4) by reducing the abundance of food available to the fish. . . .</p> <p>Plankton and inorganic suspended materials reduce light penetration into the water body, reducing the depth of the photic zone. This reduces primary production and decreases fish food." (USEPA, 1976, p. 211) (Some food items may be covered by settled sediment or obscured by murky water conditions, as well.)</p>
	90 mg/l maximum (some fresh water fish)	McKee and Wolf (1963), p. 280	
	390 mg/l <sup>10</sup> maximum (fresh water benthic macroinvertebrates)	USEPA (1976), p. 211	
	750 mg/l maximum (eggs and larvae of the venus clam)	McKee and Wolf (1963), p. 281	
	5,000 mg/l maximum (estuarine biota)	ICNRE (1972), Table B-8	
	300 mg/l <sup>11</sup> maximum	Ellis et al., (1946), p. 77	
Sulfate	0.5 mg/l minimum	McKee and Wolf (1963), p. 276	<p>"From 100 to 274 ppm (equivalent to mg/l of sulfates (are present) throughout the year in the waters of (an) impoundment which supports a mixed fauna of the common warm-water fishes." (Ellis et al., 1946, p. 77)</p> <p>"Experiments indicate that water containing less than 0.5 mg/l of sulfate will not support growth of algae." (McKee and Wolf, 1963, p. 276)</p>

(continued)

(Table B1, continued)

<u>Parameter</u>	<u>Value</u>	<u>Threshold</u>	<u>Reference</u>	<u>Comments</u>
Sulfide	0.5 mg/l maximum		McKee and Wolf (1963), p. 277	"The toxicity of solutions of sulfides toward fish increases as the pH value is lowered. . . . Inorganic sulfides have (however) proved fatal to sensitive fishes . . . at concentrations between 0.5 and 1.0 mg/l as sulfide, even in neutral and somewhat alkaline solutions." (McKee and Wolf, 1963, p. 277)
Hydrogen sulfide	2.0 mg/l <sup>12</sup> maximum		USEPA (1976), p. 213, 214	"It is recognized that the hazard from hydrogen sulfide to aquatic life is often localized and transient. Available data indicate that water containing concentrations of 2.0 mg/l undissociated H <sub>2</sub> S would not be hazardous to most fishes and other aquatic wildlife, but concentrations in excess of 2.0 mg/l would constitute a long-term hazard." (USEPA, 1976, p. 214)
Water temperature	Variation from ambient: 4°C, September to May; 1.5°C, June to August		ICNRE (1972), Table B-8	Freshwater aquatic life:  "For any time of year, there are two upper limiting temperatures for a location (based on the important sensitive species found there at that time):  1. One limit consists of a maximum temperature for short exposures that is time dependent and is given by the species-specific equation: Temperature (°C) = 1/b [log <sub>10</sub> (time in minutes) - a] - 2 Where: a = intercept on the "y" or logarithmic axis of the line fitted to experimental data which are available for some species from Appendix II-C, NAS, 1974.  b = slope of the line fitted to experimental data which are available for some

(continued)

(Table B1, continued)

Parameter	Threshold		Comments
	Value	Reference	
Water temperature (continued)			species from Appendix II-C, NAS, 1974. <sup>13</sup>
			2. The second value is a limit on the weekly average temperature that:
			a. in the cooler months (mid-October to mid-April in the north and December to February in the south) will protect against mortality of important species if the elevated plume temperature is suddenly dropped to the ambient temperature, with the limit being the acclimation temperature minus 20C when the lower lethal threshold temperature equals the ambient water temperature (in some regions this limitation may also be applicable in summer); or
			b. in the warmer months (April through October in the north and March through November in the south) is determined by adding to the physiological optimum temperature (usually for growth) a factor calculated as one-third of the difference between the ultimate upper incipient lethal temperature and the optimum temperature for the most sensitive important species (and appropriate life state) that normally is found at that location and time; or
			c. during reproductive seasons (generally April through June and September through October in the north and March through May and October through November in the south) meets site-specific requirements for successful migration, spawning, egg incubation, fry rearing, and other reproductive functions of

(continued)

Parameter	Threshold		Comments
	Value	Reference	
Water temperature (continued)			important species. These local requirements should supersede all other requirements when they are applicable, or
			d. is a site-specific limit that is found necessary to preserve normal species diversity or prevent appearance of nuisance organisms." (USEPA, 1976, pp. 218-219)
			Marine aquatic life:
			"In order to assure protection of the characteristic indigenous marine community of a water body segment from adverse thermal effects:
			1. the maximum acceptable increase in the weekly average temperature due to artificial sources is 1°C (1.8°F) during all seasons of the year, providing the summer maxima are not exceeded; and
			2. daily temperature cycles characteristic of the water body segment should not be altered in either amplitude or frequency.
			Summer thermal maxima, which define the upper thermal limits for the communities of the discharge area, should be established on a site-specific basis. Existing studies suggest the regional limits expressed (below):

(continued)

(Table B1, continued)

Parameter	Threshold	
	Value	Reference
Water temperature (continued)		Comments
		Short-term maximum
		Maximum true daily mean <sup>1</sup>
Sub-tropical Regions (south of Cape Canaveral and Tampa Bay, Fla., and Hawaii)	32.2°C(90°F)	29.4°C(85°F)
	Cape Hatteras, N.C., to Cape Canaveral, Fla.	
Cape Hatteras, N.C., to Cape Canaveral, Fla.	32.2°C(90°F)	29.4°C(85°F)
Baseline thermal conditions should be measured at a site where there is no unnatural thermal addition from any source, which is in reasonable proximity to the thermal discharge (within 5 miles) and which has similar hydrography to that of the receiving waters at the discharge." (USEPA, 1976, p. 219)		

<sup>1</sup>See also "pH."

<sup>2</sup>Also, "natural alkalinity (should not be reduced by more than 25 percent." (USEPA, 1976, p. 7)

<sup>3</sup>The threshold value for maximum acceptable ammonia concentration given by Goerlitz and Brown (1972, p. 13) is 2.5 ml/l, a misprint (should read 2.5 mg/l, the equivalent of 2.5 parts per million which is the value recommended by Ellis et al., 1946, pp. 65-66).

<sup>4</sup>"River water in areas not influenced by pollution generally has a pH between about 6.5 and 8.5." (Hem, 1970, p. 93)

<sup>5</sup>The threshold value for minimum acceptable dissolved oxygen concentration given by ICNRE (1972), Table B-8 is expressed in ppm (parts per million) which is approximately equivalent to milligrams per liter (Hem, 1970, p. 80). Value is probably too low to represent an acceptable threshold for dissolved oxygen concentrations high in the water column.

(continued)

(Table B1, continued)

6 "But not more than 0.2 (pH) units outside (the) normally occurring range." (USEPA, 1976, p. 178)

7 See also discussion of "specific (electrical) conductance" in text under "Total Dissolved Solids and Salinity."

8 "The monthly average salinity (in the Laguna Madre, a hypersaline bay and sabkha, and Baffin Bay) is slightly above 50 percent (50,000 mg/l), and salinities well over 100 percent (100,000 mg/l) are found in some years. . . . Phenomenally low salinities (2,500 to 6,500 mg/l) (have been) observed in Baffin Bay (following anomalous heavy rain) . . . Salinities of near 'normal' values were not recorded for nearly a year after (one particular) series of cloudbursts." (Collier and Hedgpeth, 1950, pp. 162, 170) Elsewhere along the Texas coast, estuarine salinities vary over a narrower range of values (near fresh water in the upper portions of some bays at times to normal seawater salinity), but are subject to rapid changes ascribable to meteorological and/or tidal (astronomical tides) influence.

9 Varies from site to site and through time.

10 The threshold value for maximum suspended sediment concentration (for benthic macroinvertebrates) given by USEPA (1976), p. 211, is expressed in ppm (parts per million) which is approximately equivalent to milligrams per liter. (Hem, 1970, p. 80)

11 The threshold value for maximum acceptable sulfate concentration given by Ellis et al. (1946), p. 77, is 300 ppm (approximately equivalent to 300 mg/l).

12 Equivalent to 0.002 mg/l.

13 National Academy of Science, National Academy of Engineering (1974), Appendix II-C.

14 True daily mean = average of 24 hourly temperature readings.

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