218B

NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT **218B**

# ECOLOGICAL EFFECTS OF HIGHWAY FILLS ON WETLANDS

## USER'S MANUAL

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

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TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. DECEMBER 1979

**NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM**

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

**NCHRP Report 218B**

Project 20-15 FY '77
ISSN 0077-5614
ISBN 0-309-03015-3

L. C. Catalog Card No. 79-57399

**Price: $7.20**

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Published reports of the

**NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM**

are available from:

Transportation Research Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America.

# FOREWORD

*By Staff*
*Transportation Research Board*

This report, *NCHRP Report 218B,* and a companion report, *NCHRP Report 218A,* "Ecological Effects of Highway Fills on Wetlands—Research Report," will be of special interest and value to people responsible for the environmental assessment of proposed transportation facilities in the area of wetlands. The user's manual, *NCHRP Report 218B,* presents guidelines for determining the physical and biological effects of locating transportation facilities in wetlands. Although environmental impact assessment is in a general state of evaluation, the guidelines represent the current state of the art and are suitable for immediate implementation. A thorough review of literature pertaining to wetland ecology and the evaluation of several specific cases of highway placement in wetlands provide the basis for the research report, *NCHRP Report 218A.*

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The importance of wetlands in the life-cycle balance of earth ecology is becoming increasingly recognized. Consequently, transportation agencies are required to make assessments of possible environmental effects when transportation facilities are being proposed for location in the vicinity of wetlands. Determination of the impact of such facilities as bridges or earth fills on the ecology of a wetland is a very complex problem. There has been rather extensive study of the biological activity in wetlands, but little research has been directed toward highway–wetland interaction. The objectives of NCHRP Project 20-15 were to (1) determine the ecological effects of placing highway fills on wetlands primarily from available literature and experience and (2) prepare guidelines for ecological assessment of the location of fills, bridges, and related elements in wetlands.

To accomplish the first project objective, the University of Massachusetts researchers conducted a very extensive literature review with particular emphasis on biological information applicable to the wetland–transportation facility interaction and made a thorough evaluation of available information from eight individual sites in various parts of the United States that had been identified as having highways constructed in wetlands.

The major product of the research is a manual, which is based on the findings of the literature review, the case studies, and the extensive knowledge and experience of the research team. The manual presents in detail the physical impacts and potential biological effects from construction activity in wetlands. A feature of the manual is the inclusion of a series of charts to assist in identifying potential biological effects associated with construction activity. A separate chart is included for each construction activity—such as consolidation, displacement, excavation and fill, and culvert placement. Each chart identifies the physical impacts associated with the particular construction activity and the resulting potential

biological effects. For example, the placement of a culvert in a wetland can alter subsurface water flow, which could change the mean water level and cause mortality of certain aquatic species in the wetland.

The research has resulted in the publication of two documents: *NCHRP Report 218A*, "Ecological Effects of Highway Fills on Wetlands—Research Report," and *NCHRP Report 218B*, "Ecological Effects of Highway Fills on Wetlands—User's Manual." *NCHRP Report 218A* contains summaries of the literature review and the case studies. It serves as background material for the manual, *NCHRP Report 218B*. The guidelines contained in the manual for determining potential biological effects of construction activity in wetlands are suitable for immediate implementation. An example problem is included.

## CONTENTS

## ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 20-15 by the University of Massachusets, Amherst, Mass., with Dr. Paul W. Schuldiner, Professor Civil Engineering, and Dr. C. A. Carlozzi, Associate Professor, Forestry and Wildlife Management, as co-principal investigators. Dr. Shuldiner, Dale Ferguson Cope, Project Coordinator, and Richard B. Newton, Research Assistant, were the principal authors of this report.

Other contributors to the report were: Dr. Carlozzi; John Foster, Professor of Food and Resource Economics; Karl Hendrickson, Professor of Civil Engineering; Joseph Larson, Professor of Wildlife Management; Kenneth Black and Bryan Swift, Research Assistants; and Caren A. Caljouw, Graphics Artist.

# ECOLOGICAL EFFECTS OF HIGHWAY FILLS ON WETLANDS
## USER'S MANUAL


## SUMMARY

The placing of highway fills on wetlands can have significant physical and biological effects on the natural environment and ecological processes of the affected area. Determination of the impacts of a structure or earth fill on the ecology of a specific wetland is a very complex problem. Nevertheless, transportation agencies are required to make environmental impact assessments for proposed facilities in or near wetlands. Hence, a need exists for a better understanding of the ecological effects of highways when wetlands and associated flood plains are involved.

Legal constraints on the use of wetlands are becoming increasingly common at state and local levels of government. These laws, and the administrative directives associated with them, usually require permits for wetland use and call for multidisciplinary descriptions and assessments of probable changes in the ecology of affected wetlands as a condition of the issuance of such permits. Plans for the mitigation of unavoidable impacts are also required.

Although the presence of water on a site has always been a challenge to the highway planner and design and construction engineer, there are now additional concerns, both legal and environmental, that must be considered when placing fills or bridges in the wetland environment. Guidelines for environmental impact statements, state and local requirements, U.S. Army Corps of Engineers permit procedures, and procedures under Section 4(F) of the U.S. Department of Transportation Act, as amended, all require that the nature and extent of wetland habitats be defined and delineated prior to the beginning of any decision-making process affecting these lands. Federal, state, and local authorities may all intercede in any land-use decision that adversely affects regulated wetland areas.

No matter what level of authority is involved, legal restraints are now a reality which the highway planner must recognize. Familiarity with existing laws and regulations can save both time and money by preventing delay and creating a climate of cooperation rather than of controversy.

Active consideration of environmental consequences, not mechanical execution of guidelines, is becoming the test of compliance. Dealing with ecological impacts of highway improvements has become a critical aspect of the highway professional's job.

The over-all objective of NCHRP Project 20-15 was to determine ecological effects of placing highway fills on wetlands and associated flood plains and to develop initial guidelines as a management tool for the decision-making process regarding routes, fills, bridges, and other design alternatives.

Highways impact on wetlands in a variety of ways. In addition to direct physical alterations that result from construction activities, there are often physical, chemical, and biological effects that extend beyond the construction and right-of-way corridor. This cascading of effects beyond the immediate site of impact

is much more likely to occur when wetlands—in contrast to uplands—are involved, because wetlands are, almost by definition, those units of the landscape that receive, detain, retain, and discharge both surface and groundwater flows. As such, each wetland reflects even the smallest changes in the waters that feed it, and transmits these changes in turn to wetlands downstream.

Identifying and assessing the probable effects that highway activities will have on wetlands require the application of knowledge that is in a state of active evolution. Considerable progress has been made in recent years in understanding how wetlands function and how highways and other engineered works affect those functions; considerable further progress is both necessary and feasible. For many decades highway engineers have been refining and applying their knowledge of soils, hydrology, and other elements of the geophysical environment to the construction of structurally sound and economically efficient highway facilities. It is now essential that this knowledge be more fully merged with that of biologists, ecologists, and other natural scientists so that the integrity of the environment through which a highway passes will be as carefully protected as the integrity of the highway itself.

The first task of any systematic analysis of the impacts and effects of a particular proposal or action is to understand the nature of the proposed intervention on the wetland system. This must be done with sensitivity toward the system being analyzed and with special emphasis given to those elements of the project that interact with the surrounding environment (*1*). It is the policy of state highway agencies and the Federal Highway Administration that in the development of a project, a systematic, interdisciplinary approach be used to assess engineering considerations and beneficial and adverse social, economic, and environmental effects. The interdisciplinary approach should not be limited to the preparation of an environmental impact statement, but should also be used in the early planning stages of the proposed action. Application of such an approach should help to assure a systematic evaluation of reasonable alternative courses of action and their potential social, economic, and environmental consequences. Legal requirements relevant to the alternatives evaluation and decision-making process are well documented. Agencies are now required to build into their decision-making process, beginning at the earliest possible point, an appropriate and careful consideration of the environmental aspects of the proposed action in order that (1) adverse environmental effects may be avoided or minimized, and (2) environmental quality previously lost may be restored.

The planning, assessment, and mitigation guidelines presented in this user's manual provide tools which will help the highway engineer determine the ecological effects of placing highway fills on wetlands and make decisions regarding routes, materials, design and construction alternatives, and maintenance and operation activities.

The manual presents a framework for performing two of the basic procedures in environmental impact analysis: (1) describing the environmental setting of a project; and (2) assessing the ecological effects of project construction on the described setting. It should be noted, however, that site-specific studies are necessary for the accurate determination of environmental factors particular to a given site, and that on-site sampling, measuring, impact assessment, and resource evaluation are recommended in every case. Acquisition of the services of ecologists, hydrologists, planners, water quality specialists, and other experts is also recommended.

The body of the user's manual describes the most common physical, chemical, and ecological effects that the highway engineer is likely to encounter when placing

fills in wetlands and displays the effects and their interactions in a series of flow charts and matrices. Analytical methods necessary to delineate the possible severity or extent of the effects, the expertise needed to analyze resulting data, and practices that can be used to minimize adverse effects or enhance positive benefits are also discussed.

As an aid in developing an understanding of the cause and effect relationship between changes in the physical environment that can be caused by highway fills and the biological response to these changes which can occur in wetland ecosystems, a series of flow charts and matrices has been drafted. Each flow chart displays a set of physical impacts that might result from a particular construction activity or culvert design consideration. These physical impacts are then matrixed with a series of potential biological effects that could possibly occur with a particular physical modification. It should be stressed at the outset that the purpose of these charts is to demonstrate a *potential* relationship between the physical modifications of the environment and the probable biological response. The flow charts are in no way intended to quantify these relationships.

However, when quantitative estimates (i.e. major, minor, variable) of the biological effects that might result from alternative construction methodologies are prepared, the value of the matrices becomes evident. They not only describe the environmental relationships, but also give the user a clear picture of the biological consequences of each alternative design procedure, thus allowing the highway planner to consider environmental impacts in conjunction with economic and other concerns.

Following the flow charts will be found sections that describe each of the physical impacts and biological effects that appear within the matrix format. These sections give detailed information concerning analytical methods, mitigation procedures, and expertise needed for a comprehensive evaluation of the area concerned.

CHAPTER ONE

# WETLAND ECOLOGY

## DEFINITION

The need to delineate wetland boundaries becomes particularly acute when a legal definition of wetlands is required to implement regulatory programs. An awareness of local wetland statutes and ordinances and their corresponding legal definitions is extremely important in highway location decisions if extensive legal proceedings are to be avoided. For example, in Connecticut, wetlands are defined exclusively on the basis of soil types, but more commonly, as in neighboring Massachusetts, vegetation lists and water regime characterize regulated wetland areas.

Each of these parameters (vegetation types, soil characteristics, and water regime), when used singly, has proved inadequate—a fact recognized in the scientific definition incorporated in "Classification of Wetlands and Deep-Water Habitats of the United States (An Operational Draft)" (*2*). (At the time of the printing of this Manual, final revisions to the Cowardin classification are in press.) This classification system, developed by the U.S. Fish and Wildlife Service, defines a wetland as:

> Land where the water table is at, near or above the land surface long enough to promote the formation of hydric soils or to support the growth of hydrophytes. In certain types of wetlands, vegetation is lacking and soils are poorly developed or absent as a result of frequent and drastic fluctuations of surface-water levels, wave action, water flow, turbidity or high concentrations of salts or other substances in the water or substrate. Such wetlands can be recognized by the presence of surface water or

saturated substrate at some time during each year and their location within, or adjacent to, vegetated wetlands or deep-water habitats.

A similar concept is incorporated in the definition adopted by the U.S. Army Corps of Engineers for use in their permit program under Section 404 of the Federal Water Pollution Control Act. The Corps defines wetlands as:

Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

## ORIGINS

Knowledge of the origins of wetlands is useful in understanding their nature and the geographic distribution of different types. Kusler (*3*) lists six principal processes of wetland formation:

1. *Glaciers*—A principal band of wetlands may be observed lying along the northern tier of states including Alaska, Maine, New York, Michigan, Wisconsin, Minnesota, North Dakota, and Washington State. Most of these wetlands were formed by glaciers 9-12,000 years ago. Glaciers created wetlands in several ways. First, the melting of chunks of ice left by receding glaciers created pits and depressions in glacial moraines, till, and outwash. Lakes and wetlands formed where the depressions intersected the ground water table or where fine clay and organics sealed their bottoms and permitted the collection of runoff waters. The majority of smaller wetlands in the northern United States were formed in this manner. Second, glaciers dammed rivers. This often created glacial lakes, sometimes thousands of square miles in area. Once the ice retreated the lakes were partially drained, resulting in extensive low lying areas with peat deposits. These form some of the large wetlands in the glaciated states. Third, glaciers scooped out and scoured river valleys and soft bedrock deposits creating, in some instances, large and deep lakes such as the Great Lakes and the New York Finger Lakes and, in others, shallow depressions and wetland areas including prairie potholes and many wetlands on the Canadian shield. Figure 1 shows the processes of glaciation that may form wetlands. A common wetland with gently sloping sides and well-rounded bottom formed from melting blocks of ice is the kettlehole (see Fig. 1).

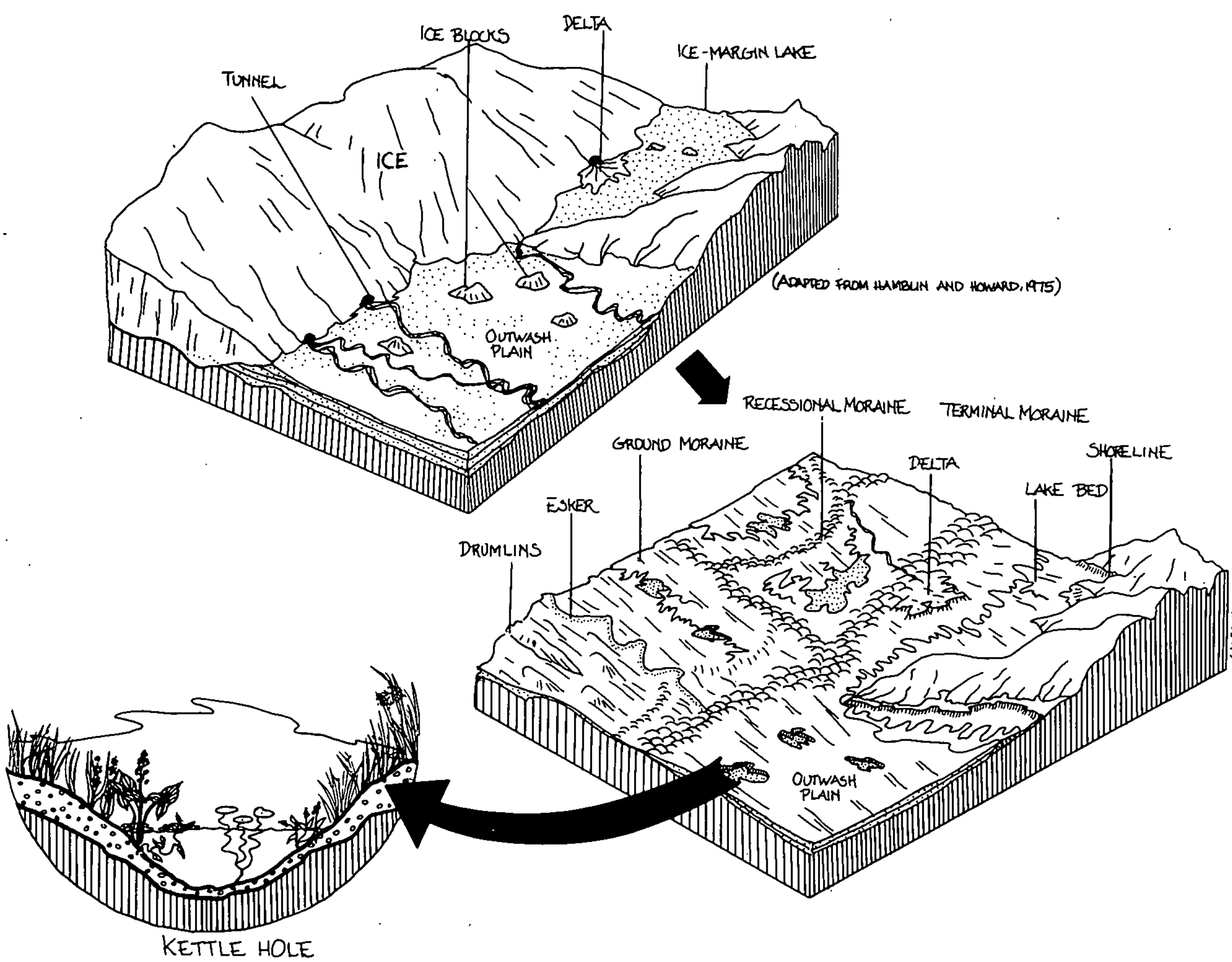



*Figure 1. Processes of glaciation.*

2. *Inundation of wave protected coastal lowlands*—A second principal band of wetland areas may be observed along the Gulf and Atlantic Coasts. Coastal wetlands form wherever a gently sloping beach of sand, gravel, silt, or other particulate matter is protected from wave action by a harbor, barrier island, or reef. Figure 2 shows the formation of a coastal wetland protected by a barrier beach. Wetlands are common along the mouths of rivers and streams. Wetland formation is favored by low elevation topography along the Atlantic and Gulf coasts. Wetland vegetation traps sand and other sediment, gradually building the wetland to a higher elevation. The deposit of organic matter and the formation of peat add to this process. Rising sea levels due to the melting of glaciers have resulted in the gradual inland migration of coastal wetlands (see Fig. 3).

3. *Erosion and deposition by rivers*—The remaining major wetlands of the United States are located along the flood plains of low gradient rivers such as the Mississippi. River flood plains are erosion-deposition features formed by the down-cutting of streams into bedrock and glacial outwash with deposition of river alluvium during times of flood on adjacent lands. Major wetlands are found along mature streams with low gradients and large sediment loadings. These wetlands are periodically flushed and scoured by major floods. New layers of alluvium are deposited by less severe flood events. Shown in Figure 4 are the features of a river flood plain and the typical flood plain communities dependent on the river's hydrology. Figure 5 is the cross section of a wetland known as a backswamp.

4. *Beaver dams*—At one time beaver dams played a major role in forming smaller inland wetlands in the forested areas of the nation (see Fig. 6). Trapping greatly reduced beaver populations, but controls have resulted in major increases in beaver population during recent years.

5. *Activities of man*—Man has created as well as destroyed many wetland areas, although the characteristics of the man-made wetlands are often quite different from those of natural wetlands. Major man-made wetlands include reservoirs and farm ponds; wetlands created by water stabilization measures on lakes; pits and depressions created by gravel pits and mines; poor drainage areas caused by

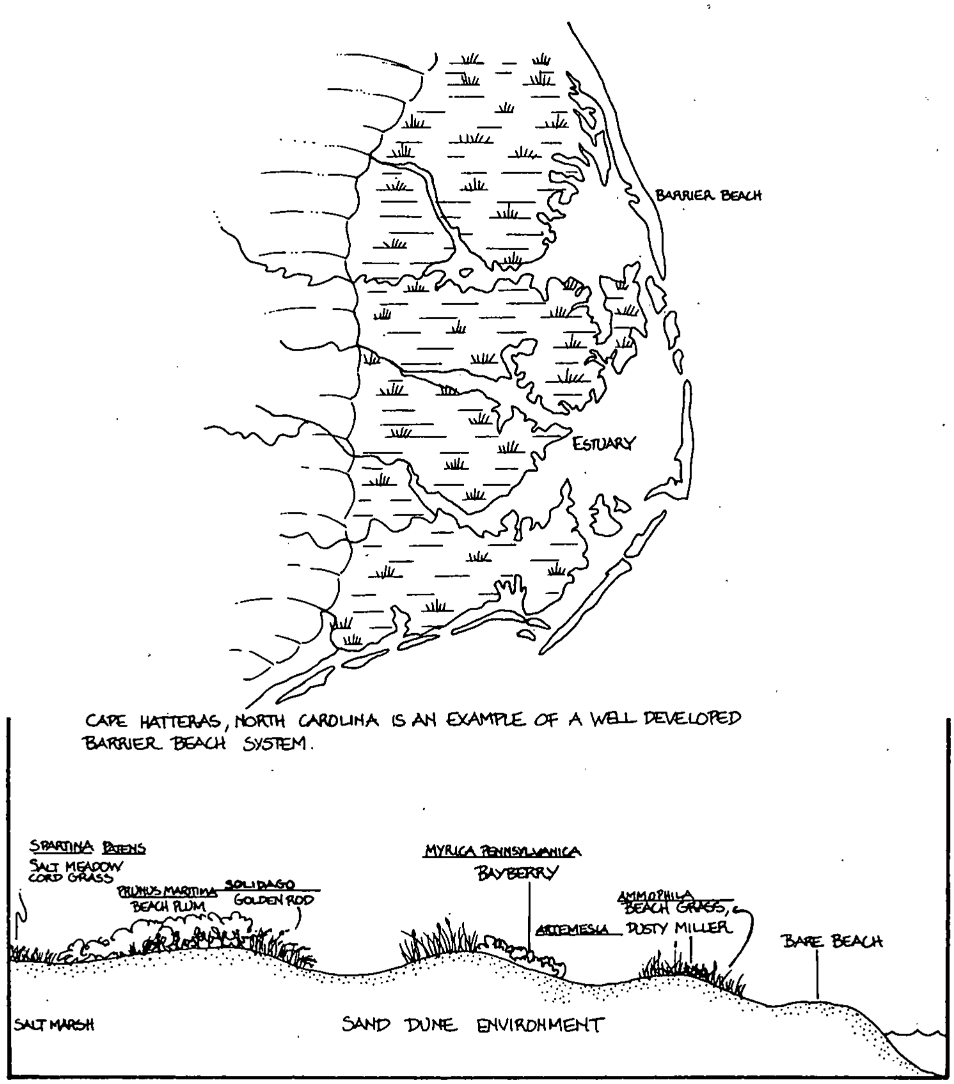



*Figure 2. Cross section of a barrier beach showing changes in vegetation moving from exposed beach to the more protected bay side.*

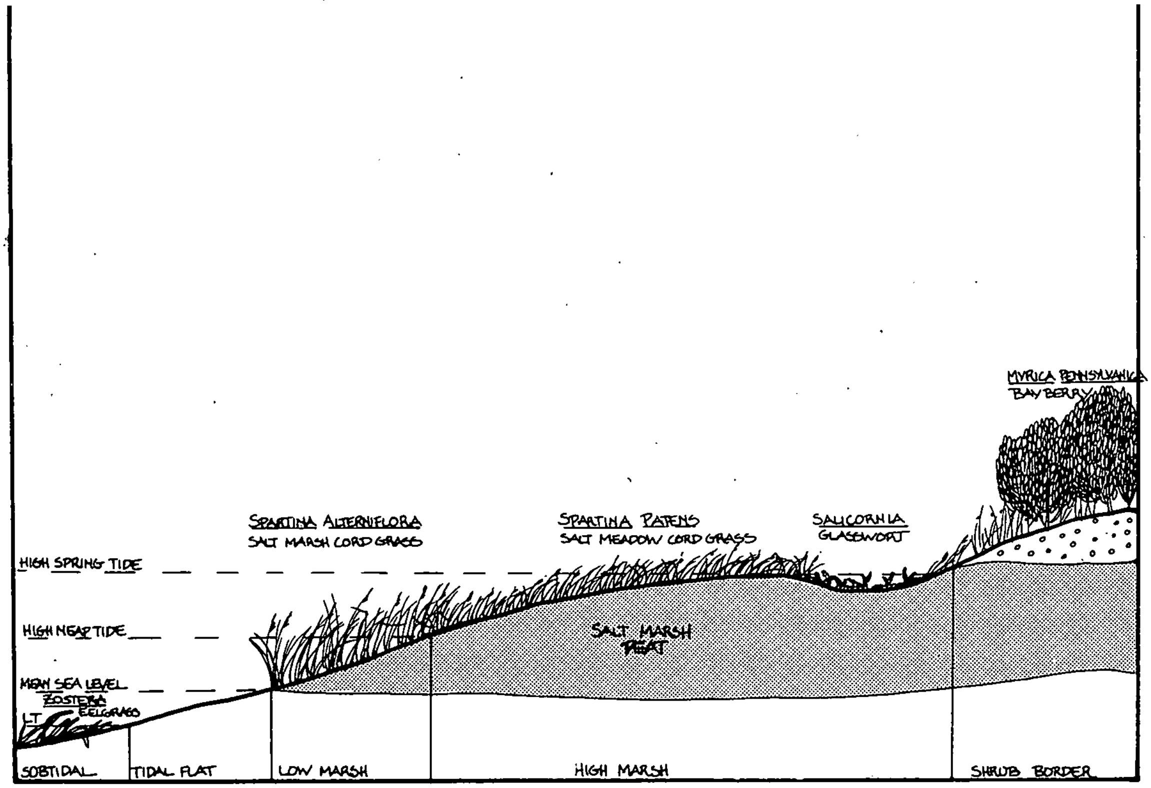



*Figure 3. Cross section of a salt marsh. This environment exemplifies the type of vegetated wetland found in protected areas away from strong waves and currents.*

roads, levees, hills, and buildings; and intentionally created wetlands by state, federal and local conservation groups. Reservoirs are often subject to severe water level fluctuations. Wetlands associated with gravel pits, mines, roads, and buildings are often subject to severe sedimentation and pollution problems.

6. *Miscellaneous processes*—Wetlands may be formed by a variety of other special processes. For example, wetlands in the sand hills of Nebraska and in other areas of the arid west have been formed wholly or in part by the action of wind. The Everglades reflect a unique flow of ground water and surface water over bedrock at and directly below the surface. Figure 7 illustrates the hydrologic cycle of the South Florida area. Wetlands are found in "sinkholes" and other solution formations in Kentucky, Indiana, and several other states. Reelfoot Lake in Tennessee was formed by the sudden sinking of the earth because of earthquakes. Similarly, San Francisco Bay was formed by movement along the San Andreas fault.

### HYDROLOGY

The quantity and flow regime of wetland water supplies are important determinants of the nature of the wetland environment. In inland areas, precipitation, runoff, and ground-water discharge may all contribute to the wetland water regime. Coastal wetland characteristics are determined by tidal flows and fresh-water input from upland sources. The hydrologic cycle is shown in Figure 8.

The land/water interface may occur at many points in the hydrologic cycle as rain water makes its way to the sea. Wetlands associated with surface runoff may form in shallow depressions with impervious substrates. These "perched" wetlands may be ephemeral or permanent, depending upon size and seasonal rainfall. Surface waters also contribute to wetland formation along lake and river shorelands, where seasonal fluctuations in water supply create a variety of wetland classes and subclasses.

Ground water is also a major contributor to wetland water regimes. In areas where surface topography intercepts or approaches the water table, ground water discharge will form wetland environments (see Fig. 9). These wetlands are often important in the maintenance of base flow in streams during times of low rainfall.

Coastal wetlands are areas where the deposition of sediments and periodic inundation by tidal flows promote the growth of particular types of aquatic vegetation. In estuarine areas, the inflow of freshwater additionally influences vegetation type and substrate formation. Tidal flushing of coastal marshes is of vital importance not only in sustaining the marsh itself but also in exporting the products of that system to the marine environment.

The importance of water regimes to wetland ecology cannot be overemphasized. Not only tidal fluctuations, but seasonal and intermittent changes in water flow and quantity in inland wetlands as well, are critical in determining species composition and promoting high rates of wetland pro-

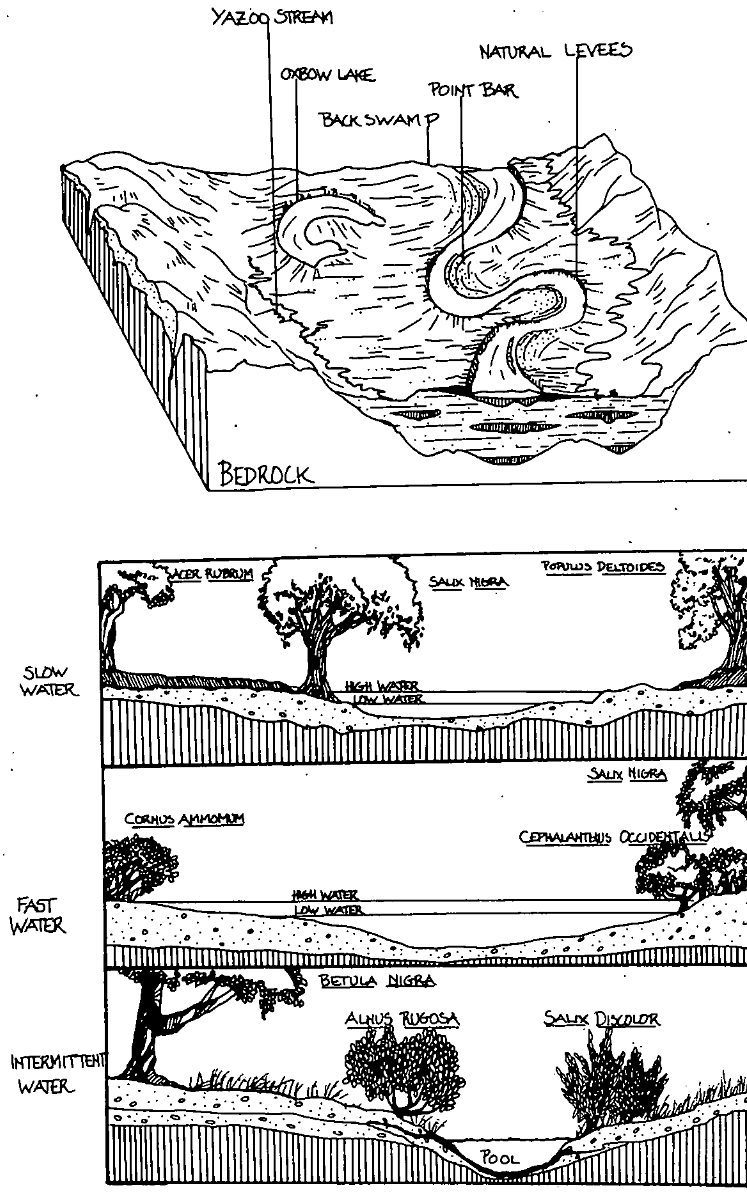



*Figure 4. Features of a river flood plain (top figure); typical riverine flood plain communities (bottom figure).*

ductivity (i.e., the formation of organic material through photosynthesis). In any wetland, the community of species that populates the site is determined by daily and seasonal variations in local hydrology. Many wetland species are adapted to a limited range of water depths and can tolerate continuous inundation or drying for only limited periods of time. In addition, seasonal timing of high water is critical to the life cycle of many wetland species.

Periodic flooding and drying also contribute to wetland productivity. During times of high water, nutrient rich sediments are carried into the composition of deposited organic material—releasing additional nutrients to the wetland soils. Many wetland ecosystems are adapted to this periodicity and could not thrive under more stable conditions.

Changes in water regimes, therefore, are associated with changes in wetland community composition and productivity. Fluctuation in water level is a natural phenomenon in many wetlands and is associated with several of the wetland functions described in the following.

## WETLAND FUNCTIONS

Wetlands perform many important physical and environmental functions, which, if lost, often must be replaced—sometimes at great cost to society.

1. *Flood conveyance*—Wetlands adjacent to streams and rivers lie within natural floodways and increase the capacity of the system to convey flood flows without inundating adjoining lands.

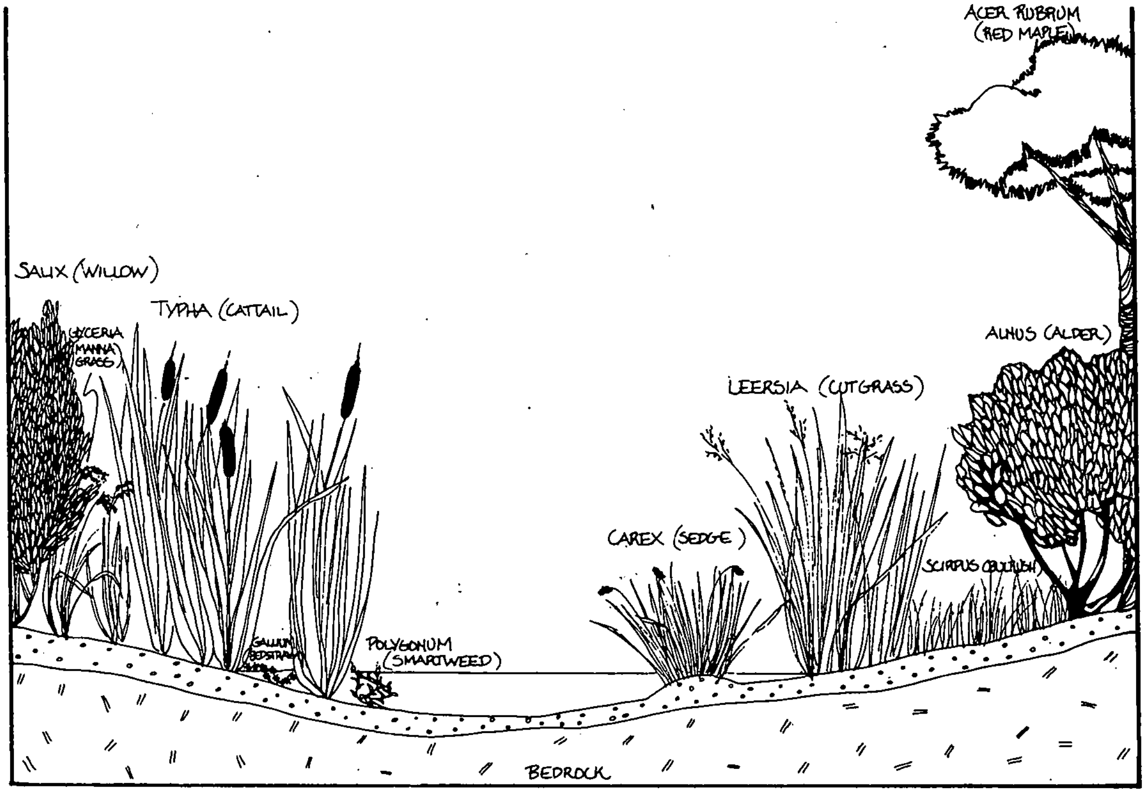



*Figure 5. Narrow leaved emergent wetland typifying a backswamp of a river.*

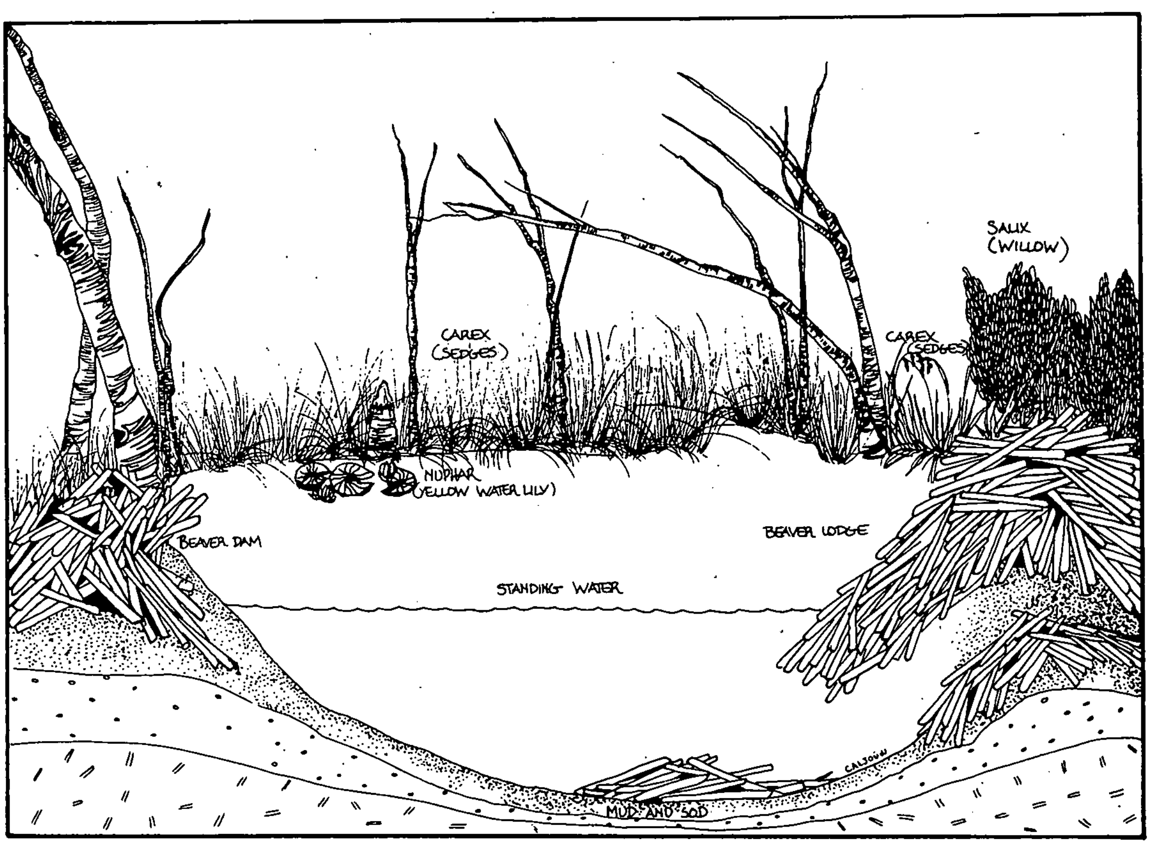



*Figure 6. Beaver impoundment creating a small inland wetland in a once forested area.*

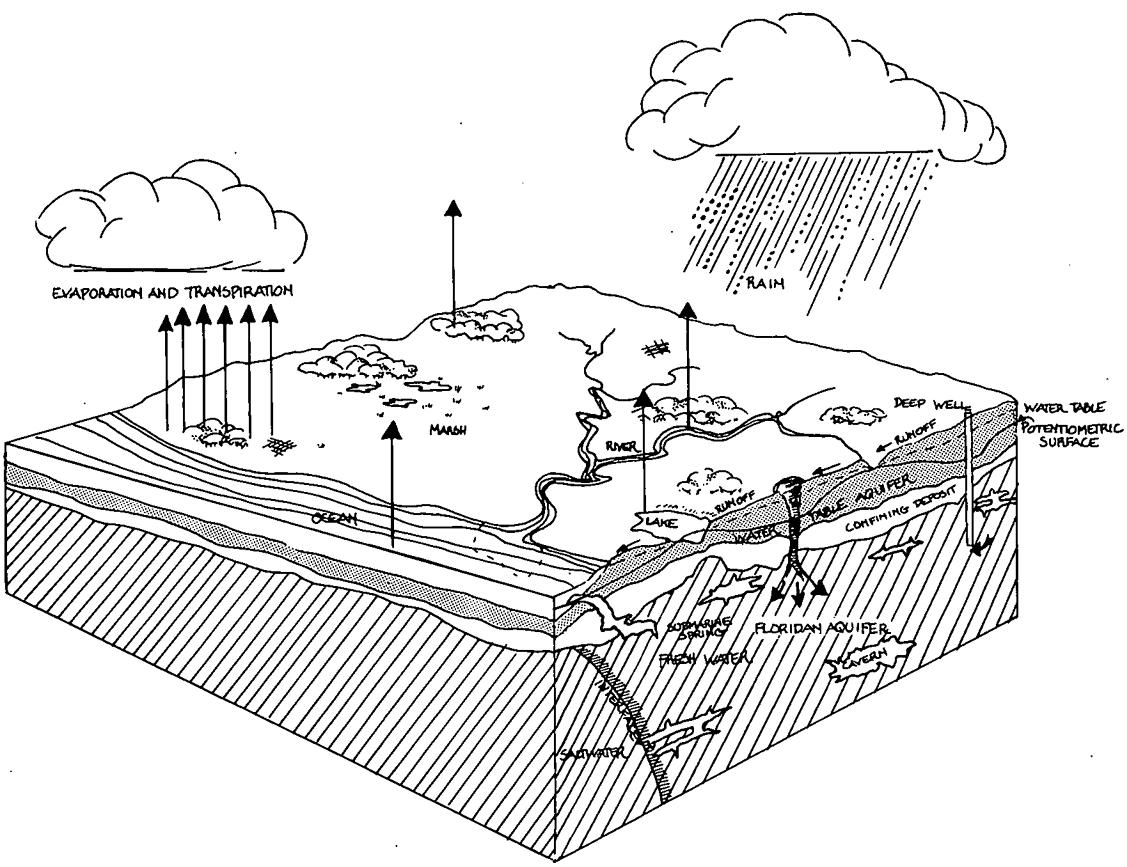



*Figure 7. Hydrologic cycle in South Florida area.* (*After Camp, Dresser, and McKee, July 1978*)

2. *Flood storage*—Wetlands have the capacity to store flood waters and release them slowly, thereby reducing peak flows. In a study of the Charles River watershed, the U.S. Army Corps of Engineers determined that flood stages would increase 0.6 m to 1.2 m in the upper and middle reaches of the river if only 40 percent of the system's wetlands were to be lost.

3. *Erosion control and storm barriers*—Wetlands, with their associated complement of vegetation are effective in stabilizing the substrate on which they are located through both a complex of root systems that binds the soil and a dense emergent vegetation that dissipates the energy of flowing waters. This function is of particular importance where wetlands are located adjacent to major lakes or in coastal areas. In these situations, wetlands may act as barriers to the destructive force of storm waves and, in some cases, may actually trap sediment in quantities sufficient to create new wetland habitat.

4. *Pollution control*—Wetlands have the ability to filter sediments and organic matter and assimilate nutrients from the water flowing through them. Studies of the feasibility of using wetlands for tertiary sewage treatment are being conducted in several areas of the country.

5. *Water supply relationships*—Wetlands, because of their relationship to both ground and surface waters, are important in maintaining the quality of water supplies. Lakeshore and riverine wetlands help maintain the quality of adjacent systems through sediment and nutrient assimilation from in-flowing waters. In some instances, ephemeral and flood plain wetlands may contribute significantly to ground-water recharge. In Massachusetts, Motts and Heeley (*4*) found significant relationships between wetlands and adequate ground-water supplies available for municipal uses.

6. *Productivity*—Wetlands are among the most productive environments on earth, comparing favorably with tropical rain forests (see Fig. 10). This productivity not only contributes to global $O_2$ production but also is the basis of a complex food web of which man is often a beneficiary. Waterfowl and other wildlife are the most evident components of the wetland food chain, but there are other relationships as well. For instance, it has been estimated that over two-thirds of the commercial catch of our marine fisheries consist of species that are dependent at some point in their life cycle on the salt marsh ecosystem.

## WETLAND CLASSIFICATION

The types of wetlands found throughout North America vary widely in terms of vegetation, hydrology, water chemistry, soil, and other characteristics. Numerous attempts have been made to classify wetlands on the basis of one or more salient characteristics. Each classification scheme has special advantages in terms of the particular use for which

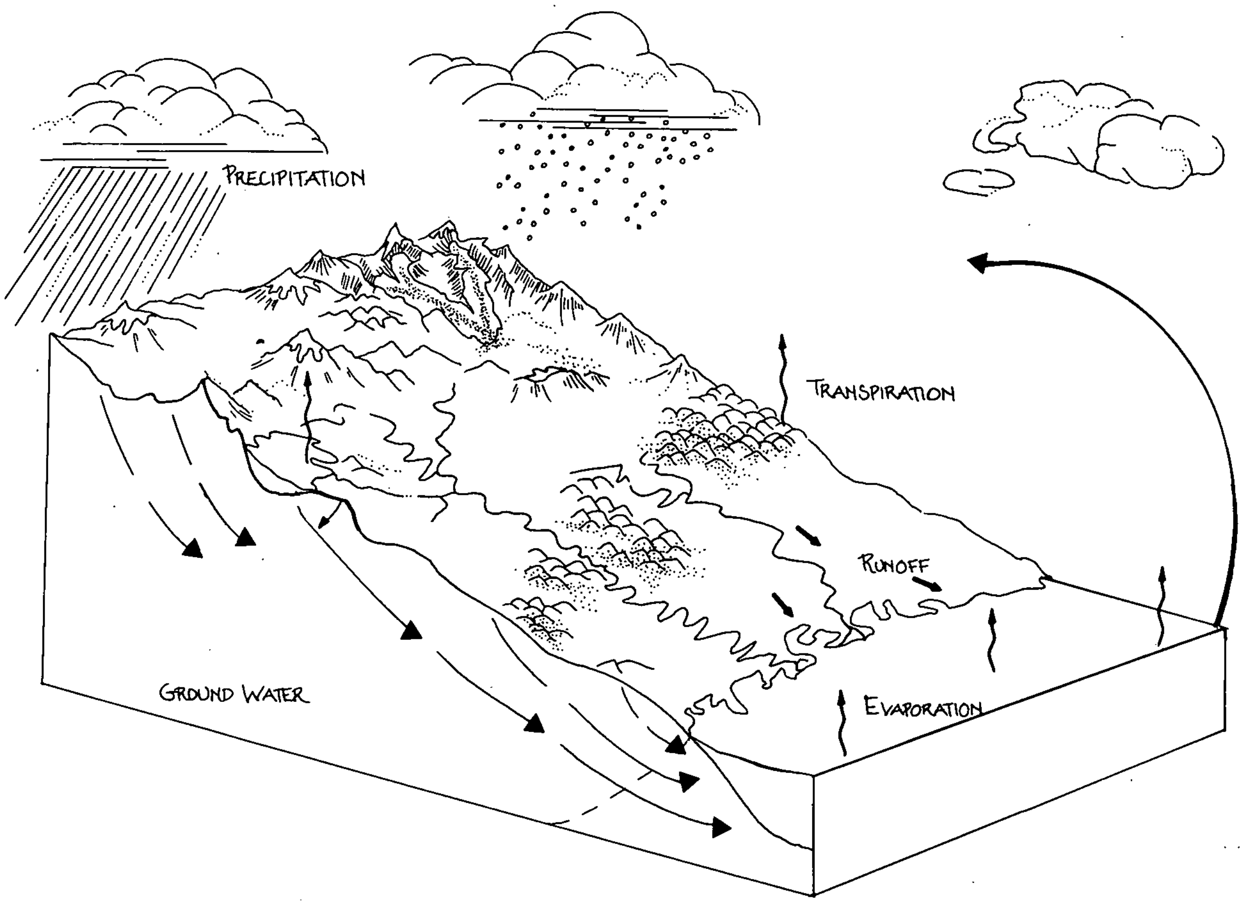



*Figure 8. The hydrologic cycle. In inland areas, precipitation, runoff, and ground-water discharge may all contribute to the wetland water regime.*

it was devised, and each has serious disadvantages when used outside its own special context.

One of the earliest national wetland classification systems was that devised in 1953 by Martin et al. as a basis for the U.S. Fish and Wildlife Service (USFWS) inventory of wetlands valuable to waterfowl. Martin et al. (*5*) organized wetlands into 20 classes, primarily on the basis of water depth during the growing season, degree of seasonal flooding, and the dominant form of vegetation. This system has been used widely, but, because it is very generalized, it has been found to be of only limited value for wetlands research and management at the regional or local scale.

Currently a more comprehensive national wetland inventory is in progress under the auspices of the U.S. Fish and Wildlife Service. A new wetland classification system has been developed by Cowardin et al. (*2*) for use with the current inventory. Wetland inventory maps that are being prepared by USFWS will provide the most widely available and consistent depiction of wetland resources, and familiarity with the Cowardin classification system will afford highway agencies ready access to a wealth of wetlands information (see Fig. 11 for a sample map section).

A more complete description of wetland classes described in the USFWS classification system can be found in Appendix A of this manual.

**WETLAND VALUES**

In some cases, wetlands provide unique examples of biological or geological phenomena and are invaluable for scientific research and education. In other cases, wetlands may be of extraordinary importance to the preservation of uncommon or specialized and highly desired flora and fauna. Some may be outstanding from a visual standpoint, because they are a type that is not frequently found in certain physiographic regions; and others have special value because of the position they occupy in a wetland system.

Wetlands that have any one of the following attributes are wetlands which should be preserved in their existing or an enhanced state (*6*):

1. *Rare, restricted, endemic, or relict flora or fauna*—A rare species is one found at very few locations within a given geographic area. A restricted species is one found only in certain very specialized habitats, such as many bog organisms. An endemic species is one that is known to occur only within a given geographic area. Relict flora or fauna were more common during an earlier age when different environmental conditions prevailed, but now persist in isolated pockets in otherwise unsuitable range.

2. *Flora or fauna at, or very near, the limits of their geographic range*—Preservation of areas such as these provides unusual educational and scientific research opportuni-

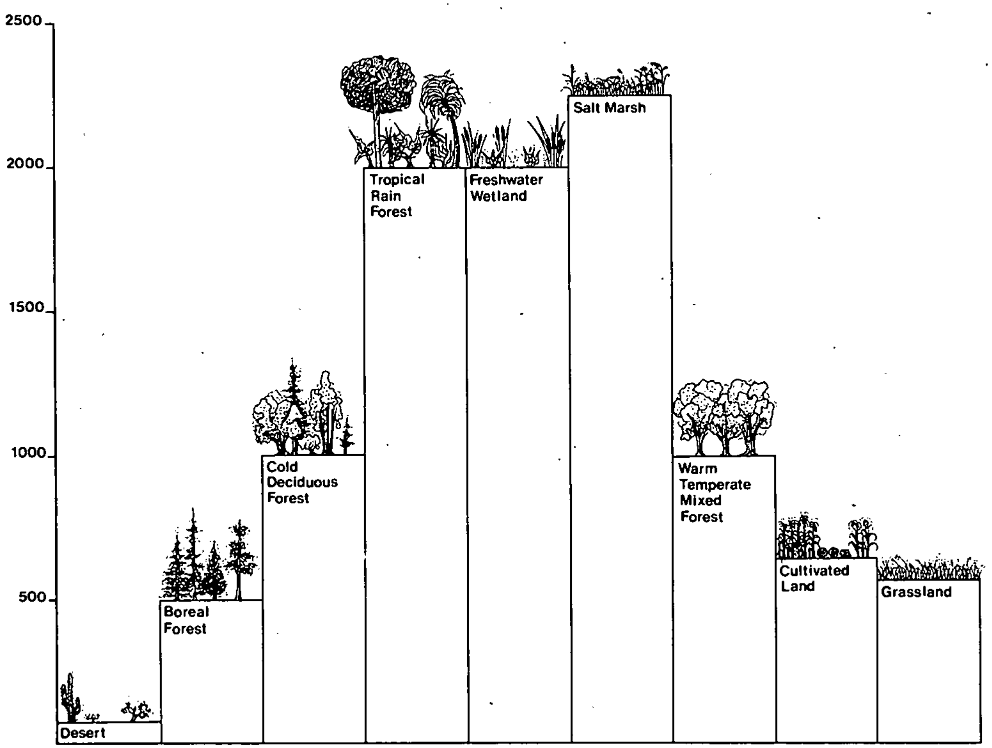



*Figure 10. Net primary productivity of selected ecosystems ($g/m^2/yr$). (After Lieth (1975) and Teal and Teal (1969))*

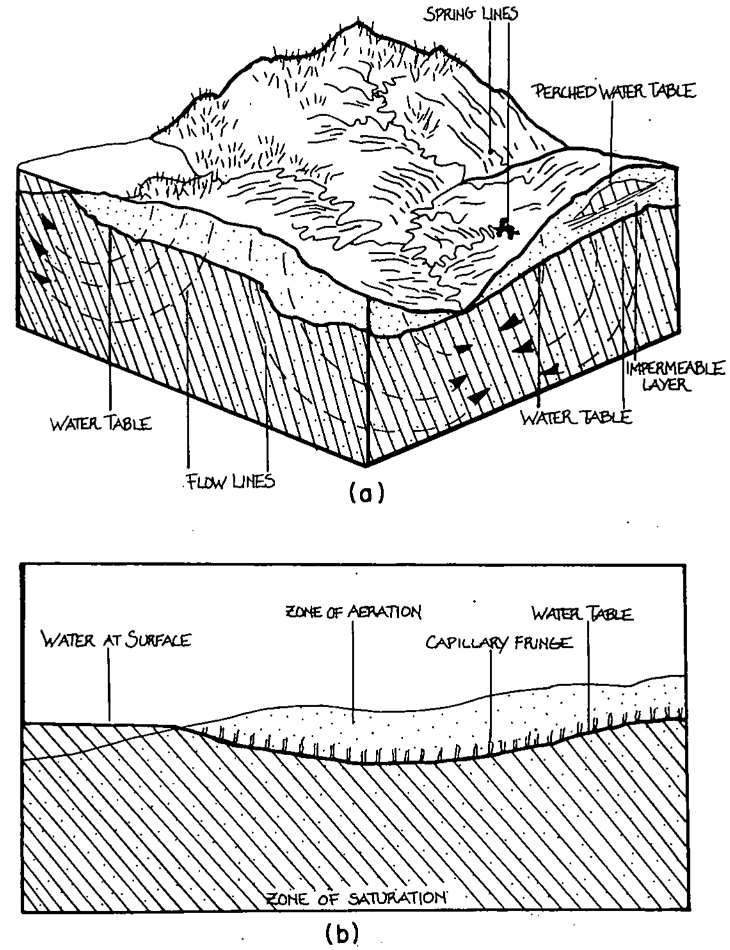



*Figure 9. (a) Movement of ground water. The water table is a subdued replica of the topography. (b) Wetlands may occur when the water table is at or near the soil surface. (After Hambun and Howard, 1975)*

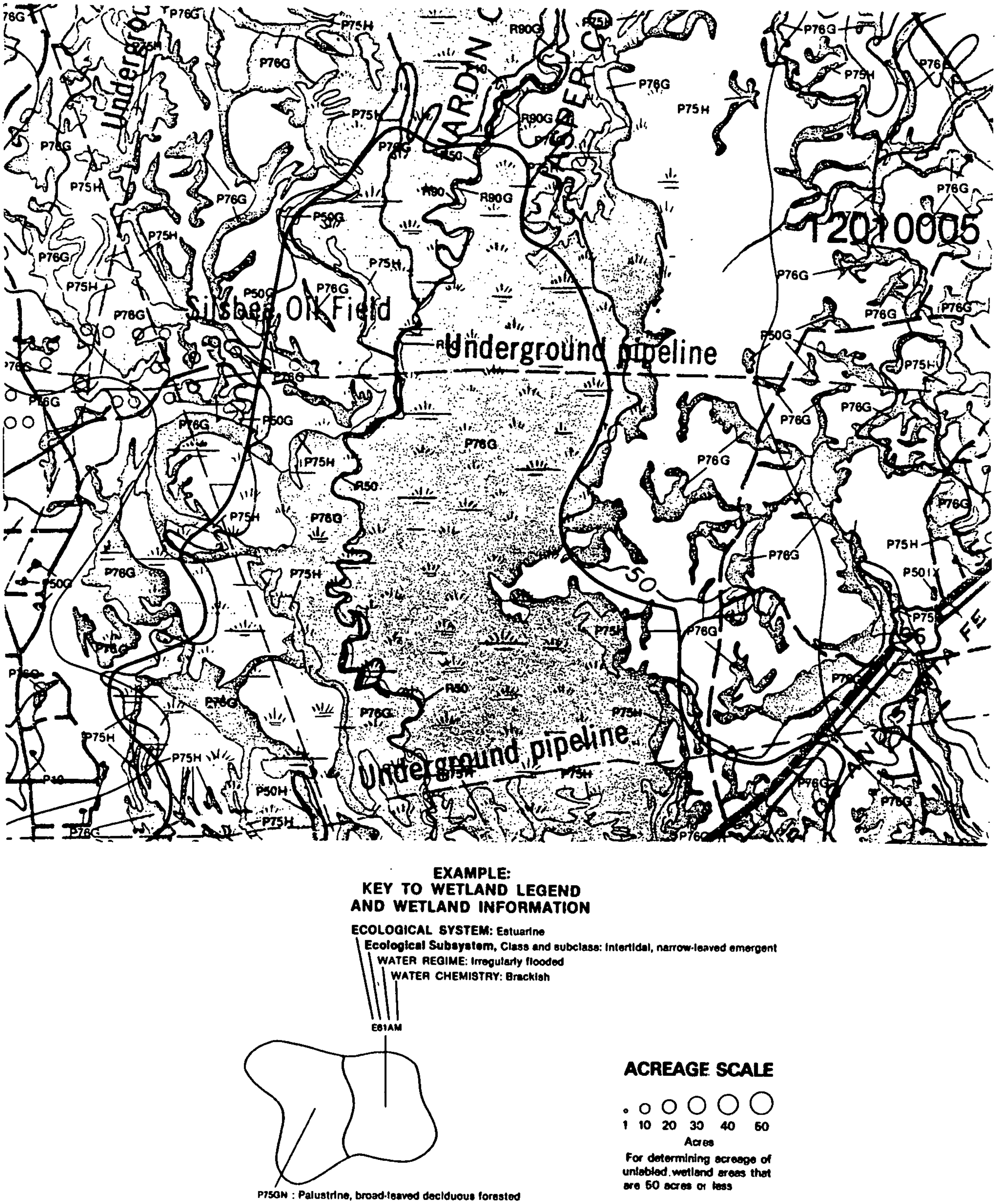



*Figure 11. Sample section of the national wetland inventory maps produced by the Division of Biological Services, U.S. Fish and Wildlife Service. The original maps are color coded and may be obtained from the Division of Biological Services.*

ties. Study of a species at the limits of its range often reveals the critical environmental factors affecting the survival of that species anywhere.

3. *Wetlands that are integral lines in a system of waterways or whose size dominates a regional watershed*—In the northeast, wetlands that are connected to other wetlands by streams of at least 15 miles navigable length, or by a water body of over 200 acres meet this criterion. Also included would be any continuous complex of over 1000 acres.

4. *Wetlands that are relatively scarce in a given physiographic region*—

5. *Wetlands or associated flora of unusually high visual quality and locally infrequent occurrence*—

6. *Outstanding or uncommon geomorphological features in or associated with a wetland*—The value of such features is both educational and scientific.

7. *The juxtaposition, in sequence, of several stages of wetland type succession*—Examples that demonstrate this ecological phenomenon are scarce, so a wetland containing several successional stages is of great educational value.

8. *High production or use by water, marsh, and shore birds*—Certain wetland habitats are extremely important as areas for local production of native species, or as resting and feeding areas for birds migrating between more northern breeding grounds and southern wintering areas. Waterfowl, which commonly concentrate in large numbers during migration, require large wetlands with abundant, open water and food.

9. *Known presence of archaeological evidence*—This includes preserved remains of animals and/or artifacts of an ancient period.

10. *An established record of scientific research on the site*—Reliable information concerning the biological, geological, or archaeological history of a wetland can be used to provide insight into the processes that generated and modify the present natural landscape.

CHAPTER TWO

# ECOLOGICAL EFFECTS OF HIGHWAY FILLS AND STRUCTURES

## A PROCEDURE FOR IDENTIFYING BIOLOGICAL EFFECTS

The previous section of this manual stressed the importance of the quality, quantity, and flow regime of wetland water supplies to the character of the ecosystem concerned. Other than the obvious loss of habitat from the placement of highway fills, modification of wetland hydrology is the primary cause of highway-related environmental impacts. One purpose of this manual is to assist the highway engineer in his/her efforts to predict these impacts by presenting a description of the nature of the biological changes resulting from highway-related activities.

As an aid in developing an understanding of the cause and effect relationship between changes in the physical environment that can be caused by highway fills and the biological response to these changes that can occur in wetland ecosystems, a series of flow charts and matrices has been drafted. Each flow chart displays a set of physical impacts that might result from a particular construction activity (consolidation; displacement; excavation and replacement with permeable fill; light weight fill; pile-supported roadway or bridging; and culvert design: capacity, placement, tidal). These physical impacts are then matrixed with a series of potential biological effects that could possibly occur with a particular physical modification. It should be stressed at the outset that the purpose of these charts is to demonstrate a *potential* relationship between the physical modifications of the environment and the probable biological response. The flow charts are in no way intended to quantify these relationships.

However, when quantitative estimates (i.e. major, minor, variable) of the biological effects that might result from alternative construction activities are prepared, the value of the matrices becomes evident. They not only describe the environmental relationships, but also give the user a clear picture of the biological consequences of each alternative construction activity, thus allowing the highway planner to consider environmental impacts in conjunction with economic and other concerns (see "Example Use of Procedures," Chap. 3).

Following the flow charts will be found sections that describe each of the physical impacts and biological effects that appear within the matrix format. These sections give detailed information concerning analytical methods, mitigation procedures, and expertise needed for a comprehensive evaluation of the area concerned.

An introductory paragraph for each impact describes the area and likelihood of its occurrence and presents background data on the significance of the impact and its predictability in the presence of certain engineering conditions. Another section describes the acquisition of ecological data related to the impact. Much of the information on ecosystem concepts must come from the published literature and general body of knowledge in ecology. Specific components of the regional ecosystem, including inventories of biota, may come from publications, technical reports, or private sources. New data generated from the project should complement available information. The data acquisition phase should include extensive liaison with numerous outside sources in addition to field and laboratory efforts.

## FLOW CHARTS AND MATRICES

Figures 12 through 19 show the flow charts and matrices on which the format of this user's manual is based. To the immediate right of each physical impact in the matrix, there can be found a series of boxes. Each box falls under a different biological effect displayed along the top of the matrix. *Whenever a box is found to be blank, there exists the potential for the particular Physical Impact to initiate the indicated Biological Effect.* (For convenience of the user, these charts are also provided in Appendix B for the purpose of making duplicates for field use.) Special attention should be given to this section, which graphically displays both the cause and effect nature of highway-induced ecological effects and the logic behind the following sections that deal with physical impacts and biological effects.

## PHYSICAL IMPACTS

This section is organized to enable the user to review only those impacts which relate to the particular construction activity under consideration.

- IMPACTS ASSOCIATED WITH SURFACE FLOWS
  - Change in Mean Water Level
  - Change in Periodicity
  - Change in Wetland Circulatory Patterns

The movement of surface water in wetlands may contribute significantly to the character of the existing ecosystem. Such factors as nutrient and oxygen distribution, period of inundation, and seasonal timing of high water may all determine the distribution of plant species. Highway fills, culverts, and bridges can inhibit, enhance, or redirect the flow of water and, in so doing, change the nature of both the established water regime and the biological community of the site.

- IMPACTS ASSOCIATED WITH SUBSURFACE FLOWS
  - Alteration of Local Water Table Levels

Ground-water movement, in most cases, is considerably slower than surface flows. However, when subsurface movement is inhibited, the local mean water table is inevitably affected. This, in turn, may cause major biological changes because many plant species are adapted to rather narrow limits of soil saturation depth and duration. Both impermeable fills and compression techniques in highway construction may cause this effect.

- IMPACTS ASSOCIATED WITH CREATION OF CHANNELS IN WETLANDS
  - Drainage of Surface Waters
  - Elimination of Periodic Flooding and Fertilization
  - Change in Retention Storage

Although natural channels often occur in wetlands, the placement of fills and culverts may create chanelized flow where none existed before. Because water movement in channels is more erosive, channel creation may instigate more severe alteration of surface hydrology.

- IMPACTS ASSOCIATED WITH INTERFERENCE WITH TIDAL FLOWS
  - Damping of Tidal Variations
  - Alteration of Salinity Patterns

Tidal flows may be distinguished in several ways. Tidal flows reverse direction, they vary daily and monthly, and they control the distribution of salinity within the hydrologic system. These factors and others combine to create the unique ecosystems found along the nation's shores. Highway structures can alter tidal water regimes severely, and may alter the associated ecosystems.

- IMPACTS ASSOCIATED WITH WATER QUALITY
  - Turbidity
  - Sedimentation
  - Chemical Pollution
  - Temperature

Highway construction activities may have detrimental effects on water quality to varying degrees. Although turbidity and sedimentation problems are usually most extensive during construction, postconstruction problems can occur as a result of operations and maintenance of the highway. In addition, although the introduction of toxic substances is commonly a consequence of highway use and maintenance, it is by no means exclusive to these activities. Water quality effects should be recognized and mitigated at all levels of highway design, construction, maintenance, and use. The assessment of highway impacts on wetland ecosystems requires determination of present and potential future use of the aquatic resource. When the particular use of the water resource has been identified, the highway engineer can determine which impacts are most important to the water quality of that resource.

The following sections describe the nature of the physical impacts that appear in the *vertical* column of the matrix. In addition, each section contains information regarding baseline data needs, expertise required, analytical methods, data sources, and mitigation techniques that could be used to reduce any anticipated harmful biological effects.

### Change in Mean Water Level

Because wetlands are associations of plants with varying requirements for water, the spatial arrangement of species within the wetland environment is intimately related to water depth. Depending on the morphology of the basin, engineering structures and features can either increase levels through damming effects or decrease levels through drainage.

Environmental response to such changes can be dramatic, and an awareness of the extent of water level modifications that will occur on completion of the roadway is critical to impact assessment.

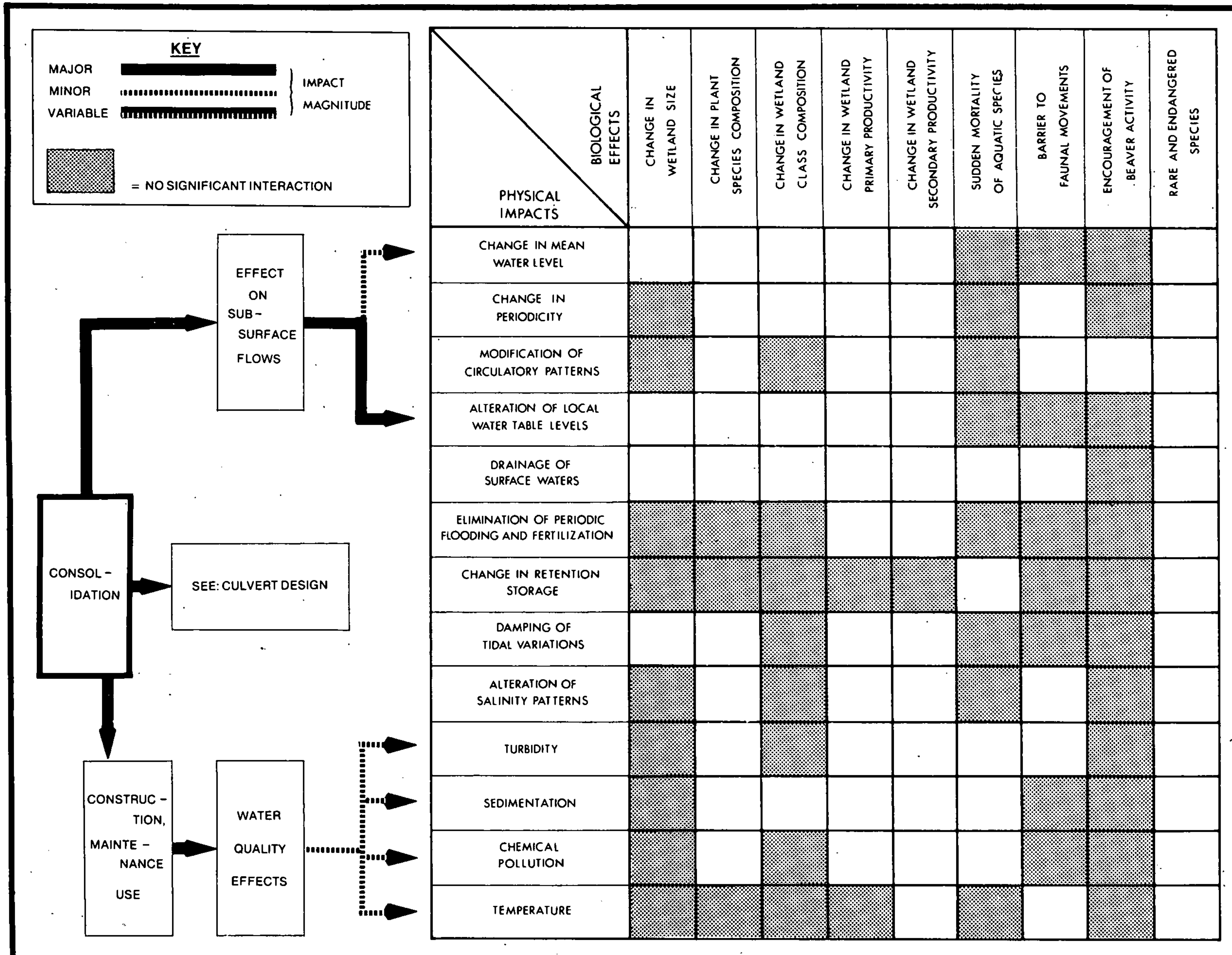



*Figure 12. Physical impacts flow chart and biological effects matrix.*

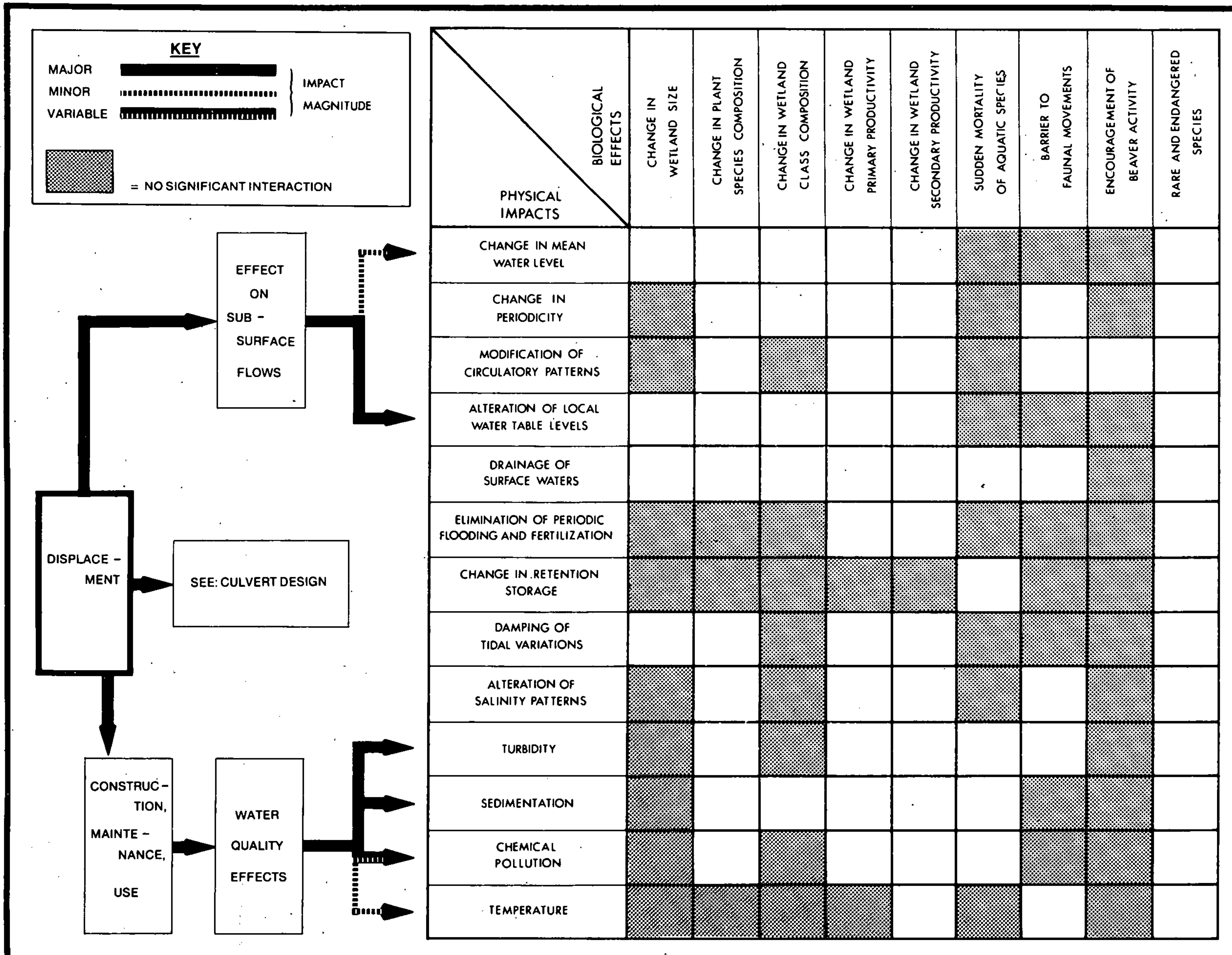
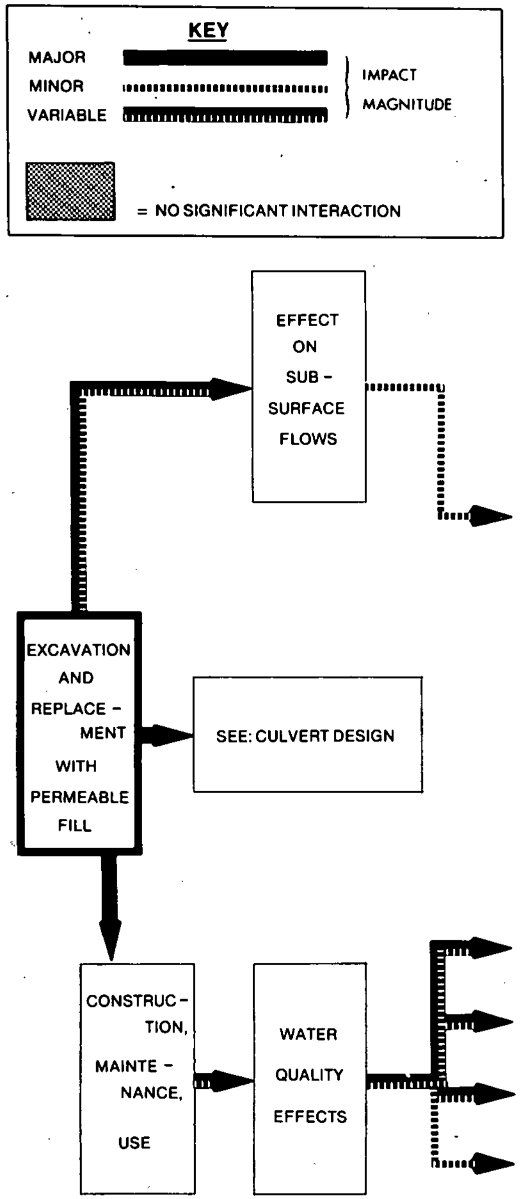



*Figure 13. Physical impacts flow chart and biological effects matrix.*




| PHYSICAL IMPACTS \ BIOLOGICAL EFFECTS | CHANGE IN WETLAND SIZE | CHANGE IN PLANT SPECIES COMPOSITION | CHANGE IN WETLAND CLASS COMPOSITION | CHANGE IN WETLAND PRIMARY PRODUCTIVITY | CHANGE IN WETLAND SECONDARY PRODUCTIVITY | SUDDEN MORTALITY OF AQUATIC SPECIES | BARRIER TO FAUNAL MOVEMENTS | ENCOURAGEMENT OF BEAVER ACTIVITY | RARE AND ENDANGERED SPECIES |
|---|---|---|---|---|---|---|---|---|---|
| CHANGE IN MEAN WATER LEVEL | | | | | | ▒ | ▒ | ▒ | |
| CHANGE IN PERIODICITY | ▒ | | | | | ▒ | | ▒ | |
| MODIFICATION OF CIRCULATORY PATTERNS | ▒ | | ▒ | | | ▒ | | | |
| ALTERATION OF LOCAL WATER TABLE LEVELS | | | | | | ▒ | ▒ | ▒ | |
| DRAINAGE OF SURFACE WATERS | | | | | | | | ▒ | |
| ELIMINATION OF PERIODIC FLOODING AND FERTILIZATION | ▒ | ▒ | ▒ | | | ▒ | ▒ | ▒ | |
| CHANGE IN RETENTION STORAGE | ▒ | ▒ | ▒ | ▒ | ▒ | | ▒ | ▒ | |
| DAMPING OF TIDAL VARIATIONS | | | ▒ | | | ▒ | ▒ | ▒ | |
| ALTERATION OF SALINITY PATTERNS | ▒ | | ▒ | | | ▒ | | ▒ | |
| TURBIDITY | ▒ | | ▒ | | | | | ▒ | |
| SEDIMENTATION | ▒ | | | | | | ▒ | ▒ | |
| CHEMICAL POLLUTION | ▒ | | ▒ | | | | ▒ | ▒ | |
| TEMPERATURE | ▒ | ▒ | ▒ | ▒ | | ▒ | | ▒ | |

*Figure 14. Physical impacts flow chart and biological effects matrix.*

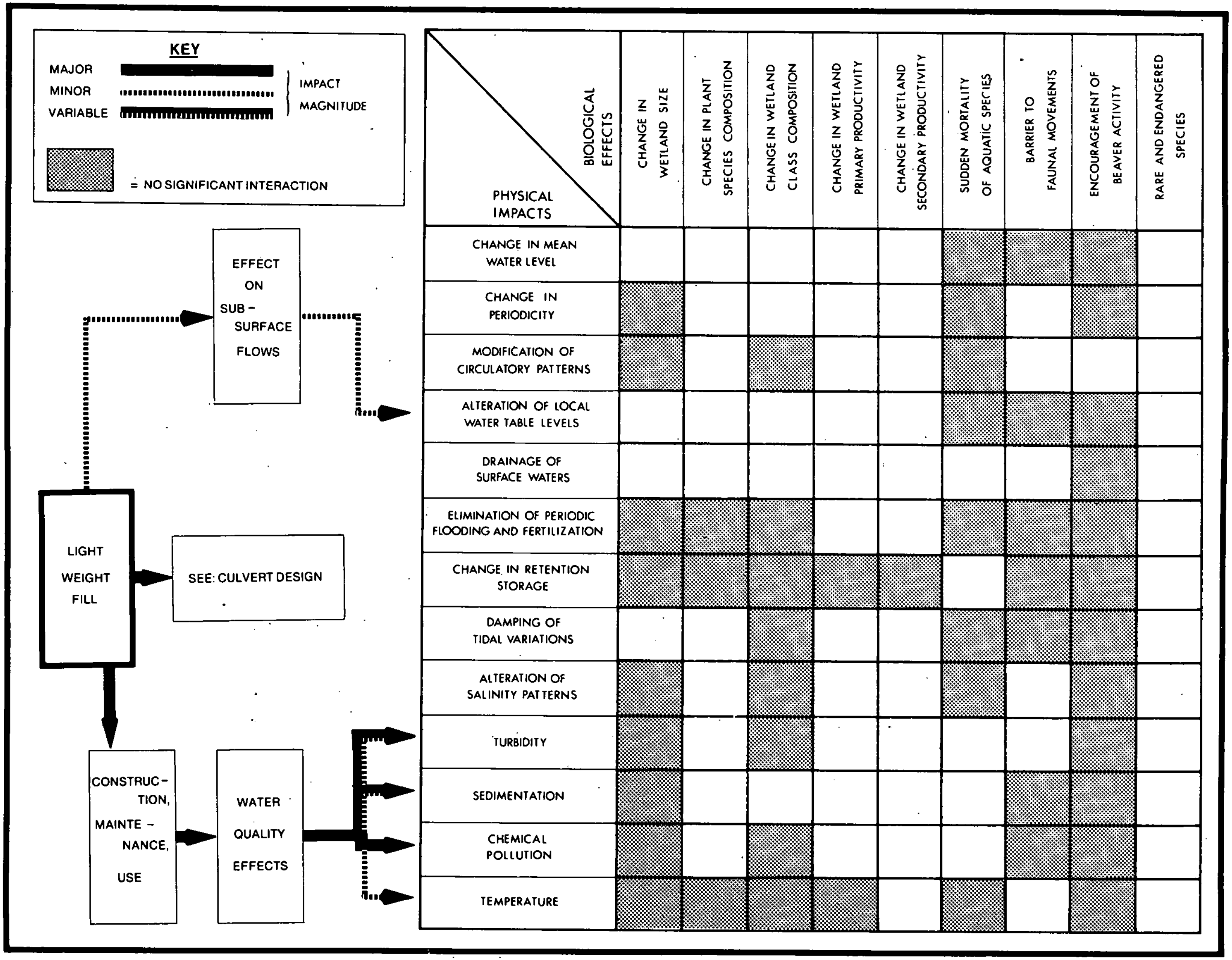



*Figure 15. Physical impacts flow chart and biological effects matrix.*

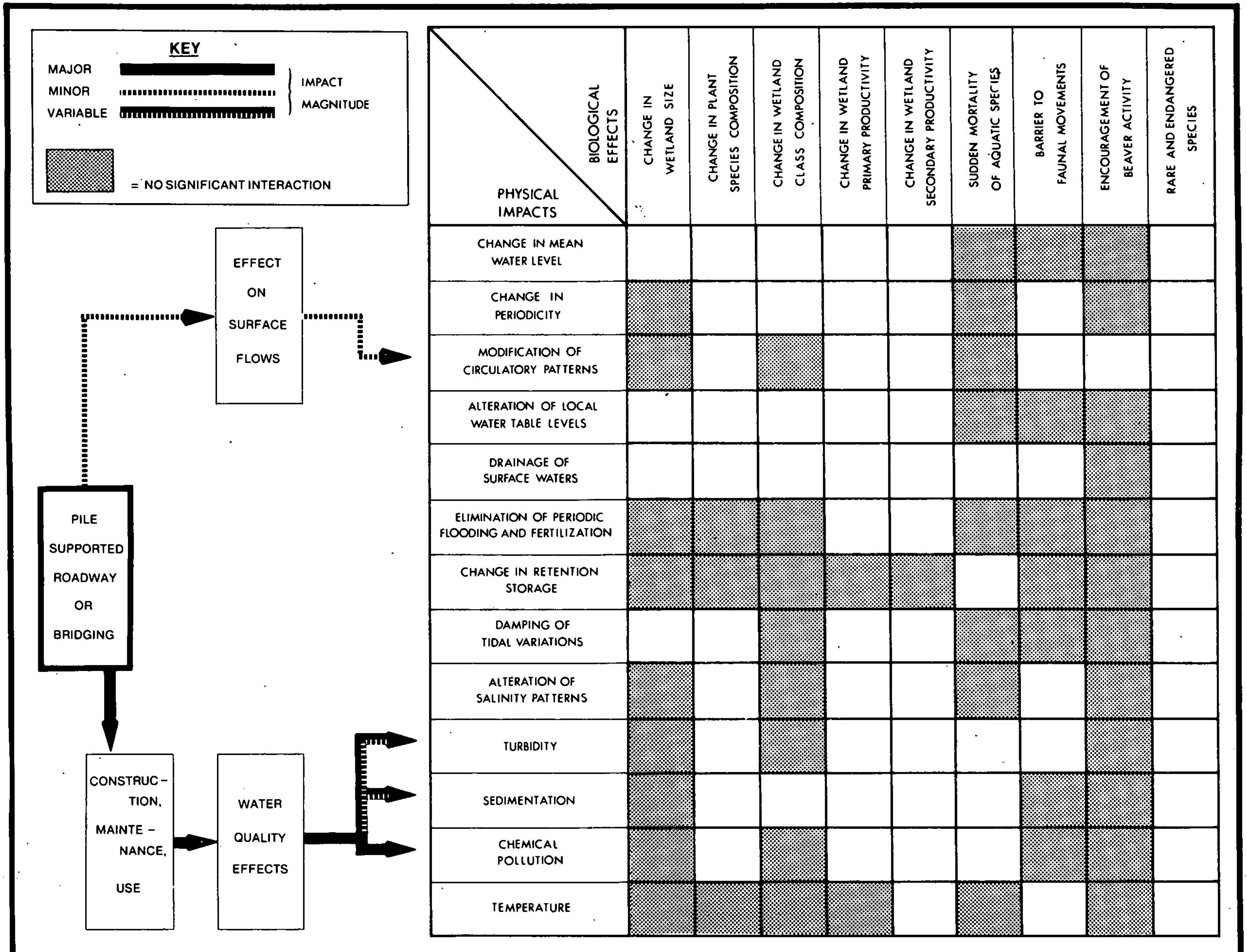
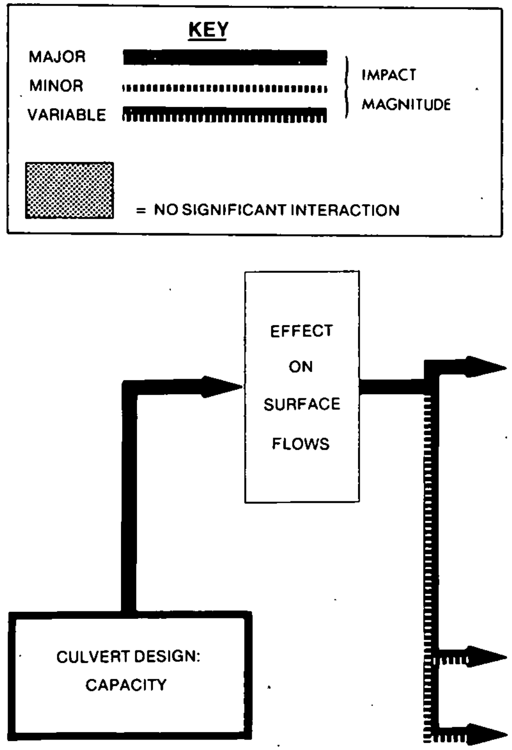



*Figure 16. Physical impacts flow chart and biological effects matrix.*




(▒ = NO SIGNIFICANT INTERACTION)

| PHYSICAL IMPACTS \ BIOLOGICAL EFFECTS | CHANGE IN WETLAND SIZE | CHANGE IN PLANT SPECIES COMPOSITION | CHANGE IN WETLAND CLASS COMPOSITION | CHANGE IN WETLAND PRIMARY PRODUCTIVITY | CHANGE IN WETLAND SECONDARY PRODUCTIVITY | SUDDEN MORTALITY OF AQUATIC SPECIES | BARRIER TO FAUNAL MOVEMENTS | ENCOURAGEMENT OF BEAVER ACTIVITY | RARE AND ENDANGERED SPECIES |
|---|---|---|---|---|---|---|---|---|---|
| CHANGE IN MEAN WATER LEVEL | | | | | | ▒ | ▒ | ▒ | |
| CHANGE IN PERIODICITY | ▒ | | | | | ▒ | | ▒ | |
| MODIFICATION OF CIRCULATORY PATTERNS | ▒ | | ▒ | | | ▒ | | | |
| ALTERATION OF LOCAL WATER TABLE LEVELS | | | | | | ▒ | ▒ | ▒ | |
| DRAINAGE OF SURFACE WATERS | | | | | | | | ▒ | |
| ELIMINATION OF PERIODIC FLOODING AND FERTILIZATION | ▒ | ▒ | ▒ | | | ▒ | ▒ | ▒ | |
| CHANGE IN RETENTION STORAGE | ▒ | ▒ | ▒ | ▒ | ▒ | | ▒ | ▒ | |
| DAMPING OF TIDAL VARIATIONS | | | ▒ | | | ▒ | ▒ | ▒ | |
| ALTERATION OF SALINITY PATTERNS | ▒ | | ▒ | | | ▒ | | ▒ | |
| TURBIDITY | ▒ | | ▒ | | | | | ▒ | |
| SEDIMENTATION | ▒ | | | | | | ▒ | ▒ | |
| CHEMICAL POLLUTION | ▒ | | ▒ | | | | ▒ | ▒ | |
| TEMPERATURE | ▒ | ▒ | ▒ | ▒ | | ▒ | | ▒ | |

*Figure 17. Physical impacts flow chart and biological effects matrix.*

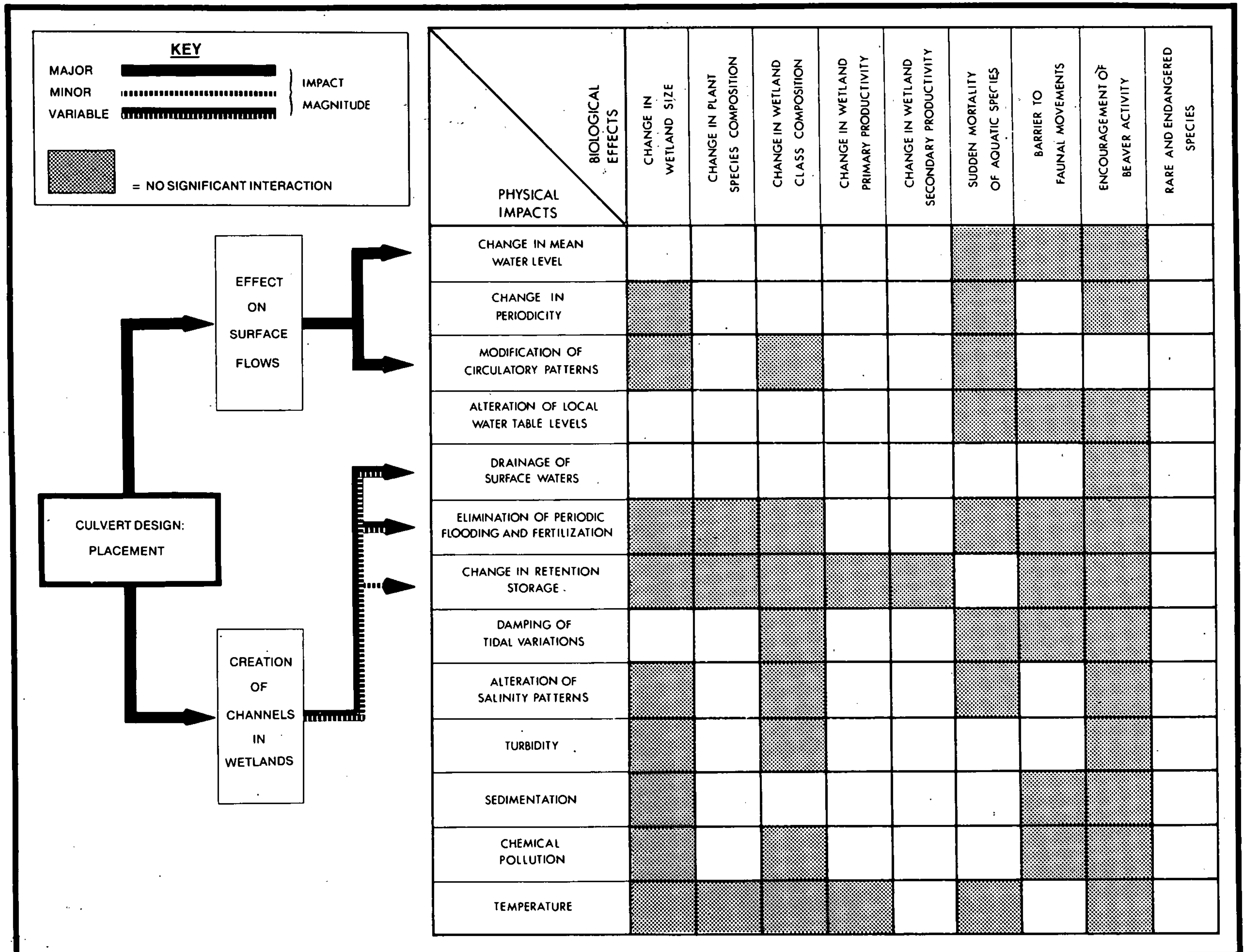
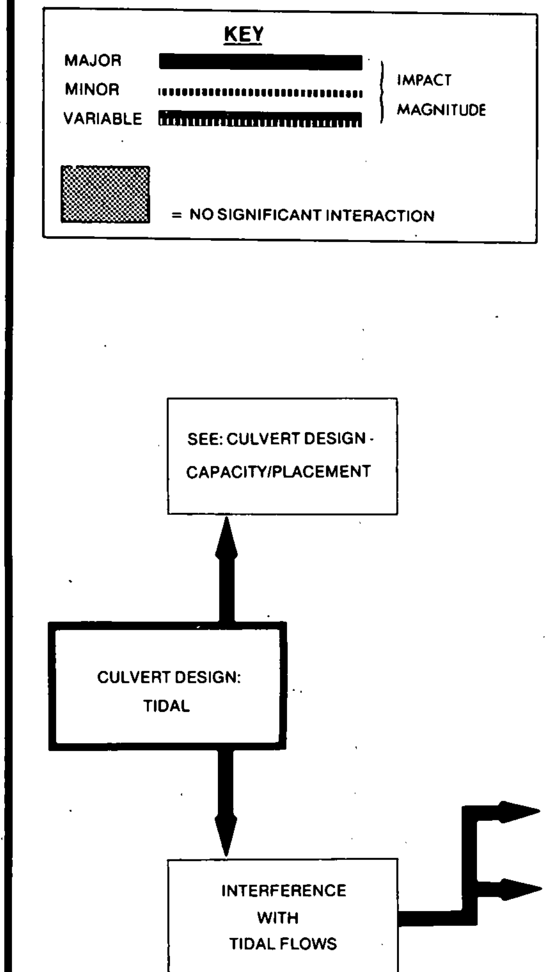



*Figure 18. Physical impacts flow chart and biological effects matrix.*




| PHYSICAL IMPACTS \ BIOLOGICAL EFFECTS | CHANGE IN WETLAND SIZE | CHANGE IN PLANT SPECIES COMPOSITION | CHANGE IN WETLAND CLASS COMPOSITION | CHANGE IN WETLAND PRIMARY PRODUCTIVITY | CHANGE IN WETLAND SECONDARY PRODUCTIVITY | SUDDEN MORTALITY OF AQUATIC SPECIES | BARRIER TO FAUNAL MOVEMENTS | ENCOURAGEMENT OF BEAVER ACTIVITY | RARE AND ENDANGERED SPECIES |
|---|---|---|---|---|---|---|---|---|---|
| CHANGE IN MEAN WATER LEVEL | | | | | | ▒ | ▒ | ▒ | |
| CHANGE IN PERIODICITY | ▒ | | | | | ▒ | | ▒ | |
| MODIFICATION OF CIRCULATORY PATTERNS | ▒ | | ▒ | | | ▒ | | | |
| ALTERATION OF LOCAL WATER TABLE LEVELS | | | | | | ▒ | ▒ | ▒ | |
| DRAINAGE OF SURFACE WATERS | | | | | | | | ▒ | |
| ELIMINATION OF PERIODIC FLOODING AND FERTILIZATION | ▒ | ▒ | ▒ | | | ▒ | ▒ | ▒ | |
| CHANGE IN RETENTION STORAGE | ▒ | ▒ | ▒ | ▒ | ▒ | | ▒ | ▒ | |
| DAMPING OF TIDAL VARIATIONS | | | ▒ | | | ▒ | ▒ | ▒ | |
| ALTERATION OF SALINITY PATTERNS | ▒ | | ▒ | | | ▒ | | ▒ | |
| TURBIDITY | ▒ | | ▒ | | | | | ▒ | |
| SEDIMENTATION | ▒ | | | | | | ▒ | ▒ | |
| CHEMICAL POLLUTION | ▒ | | ▒ | | | | ▒ | ▒ | |
| TEMPERATURE | ▒ | ▒ | ▒ | ▒ | | ▒ | | ▒ | |

*Figure 19. Physical impacts flow chart and biological effects matrix.*

*Analytical Methods*

*Baseline Data Needs.* Baseline data should include water level information obtained at intervals to encompass both high and low water periods. Although some wetlands exist with stable water levels for extended periods of time, most experience normal seasonal fluctuations about the mean. (See also section under "Change in Periodicity.")

*Sampling and Measuring.* Levels are normally determined by use of a staff gauge set in the wetland. This gauge must be read at intervals sufficient to produce a plot of water level vs. time. An alternate method involves the use of a continuous reading water level gauge as used in stream gauging stations.

*Data Sources.* U.S. Geological Survey, Reston, Va.

*Expertise Needed.* Hydrology, geomorphology (see Chap. 5, "Sources of Expertise.")

*Mitigation Procedures*

If the existing environment is to be maintained, engineering structures and fills should be designed to avoid damming effects. The culvert system must provide water level equalization across the fill similar to natural conditions.

**Change in Periodicity**

Natural ecological systems are often adapted to periodic fluctuations in physical characteristics of the site. For example, many northern tree species cannot germinate without experiencing a period of cold temperatures. This assures that seedlings are being established at favorable times for successful growth. In a similar way, many species require a varying water regime for germination, establishment, and survival. In many cases, wetland plants may require both periods of inundation and periods when water levels fall below the soil surface. In addition, seasonal timing is important. Table 1 lists the species relevant to changes in periodicity (*7*).

Periodicity also contributes to a high level of wetland primary productivity (see section under "Elimination of Periodic Flooding and Fertilization"). Engineered structures in wetlands can often affect both the timing and duration of water regime fluctuations. When the changes are pronounced, they may have demonstrable effects on the wetlands involved.

*Analytical Methods*

*Baseline Data Needs.* Water level data taken at intervals that will yield information on both the extent and timing of fluctuations are required. Because level changes can vary from twice a day (tidal) to seasonal, sampling methodology must be site-specific.

*Sampling and Measuring.* Automatic measuring devices are necessary in this case, because both the water levels and its rate of change are of interest. Plots must be prepared to show water level vs. time. The slope of any portion of this plot reveals the rate of change of water level at that time. Another method would be to make measurements throughout one day using a tide staff(s) and correlate these measurements with nearby tide gauging stations.

TABLE 1

SPECIES TOLERANT TO FLUCTUATING WATER LEVELS (SOURCE: REF. 7)

| |
|---|
| Soil Always Quite Moist |
| Potamogeton americanus (pondweed) |
| P. gramineus (variable pondweed) |
| Sparganium spp. (bur reeds) |
| Triglochin maritime (arrow grass) |
| Sagittaria spp. (arrowhead) |
| Glyceria striata (manna grass) |
| Distichlis spp. (spike grass) |
| Leersia cryzoides (cutgrass) |
| Leptochloa fascicularis (leptochloa) |
| Eleocharis quadrangulata (spike rush spp.) |
| E. parvula (spike rush spp.) |
| E. acicularis (spike rush spp.) |
| Scirpus americanus (3-square sedge, bulrush) |
| S. acutus (bulrush) |
| S. robustus (bulrush) |
| S. paludosus (bulrush) |
| Rynchospora spp. (beak rush) |
| Cladium jamaicense (saw grass) |
| Pontederia spp. (pickerel weed) |
| Salicornia spp. (glasswort) |
| Acnida cannibinus (salt marsh water hemp) |
| Prosperpinaca spp. (mermaid weed) |
| Cephalanthus occidentalis (buttonbush) |
| Soil Sometimes Dry |
| Panicum dichotomiflorum (switch grass) |
| Echinochloa spp. (barnyard grass) |
| Cyperus esculentus (umbrella sedge) |
| Polygonum spp. (smartweeds) |

*Expertise Needed.* Hydrology, ecology, limnology, wetland plant community ecology.

*Mitigation Procedures*

Periodicity patterns can be altered by structures that inhibit or enhance flows of wetland water supplies. Proper culvert design, which allows peak flows to dissipate at normal rates and which prevents damming, can aid in maintaining the existing regime.

**Change in Wetland Circulatory Patterns**

The distribution of nutrients and dissolved gases in wetlands is dependent on the circulatory patterns established in the basin. In coastal areas, these patterns also determine the nature of the salinity gradient. Wetland flora and fauna have differing tolerances to the concentrations of these substances. Therefore, species distribution can be, in part, a reflection of existing wetland circulatory patterns.

*Analytical Methods*

*Baseline Data Needs.* A map displaying the direction

and the rate of flow of surface waters at the site is necessary to assess the impact of engineering features on existing circulatory patterns.

*Sampling and Measuring.* Circulatory patterns can be determined by use of a dye test. A nontoxic, nonreactive dye solution can be introduced into the wetland in a known quantity and at a specific point. A grid of sampling points is established and samples taken at regular intervals. These samples, when analyzed for color, give a plot of dye concentration vs. time at each sampling station. By comparing the time and magnitude of each station's peak, the diffusivity of the area can be estimated.

If the wetland is a dynamic one, it may be possible to determine the normal flow patterns from low level aerial photographs taken after an intense rain. Turbidity in areas of primary flow may be great enough to be seen in these photographs.

*Expertise Needed.* Hydrology, chemical engineering, wetland plant community ecology.

### *Mitigation Procedures*

Emphasis on design features that retain established circulatory patterns is required. Fills and culverts must be designed to minimize any channelization. Careful placement of culverts must be made at areas that are shown to have significant natural circulatory flow.

## Alteration of Local Water Table Levels

Because wetlands are frequently areas where surface topography intercepts local water tables, changes in water table levels often occur simultaneously with surface water alterations. Although some wetland classes have no surface water for extended periods of time, they are still dependent on locally high water table levels for survival and growth.

### *Analytical Methods*

*Baseline Data Needs.* Both maximum and minimum depths to ground water should be determined according to seasonal fluctuations. An accurate contour map of the piezometric surface will aid in determining the potential effect of highway structures on the local soil moisture regimes.

*Sampling and Measuring.* Depth to ground water is determined with a piezometer.

*Data Source.* U.S. Geological Survey, Reston, Va.

*Expertise Needed.* Hydrology, soil mechanics, wetland plant community ecology.

### *Mitigation Procedures*

Movement of ground water is inhibited by impervious fills and highly compressed substrates. The resultant damming effect can alter local water table levels. Highway design should allow for adequate passage of subsurface water.

Creation of channels in wetlands to direct flows through culverts can lower surrounding water table levels. Efforts should be made to maintain diffuse drainage patterns where possible.

## Drainage of Surface Waters

A large array of wetland species is dependent on the presence of surface water for survival. Both flora and fauna suffer severe impacts when surface water is removed from a wetland area. Not only resident species, but also those dependent on surface water for normal migrations, are affected. In many cases, sudden mortality is the resulting impact; recovery is very slow if and when the wetland is restored to its original condition. Upland species that depended on the habitat for water would also be affected.

### *Analytical Methods*

*Baseline Data Needs.* A map showing both surface area and basin morphology will aid in determining the effect of highway construction on the existing wetland.

*Sampling and Measuring.* Mapping of surface waters in wetlands is most readily accomplished through interpretation of "leaves off" aerial photographs. Depths may be sounded electronically.

*Data Source.* ERTS Sioux Falls, Iowa, USDA, private companies, state highway departments.

*Expertise Needed.* Hydrology, limnology, wetland plant community ecology.

### *Mitigation Procedures*

Construction methods and design featuers should be employed that will avoid draining surface water. Channels should not be created that would eliminate areas of surface water concentrations on the site.

## Elimination of Periodic Flooding and Fertilization

A major contributing factor to the high primary productivity of wetland ecosystems is the periodic input of nutrients at times of high water. This, coupled with periods of drier conditions which encourage decomposition of dead plant material and, thus, additional nutrient availability, produces conditions favoring rapid growth. Stabilization of water levels (see section under "Change in Periodicity") or elimination of periodic flooding conditions will reduce wetland productivity and may induce changes in wetland class.

### *Analytical Methods*

*Baseline Data Needs.* Necessary information includes both the extent and the frequency of periods of high water.

*Sampling and Measuring.* A gauging station with a recording water level indicator is required.

*Expertise Needed.* Hydrology, ecology, wetland plant community ecology.

### *Mitigation Procedures*

Design features that tend to stabilize standing water through damming effects or which facilitate rapid drainage at times of high water should be avoided.

## Change in Retention Storage—Increase or Decrease Flow Downstream

Many wetlands function as regulatory bodies in the local

hydrology. Because wetlands retain water, they aid in diminishing peak flow downstream—a function often critical to flood prevention. In addition, wetlands often support base flows during drier periods and may prevent smaller streams from disappearing in times of drought. Because of these relationships, effects from wetland alterations may often be experienced some distance from the site.

*Analytical Methods*

*Baseline Data Needs.* Knowledge of basin morphology is necessary to calculate the potential storage capacity of the wetland. Peak flows with and without this storage may be calculated to determine downstream effects from wetland storage functions. Mathematical modeling can be helpful in locating the optimum fill and culvert locations.

*Sampling and Measuring.* Basin morphology may be determined from USGS topographic maps and through interpretation of aerial photographs.

*Data Sources.* U.S. Geological Survey, Reston, Va.

*Expertise Needed.* Geology, hydrology.

*Mitigation Procedures*

Maintaining wetland storage and base flow functions involves design considerations that avoid channel and culvert designs that rapidly drain wetland waters. Base flows require culvert placement that will support flows during low water periods.

**Damping of Tidal Variations**

Tidal effects in coastal wetlands are often pronounced. These effects can also be observed well upstream in estuarine areas where extensive tidal fresh water wetlands can be found. Tidal patterns influence both water level periodicity and salinity gradients. Wetland plant adaptations to these effects determine the species distribution. Tidal flows are distinguished from other hydrologic phenomena by the fact that the movement is periodically reversed.

*Analytical Methods*

*Baseline Data Needs.* Measurement of tidal flows should include both rate data and maximum and minimum elevations at the point where highway structures would intervene.

*Sampling and Measuring.* Flow rates are determined with stream gauging techniques. Flows must be analyzed for both ebb and flood tide conditions.

*Expertise Needed.* Hydrology, oceanography, wetland plant community ecology.

*Mitigation Procedures*

When structures are placed that will intercept tidal flows, design considerations should account for peak tidal flows in both directions (see also sections under "Change in Periodicity" and "Alteration of Salinity Patterns").

**Alteration of Salinity Patterns**

The distribution of species in coastal wetlands is critically dependent on the salinity gradient of the water supply. This gradient is, in turn, dependent on tidal forces, freshwater input, circulatory patterns, and the morphological characteristics of the site. Structures which interfere with the natural mixing of fresh and salt water can cause dramatic shifts in habitat and species composition in coastal wetland areas. Because detritus export from coastal wetlands may be extremely important to estuarine food chains, impacts from coastal wetland alterations may be experienced far from the immediate site.

*Analytical Methods*

*Baseline Data Needs.* In determining the nature of existing salinity gradients it is necessary, in most cases, to consider tidal effects that may continuously alter the freshwater and salt-water mix. Vegetation analysis will often give a general picture of existing conditions, but more precise maps are produced through periodic measurement of the specific conductance of selected areas of the site.

*Sampling and Measuring.* Salinity is measured by determining the specific conductance of the sample with a conductance meter.

*Expertise Needed.* Oceanography, ecology, wetland plant community ecology.

*Mitigation Procedures*

It is extremely important in coastal areas that highway design avoid interference with tidal and fresh-water flows. Adequate culverting to maintain existing flow patterns is critical if the integrity of the wetland is to be maintained.

**Turbidity**

Excess suspended solids are a by-product of practically all phases of highway construction, maintenance, and use. They include both inorganic and organic materials, which vary in size from minute clay particles to materials the size of rocks. Turbidity is known to have adverse effects on aquatic primary productivity (see Tables 2 and 3), feeding, and reproductive success of higher organisms, and upstream migration and spawning in certain species. These effects may be of critical importance to the entire aquatic community and, when prolonged turbidity is experienced, significant changes in wetland function and class structure can be expected.

*Analytical Methods*

*Baseline Data Needs.* Natural waters experience various levels of turbidity depending on such things as plankton populations and variations in runoff due to local climatic conditions. Normal turbidity levels should be determined as a basis for assessing the impact of expected additional sediment loads.

*Sampling and Measuring.* Turbidity is commonly measured by use of a nephelometer and is expressed in nephelometric turbidity units. A nephelometer measures the intensity of scattered light at right angles to an incident beam. The more turbidity the sample has the more light it will scatter.

TABLE 2

AQUATIC AND MARSH PLANT SPECIES APPARENTLY INTOLERANT OF TURBIDITY, POLLUTION, AND RELATED FACTORS (COMPILED FROM REFS. 7-13)

| Submersed and Floating Species | Emersed Species |
|---|---|
| Megalodonta beckii (water marigold) | Carex aquatilis (sedge) |
| Myriophyllum alterniflorum (watermilfoil) | Equisetum fluviatile (horsetail) |
| Najas flexilis (naiad) | Hibiscus militaris (marsh mallow) |
| Najas gracillima (naiad) | Justicia americana (water willow) |
| Najas guadalupensis (naiad) | Lippia lanceolata (fog fruit) |
| Potamogeton amplifolius (pondweeds) | Rumex verticillatus (swamp dock) |
| Potamogeton filiformis (pondweeds) | Sagittaria rigida (arrowhead) |
| Potamogeton friesii (pondweeds) | Saururus cernuus (lizard's tail) |
| Potamogeton gramineus (pondweeds) | Scirpus americanus (3-square sedge, bulrush) |
| Potamogeton praelongus (pondweeds) | Scirpus expansus (bulrush) |
| Potamogeton richardsonii (pondweeds) | |
| Potamogeton zonsteriformis (pondweeds) | |

TABLE 3

AQUATIC AND MARSH PLANT SPECIES APPARENTLY TOLERANT OF TURBIDITY, MODERATE POLLUTION, AND RELATED FACTORS (COMPILED FROM REFS. 7-13)

| Submersed and Floating Species | Emersed Species |
|---|---|
| Alisma plantago-aquatics (waterplantain) | Botumus umbellatus (flowering rush) |
| Ceratophyllum demersum (hornwort) | Polygonum hydropiper (smartweed) |
| Elodea spp. (water weed) | Polygonum lapathifolium (smartweed) |
| Heteranthera dubia (mud plantain) | Polygonum pennsylvanicum (smartweed) |
| Lemna minor (duckweed) | Polygonum punctatum (smartweed) |
| Myriophyllum exalbescens (water milfoil) | Sagittaria latifolia (arrowhead) |
| Najas minor (naiad) | Sagittaria sagittifolia (arrowhead) |
| Nuphar lutes (cow lily, spatter dock) | Sparganium eurycarpum (burreed) |
| Potamogeton crispus (crisp pondweed) | Typha angustifolia (narrow-leaved cattail) |
| Potamogeton pectinatus (sago pondweed) | Typha latifolia (common cattail) |
| Riccia fluitans (crystalwort, liverwort) | |
| Ricciocarpus natans (crystalwort, liverwort) | |
| Spirodela polyrhiza (duckweed, water flaxseed) | |
| Utricularia vulgaris (bladderwort) | |
| Vallisneria americana (eelgrass) | |
| Zannichellia palustris (horned pondweed) | |

*Data Sources.* Sawyer, C. N., and McCarty, P. L., *Chemistry for Environmental Engineering,* McGraw-Hill, New York, N.Y. (1978). State of New York, Department of Transportation, "Construction Guidelines for Temporary Erosion Controls" (1974).

*Expertise Needed.* Hydrology, limnology.

*Mitigation Procedures*

Control of turbidity resulting from highway construction, maintenance, and use is achieved through the control of erosion and highway runoff. Both temporary and permanent control measures are necessary to prevent erosive

materials from polluting adjacent wetland sites. In general, the best method of preventing erosion of bare soils is to reestablish vegetation as soon as possible. (For more information, refer to (*19*).)

### Sedimentation

Sedimentation follows, at varied time intervals, the events that place solids in suspension. Sediments deposited on bottom flora and fauna can have severe impacts on their survival and productivity.

Attached algae is eliminated through smothering, and vascular plant productivity can be reduced significantly as a result of interference with the free exchange of gases (oxygen and carbon dioxide). Sedimentation can also change the physical characteristics of the bottom habitat, which, in turn, may have dramatic effects on the survival of benthic fauna. For instance, only a small amount of sand or silt sifting in among bottom gravel eliminates much of the area suitable for the attachment or hiding of aquatic insects and drastically reduces the total production in these forms. When extensive, sedimentation can actually eliminate aquatic habitats by filling shallows and promoting drier conditions.

*Analytical Methods*

*Baseline Data Needs.* Baseline data should include estimates of annual solids deposition within the wetland. Data should be collected during the spring freshet and during times of low flow. Sedimentation rates can then be determined. By predicting the soil loss both during construction and while the highway is in operation, it is possible to estimate the percent increase in the rate of solids deposition the highway will cause. A judgment must be made as to whether the system can tolerate this percent increase.

*Sampling and Measuring.* Settleable solids are measured with an Imhoff cone. The results are expressed as milliliters of solids per liter of water.

The influent flow rate must be determined so that the sediment loadfill rate can be determined. If the flow into the area is channelized, measurement can be made with a broad crested wier. Stream gauging techniques can be used if critical flow devices are not suitable.

*Expertise Needed.* Hydrology.

*Mitigation Procedures*

Erosion control practices must be used at the construction site. It may be necessary to pass all runoff from a highway crossing through a sedimentation basin prior to introduction into the wetland.

### Chemical Pollution

The potential for chemical pollution of adjacent wetlands exists at all stages of highway construction, maintenance and use. Contamination from such sources as construction machinery, gasoline and oil, pavement materials, dredge spoil, deicing chemicals, herbicides, automotive exhaust, and brake linings may occur. The severity of the impact of these substances on a wetland habitat may be moderated by water regime, precipitation patterns, topography, and the sensitivity of the particular organisms to the chemical concerned. Maintaining water quality in highway-associated wetlands should be considered a major priority of both the design and construction of the roadway.

*Analytical Methods*

*Baseline Data Needs.* Some of the more common water quality parameters that are measured when establishing an environmental baseline are described in the following. Table 4 is a listing of water quality characteristics. The items selected for monitoring will be dependent on the anticipated changes in the environment due to a new highway project. A detailed explanation of the laboratory and field procedures involved in the proper analyzing of a water sample is available in the FHWA *Water Quality Manual* (see also (*14*)).

*Sampling and Measuring.* The following describes the means employed for sampling and measuring water quality:

1. *Standards*—The application of standards in inventorying a particular area is to evaluate the current, or baseline condition. The same standards can be used later to predict changes in the base conditions as a result of the proposed action, and still later to measure the actual changes in the base conditions as a result of the action. Inventories may also point up the suitability, or lack thereof, of particular areas for serving various purposes (e.g., wildlife habitat, recreational uses, construction activities, etc.).

2. *Water quality survey*—Potential water quality impacts must be considered based on a clear delineation of various water quality characteristics. In the establishment of a water monitoring program, sites must be selected for col-

TABLE 4
WATER QUALITY CHARACTERISTICS

| | |
|---|---|
| Turbidity | Conductivity |
| Suspended sediment | Biochemical oxygen demand |
| Bed material analysis | Chemical oxygen demand |
| Streamflow | Dissolved oxygen |
| Temperature | Coliform count (MPN) |
| Toxicity | Total hardness |
| Pesticides | Total dissolved solids |
| Metal ion content | Nutrients (biostimulation) |
| Chloride ion | Phenols |
| Sulfate | Flouride ion |
| Nitrate | pH |
| Phosphate | Lead |
| Biological organisms | Alkalinity |

lecting water samples that will represent adequately the actual water quality characteristics of the existing wetland. The procedures and essential elements of such a study are covered in detail in the *Water Quality Manual,* Vol. 1, (Section III, "Water Quality Survey"). The manual recommends that before the selection of sites, a reconnaissance of the affected area be performed. Topographic maps delineating areas in sufficient detail to identify important land features such as tributaries, upstream watersheds, water barriers, landslides, vegetation, and soil type (erosion potential) will be useful for this survey. In addition, any hydrologic information and existing hydrologic instrumentation available on a watershed should be obtained and used.

An essential step in a water quality survey is the proper selection of the sampling sites. The Manual recommends selection of a site that can be used for both low and high flows and can be used for a long-term period, including post-construction if necessary. Changing sampling sites during the course of a study is not recommended because this will generally lead to varying results.

3. *Measured water quality parameters*—The following is a list of potential pollutants that may be monitored in a water quality survey in order to assess the environmental impact. The list is not meant to be complete, but it does provide an indication of the areas that should be considered when establishing a monitoring program.

a. Chemical Pollution
   (1) pesticides, herbicides, and other toxic substances
   (2) oil, grease, fuels, lead, etc.
   (3) mineral leachates from newly exposed slopes
   (4) accidental chemical spills on highway
   (5) leachates from disposal or storage areas
   (6) residue (ash) from fires within right-of-way
   (7) runoff from deicing chemicals
   (8) nutrients from erosion of slopes
   (9) fertilizer washoff
b. Biological Pollution
   (1) organics from diseased or destroyed vegetation
   (2) contaminants from sewage facilities at rest stops
c. Groundwater
   (1) leachates
   (2) recharge and ponds
   (3) wells

4. *Collection and preservation of samples*—The result of any test for water quality can be no better than the quality of the sample on which it was performed. Since the testing procedure involves analysis of a comparatively small sample, and the results of the tests will be used to infer certain characteristics of a large body of water, it is important that the sample be of high quality and truly representative of the area in which it is taken at frequent enough intervals to ensure reproducibility of the results. Care must be taken to prevent any significant changes in the sample while enroute to the testing laboratory. It is usually best to have the testing and sampling personnel confer in advance about the purpose of the testing, so that the most appropriate procedure will result in data that can be applied only to the sample at the time of testing, but not with any certainty to the larger body of water from which it came.

The need for clean containers when sampling is obvious. Before taking a sample it is desirable to rinse the sample bottle several times in the water to be sampled. In order to acquire representative data, it may be necessary to take samples over a large area. Self-contained samplers that can automatically take a composite sample over a preset time period are available. At times the analysis of consecutive samples may be desirable. The sampling of a drainage outfall is a situation where a number of discrete samples is preferred over a composite sample. In this way the effect of the "first flush" of material washed from the pavement can be more readily determined.

Turbidity can distort water quality test results. The method chosen to remove turbidity prior to testing, and the physical and chemical changes brought about because of aeration or storage can also affect test results. Some turbidity can be allowed if it is known that its presence will not interfere with gravimetric or volumetric testing. Turbidity can be corrected for in colorimetric tests, where its effect on test results can be extreme.

Accurate records of sampling should be kept, identifying each bottle, the date, time, exact location of sample, the water temperature, and any other information that may be needed at a later date. Sampling points should also be suitably marked on maps and in the field with stakes or buoys so they may be identified without reliance on memory or personal guidance.

Samples taken from a river or stream may vary with depth, flow, and distance from shore. If possible, the sampling strategy should take these factors into effect. If only one sample is collected, it is best to take it at midstream and middepth.

Samples from lakes, reservoirs, marshes, and other static bodies of water vary with the season, rainfall, runoff, and wind. The choice of sampling methodology will depend on local factors and the purpose of the investigation. A sample taken at a specific place and time can only truly represent the conditions that existed at that place and time. If conditions are known to remain constant with either time or location, it may be safe to infer that the sample represents the characteristics of a larger area or a longer time span.

If sources are known to vary with time, grab samples are often helpful when taken at specific time intervals. A mixture of grab samples is known as a composite sample. Samples can be composited with respect to time or flow rate. They are most useful when the average concentration is of interest. This type of sample results in a considerable saving in testing expense. The standard time interval for a composite sample is 24 hours. However, certain conditions may dictate other intervals.

Composite samples cannot be used to measure characteristics subject to change during storage. Dissolved gases, soluble sulfides, temperature, and pH are examples of such characteristics. It is essential to demonstrate that the characteristic being tested does not change during storage. If samples are taken from various locations and mixed, the resulting mixture is called an integrated sample. Such a sample is desirable when working with streams and rivers, whose composition varies across its width and with depth.

Three or more samples may be desirable at each section, with samples taken at the midpoints of equal cross-sectional areas. Integrated samples are not appropriate for lakes and ponds, whose characteristics vary with both vertical and horizontal location. Since local rather than average conditions are of greater importance, samples should be analyzed separately.

Because complete stabilization of a sample cannot be achieved, an effort must be made to retard the chemical and biological changes that occur once the sample is removed. Some test results are more likely to be affected by storage than others. Generally speaking, the shorter the time interval between collection and analysis, the more reliable the results. Certain parameters, such as temperature, must be measured immediately in the field. If analysis cannot be performed in a very short time, preservation methods can be applied. Elapsed time between collection and testing should be included in the statement of analysis results.

Storage at 4 C in the absence of light is the best way to preserve a sample for analysis the next day. Chemical additives can be used if it is known that they do not interfere with the results. Table 5 summarizes sample and handling techniques (*15*).

5. *Biochemical oxygen demand*—The biochemical oxygen demand (BOD) test is an empirical bioassay in which standardized laboratory procedures are used to determine the relative oxygen requirements of various waters. It is of very limited value in determining the actual oxygen demand in natural waters. To perform the BOD test properly, temperature, pH, time, dilution, water, light, and seed material all must be controlled. Although this is possible, it leads to a very long, tedious test, that may not be representative of natural conditions. The test's value lies in comparing different samples with each other, and not in determining absolute values. For this reason, the ASTM has discontinued without replacement this test procedure, and a warning of its shortcomings is contained in *Standard Methods for the Examination of Water and Wastewater* (*15*).

6. *Dissolved oxygen*—Dissolved oxygen (DO) levels in water depend on the physical, chemical, and biological activities occurring in the water. It is a pollution indicator and measures a parameter necessary for life in the water.

Two methods are used for DO analysis. They are the Winkler method and the electrometric method. The Winkler, or iodiometric, method is the most accurate and precise method of DO measurement. Iodine is liberated in an amount equivalent to the DO concentration. The sample is titrated with thiosulfate using a starch indicator to determine the amount of iodine present. The electrometric method utilizes a probe to measure molecular oxygen. Two charged plates are put in contact with an electrolyte and separated with a membrane. When placed in a sample, the current flow is proportional to the DO.

7. *Grease and oil*—The term grease applies to a wide variety of organic substances that are removed from aqueous solution or suspension by a hexane extraction method. Hydrocarbons, esters, oils, fats, waxes, and high-molecular-weight fatty acids are the major materials dissolved by hexane. Hexane has been chosen as a good solvent for all the materials that are normally associated with the terms grease or oil and has a minimum solvent power for other organic compounds. The method does not measure very low molecular weight hydrocarbons such as gasoline.

Relatively clean water, as might be expected in a wetland, is not routinely checked for oil or grease unless contamination is suspected. Special distillation measures or infrared analysis must be used to measure the low molecular weight fraction.

8. *Metals*—The concentration of various metals (mercury, iron, etc.) in a solution may be determined by methods described in the latest edition of *Standard Methods for the Examination of Water and Wastewater* (*15*). For example, lead is measured with the dithizone method. Dithizone is dissolved in carbon tetrachloride and mixed with the sample. The lead is extracted from the sample by the carbon tetrachloride and reacts with the dithizone to form a metal complex red in color. The intensity of the color indicates the lead concentration.

9. *Temperature*—Temperature measurements may be made with any good grade of mercury-filled centigrade thermometer certified by the National Bureau of Standards. The temperature of the water at the sampling point should be expressed to the nearest degree centigrade, or closer if more precise data are required. The thermometer must be immersed in the sample long enough for stabilization.

10. *Total organic contaminants*—The total organic carbon test is used to measure the concentration of organic contaminants. It is a more direct measure of the organic chemical content of water than other methods, such as BOD. The basic procedure involves injecting a very small amount of homogenized sample into a stream of heated oxygen. The water is vaporized, and organic matter is oxidized to carbon dioxide. The carbon dioxide is measured with a nondispersive type infrared analyzer. The result is the total carbon concentration. This test can be run in a total organic carbon analyzer, which is a package unit that reads out the concentration value directly when the sample is injected.

11. *pH*—The pH of a solution is a measure of its hydrogen ion activity. The pH is expressed as the base 10 logarithm of the reciprocal of the hydrogen ion activity in moles/liter at a given temperature. The pH scale ranges from 0, very acidic, to 14, very alkaline, with 7 being neutral at 25 C. The pH of most natural waters lies within the range of 4 to 9. Most waters are slightly alkaline because of the carbonate and bicarbonate presence.

The pH can be measured colorimetrically or electrometrically. Colorimetric measurement involves the use of indicators that change color at a certain pH value. For several reasons this method is suited only for rough estimates. Interferences such as color, turbidity, salinity, colloidal matter, and others induce error. The indicators deteriorate with time, and individual indicators are not good over the entire pH range.

Electrometrical measurement utilizes an electrical pH meter with a glass and reference electrode. The pH can be found by measuring the electromotive force between the electrodes when immersed in an aqueous solution. Commercial meters are calibrated to read pH directly. These units are simple and convenient to use. At pH less than

TABLE 5

SUMMARY OF SPECIAL SAMPLING OR SAMPLE HANDLING REQUIREMENTS (SOURCE: REF. 15)

| Determination | Container† | Minimum Sample Size, ml | Storage and/or Preservation |
|---|---|---|---|
| Acidity | P, G(B) | 100 | 24 hr; refrigerate |
| Alkalinity | P, G(B) | 200 | 24 hr; refrigerate |
| BOD | P, G | 1,000 | 6 hr; refrigerate |
| Boron | P | 100 | — |
| Carbon, organic, total | G(brown) | 100 | Analyze as soon as possible, refrigerate or add HCl to pH ≤ 2 |
| Carbon dioxide | P, G | 100 | Analyze immediately |
| COD | P, G | 100 | Analyze as soon as possible; add $H_2SO_4$ to pH ≤ 2 |
| Chlorine dioxide | P, G | 500 | Analyze immediately |
| Chlorine, residual | P, G | 500 | Analyze immediately |
| Chlorophyll | P, G | 500 | 30 days in dark; freeze |
| Color | G | 500 | — |
| Cyanide | P, G | 500 | 24 hr; add NaOH to pH 12; refrigerate |
| Fluoride | P | 300 | — |
| Grease and oil | G, wide-mouth, calibrated | 1,000 | Add HCl to pH ≤ 2 |
| Iodine | P, G | 500 | Analyze immediately |
| Metals | P, G | — | For dissolved metals separate by filtration immediately; add 5 ml conc $HNO_3$/l |
| Nitrogen | | | |
| Ammonia | P, G | 500 | Analyze as soon as possible; add 0.8 ml conc $H_2SO_4$/l; refrigerate |
| Nitrate | P, G | 100 | Analyze as soon as possible; add 0.8 ml conc $H_2SO_4$/l; refrigerate |
| Nitrite | P, G | 100 | Analyze as soon as possible; add 40 mg $HgCl_2$/l and refrigerate or freeze at −20 C |
| Organic | P, G | 500 | Analyze as soon as possible; refrigerate or add 0.8 ml conc $H_2SO_4$/l |
| Odor | G | 500 | Analyze as soon as possible; refrigerate |
| Oxygen, dissolved | G, BOD bottle | 300 | Analyze immediately |
| Ozone | G | 1,000 | Analyze immediately |
| Pesticides (organic) | G(S) | — | — |
| pH | P, G(B) | — | — |
| Phenol | G | 500 | 24 hr; add $H_3PO_4$ to pH ≤ 4.0 and 1 g $CuSO_4 \cdot 5H_2O$/l; refrigerate |
| Phosphate | G(A) | 100 | For dissolved phosphates separate by filtration immediately; freeze at ≤ −10 C and/or add 40 mg $HgCl_2$/l |
| Residue | P, G(B) | — | — |
| Salinity | G, wax seal | 240 | Analyze immediately or use wax seal |
| Silica | P | — | — |
| Sludge digester gas | G, gas bottle | — | — |
| Sulfate | P, G | — | Refrigerate |
| Sulfide | P, G | 100 | Add 4 drops 2N zinc acetate/100 ml |
| Sulfite | P, G | — | Analyze immediately |
| Taste | G | 500 | Analyze as soon as possible; refrigerate |
| Temperature | — | — | Analyze immediately |
| Turbidity | P, G | — | Analyze same day; store in dark for up to 24 hr |

1.0, there is a so-called acid error and at pH greater than 10.0, a sodium ion error. These pH ranges are not found in natural waters so this would not cause a problem.

*Data Sources.* Federal Highway Administration, *Water Quality Manual,* Vols. 1-4, Washington, D.C. (1972). American Public Health Association, American Watershed Association, Water Pollution Control Federation, *Standard Methods for the Examination of Water and Wastewater, 14th Edition,* Washington, D.C. (1975).

**Change in Temperature Patterns**

Subtle changes in the thermal regime of aquatic ecosystems are possible as a result of highway construction. Temperature impacts arise as a result of hydrologic impacts, particularly impoundment or drainage, and change in periodicity. Any increase in the amount of exposed open water increases the thermal input, elevating water temperatures—those effects which are transferred downstream. In summer, this is especially critical because extreme high temperatures are reached and conditions are most severe for aquatic life.

This impact becomes important where species are presently existing at the extremes of their thermal tolerance range. Alteration of the mean seasonal temperatures and the magnitude of fluctuations would eliminate species as these thresholds are surpassed. The distribution of freshwater fishes and certain estuarine shellfish has been affected by temperature changes of less than 5 degrees. Temperature affects these organisms principally through its effect on water chemistry.

*Analytical Methods*

*Baseline Data Needs.* Baseline data should be collected to determine mean monthly temperatures, and the range and extremes of daily temperature fluctuations. Ideally, a record of annual thermal patterns for several recent years is recommended. This would prevent a bias that might be introduced by a single sampling in a year of unusual hydrologic patterns. Data on thermal patterns at hydrologic inlets, outlets, and basins are needed.

*Sampling and Measuring.* A record of temperatures throughout the year can be made by portable recording thermometers. Monitoring stations should be established at all inlets, outlets, and open water basins.

*Data Sources.* Fisheries managers may have some data available, but it is recommended that a sampling program be designed specifically for the impact assessment.

*Expertise Needed.* Limnology.

*Mitigation Procedures*

Impacts on temperature in aquatic ecosystems can be minimized in various ways. Minimizing all surface hydrologic impacts will avoid disruption of thermal patterns. In addition, unnecessary removal of vegetative cover often contributes to elevated water temperatures and should be prevented.

Where unavoidable temperature changes do occur, mitigation to prevent downstream effects is possible by constructing the outlet to allow for release of water from various depths. The temperature of water flowing out of an impoundment can be regulated crudely because water is stratified thermally with cooler temperatures found at increasing depths.

**BIOLOGICAL EFFECTS**

- Change in Wetland Size
- Change in Wetland Plant Species Composition
- Change in Wetland Class Composition
- Change in Wetland Primary Productivity
- Change in Wetland Secondary Productivity.
- Sudden Mortality of Aquatic Species
- Barrier to Faunal Movements
- Encouragement of Beaver Activity
- Rare and Endangered Species

The structure of this section of the manual parallels that of the physical impacts section, except that, here, the mitigation notations are omitted in keeping with the intent of this manual that ecological effetcs can and should be mitigated at the physical impacts level. Mitigation for the alteration of subjective ecological values requires an evaluation by trained ecologists and environmental planners, whose expertise is most valuable in the route location and design decision-making process. For the purposes of this manual, it should suffice to remind the highway planner that many localities now require compensatory mitigation for the loss of ecological value by purchase and protection of additional habitat.

The essence of an environmental impact assessment for a given wetland is the projection of the ecological effects of the proposed highway in that particular wetland. The purpose of this section is to delineate the potential biological responses of wetlands to the physical impacts of highway construction. It is impossible to determine in the abstract which specific biota will be affected, to what degree an ecological response may occur, or to impose an evaluation of the significance of these possible impacts in any situation. Instead, categories of biological effects have been defined for practical purposes, setting aside the interrelatedness of ecological phenomena, but providing information that will be useful to the impact assessor in considering ecological effects in a systematic way.

Prior to discussion of the biological effects, an overview is provided of the basic ecological principles and the sensitivity of wetland ecosystems to highway-related impacts, as follows.

Ecology is defined as the organization of relations that exist between organisms and their environment. The ecology of wetlands focuses on an assemblage of organisms that typically inhabit these wet environments.

An ecosystem is a major ecological unit, having both structure and function. Aquatic ecosystems are characterized by various combinations of water depth and movement, suspended and dissolved material, proximity to upland areas, and many other features. Since aquatic organisms are specialized to survive and reproduce within a limited range of environmental conditions, each type of wetland has a unique composition of plants and animals.

The primary productivity of a wetland is that amount of solar energy (sunlight) which is used by green plants to

produce carbohydrates (photosynthesis), much of which is stored as plant biomass (growth). With few exceptions, all other forms of life are limited by the availability of plant tissue as a food base. The energy stored by plants is passed along through the community in a series of steps known as a food chain. An example of a food chain is as follows: marsh vegetation is eaten by a grasshopper; the grasshopper is consumed by a shrew; and the shrew is consumed by a marsh hawk. After its death, the marsh hawk will serve as food for decomposer microorganisms. At each step in a food chain, a considerable portion of the potential energy is lost as heat, limiting the number of steps in any food chain to four or five. Because few organisms subsist entirely on another, food chains become interwoven to form a food web (see Fig. 20).

As ecosystems mature, they develop a composition of species which is best adapted for long-term occupation of the site. The final vegetative form ("climax") of a wetland ecosystem is dependent on various regional (climate, elevation, etc.) and local (hydrology, soils, etc.) influences, and ranges from emergent marsh to a mature woodland. The structural complexity of an ecosystem is often directly related to the number of species of plants and animals. More diverse habitats probably result where the occurrence of regular periodic environmental phenomena favors the eventual utilization of all niches of the ecosystem by a diverse community of organisms. Irregular or unpredictable alterations or disturbances in the environment represent continual shifts in selective pressures on the populations. If a disturbance is maintained, those organisms that cannot adjust disappear, leaving vacant niches. Subsequently, environments which undergo sudden or irregular changes produce less diverse ecosystems. This instability is not to be confused with the concept of periodic environmental phenomena, since many organisms have successfully adapted to a widely fluctuating environment, as long as the regularity of events is not altered. It is often suggested that more mature and, therefore, more variegated ecosystems are better able to withstand temporary unstable conditions because only a small proportion of the resident species may be adversely affected.

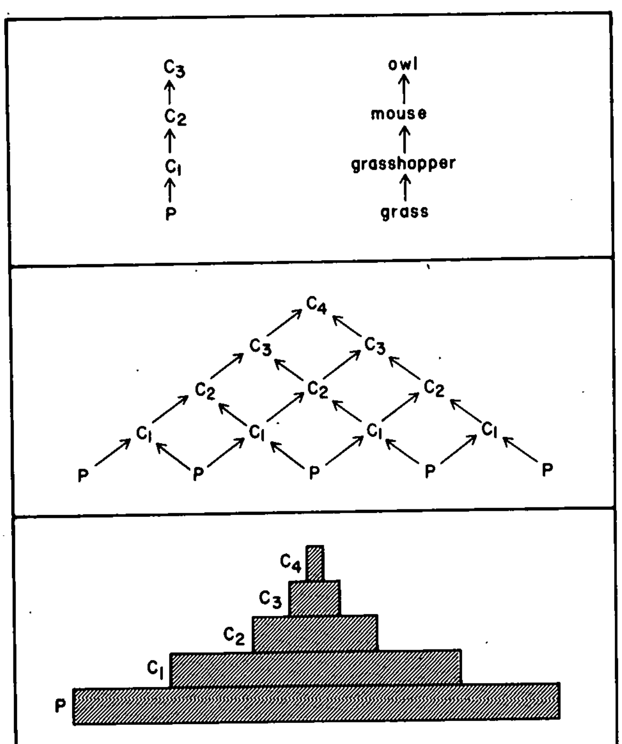



*Figure 20. Representations of nutrient flow within natural communities. The top figure shows a simple food chain with one species at each level. The middle figure represents a food web with numerous species at the lower levels. The bottom figure is a food pyramid showing the amount of living material or energy bound at each level. The symbol P represents producers (plants); C, consumers (animals and decomposing microbes), with the level number represented by a subscript.*

The sensitivity of plants and animals to changes in their environment is derived from their adaptation to a limited range of environmental conditions. Within these limits, they are able to survive and reproduce, perpetuating their populations until conditions change. Because of this specialization, a different assortment of organisms may be favored as the wetland environment is changed.

The most obvious and far reaching impact of a highway facility in a wetland is the alteration of hydrologic patterns. Although documentation of such effects is limited, on-site investigations of wetland-highway crossings illustrate the importance of this impact when planning highways. Route location, orientation of the structure to direction of water flow, and accommodation of surface and subsurface flows are important factors that determine the extent of hydrologic disruption. The effects of permanent impact are especially important; temporary disruptions are often followed by a recovery to preconstruction ecological conditions.

The quality of wetland waters is also subject to severe disturbances from highway construction. Water quality may suffer from extremely adverse local and/or short-term effects; widespread or long-term effects on water quality are less common and generally poorly understood. The predominance of aquatic-based food chains in wetlands implies that water quality changes have great potential for impact on wetland productivity and diversity.

Suspended solids from highway construction represent a significant threat to aquatic life by causing the wetland to become inhospitable for most organisms. The severity of problems caused by suspended solids generally decreases with distance from the roadway, and with time after construction is completed. Long-term effects may result when mitigation procedures are not implemented, or if heavy sedimentation or scouring alters the depth or topography of the basin.

Potentially long-term chemical alterations of wetland waters can also occur. Deicing salts and a variety of heavy metals and hydrocarbons can enter wetlands from the highway environment, but the ecological impact on the wetland community from such chemical inputs has not been well evaluated.

Wetlands are also subject to ecological impacts when the highway operates as an obstruction to animal movements.

Movements of many faunal species are affected by such physical barriers. Wetland mammals such as beaver, muskrat, and deer normally disperse or migrate across considerable distances to reach uncolonized or required seasonal habitats; fish and other aquatic organisms migrate considerable distances and disperse over wide areas to complete their life cycles. These movements are necessary mechanisms of population survival and productivity; therefore, highways in the wetland environment should be planned to minimize disruption and dislocation of such migratory movements.

Finally, it is also important to recognize that most rare and endangered wetland species are especially sensitive to wetland disruption, and that even temporary impacts may lead to their extinction. In situations where these vulnerable species occur, construction of a highway facility should be avoided if at all possible.

The following sections describe the nature of each of the biological effects that appear in the horizontal column of the matrix. As in the preceding sections dealing with physical impacts, there will be found information regarding baseline data needs, data sources, analytical methods, and expertise required. There is no subsection, however, dealing with mitigation. The authors of this manual believe that the most effective mitigation procedures are those that reduce the physical causes of the biological changes.

### Change in Wetland Size

Wetland boundaries do not exist as discrete edges, but are typically zones of transition with upland, making them difficult to define and establish. However, defined changes in mean levels and periodicity of water extend throughout a wetland, and will shift these border zones so that areal changes are apparent. The results of elevated and lowered water levels are generally obvious, being manifested as an increase and decrease in wetland size, respectively. Changes in periodicity are likely to produce only minor shifts in the edge location, particularly where wetlands are defined on the basis of vegetative composition. Stabilization of normally fluctuating marsh water levels may encourage a marginal invasion by upland plant species, which would be interpreted as a decrease in wetland size.

#### *Analytical Methods*

*Baseline Data Needs.* Baseline information on wetland size requires an accurate base map which discriminates the wetland boundary by specific vegetative and/or hydrologic elements. Base maps should be precise enough to detect areal changes of 5 percent or less (in larger wetlands).

*Sampling and Measuring.* Determination of wetland size is best obtained from remote sensing imagery. Interpretation of wetland size from remotely sensed imagery is quite precise and accurate, given a wetland definition that is based on vegetation and/or hydrology. A distinct advantage of using maps from aerial imagery is that the procedure can be repeated to accommodate periodic monitoring of wetland size in addition to many other parameters.

Panchromatic (black/white) aerial photography is least expensive, but must be interpreted by a trained professional with additional familiarity with local wetlands and their vegetation. Color IR (infrared) and black/white IR photography have been used for many wetland inventories because of the enhanced detection of moisture regimes and water levels. More sophisticated imagery, such as multispectral photography, provides greater potential for interpretation of vegetative associations and moisture regimes, but is more expensive and must be often interpreted by automated methods.

Determination of wetland size from ground surveys alone, or from topographic and/or soil surveys, is not recommended because of the potential for large error and time and cost inefficiency. Also, these methods do not lend themselves to continuous monitoring programs, as is desirable for ecological impact studies.

*Data Sources.* Currently, the U.S. Fish and Wildlife Service is engaged in a national wetlands inventory, and it appears that the results will not be available for at least one or two years. Several states have already completed such inventories from aerial surveys. The highway planner should refer to "Existing State and Local Wetland Surveys" (*17*) to determine the status of the respective state's wetland mapping program and for the source of any existing maps.

If these formal inventories are incomplete, commercial firms can be contacted to produce and interpret low altitude aerial photography. Where large wetland areas are affected, excellent high altitude imagery of the whole United States is available from satellites and other federal agency remote sensing programs. For a complete listing of products available for a given location (by topographic coordinates), the Earth Resources Observation Service should be contacted at:

User Services Unit
EROS Data Center
Sioux Falls, South Dakota 57198

*Expertise Needed.* Aerial photogrammetry, synecology.

### Change in Wetland Plant Species Composition

The specific assemblage of plants which inhabit a wetland is influenced to a large degree by environmental variables that are affected by highway construction. Even apparently minor hydrologic or water quality disturbances may shift the balance to some significantly different vegetative community. Various aspects of the plant species composition may be altered in response to physical impacts of highways. Three categories of biological effects can be recognized as changes in plant species composition: change in wetland class composition, change in wetland primary productivity, and change in plant species diversity.

The most visible form of altered plant species composition occurs when a redistribution of vegetative life forms is produced. This topic is discussed as a distinct biological effect in the next section ("Change in Wetland Class Composition"). Less obvious plant species changes may have equally significant implications for the wetland ecosystem. Included in this are the changes in wetland primary productivity, discussed as a distinct biological effect in a later

section, and change in plant species diversity, discussed in the following.

Plant species diversity is an important component of ecosystem analysis because nearly all other organisms depend on plants for their survival. Most aquatic organisms have relatively specialized food and cover requirements that dictate very rigid plant species/animal species associations. The number of plant species is often a good indicator of the diversity of wetland biota and of environmental stability. The environmental impact assessment should include a determination of plant species diversity for use as a monitor of environmental disturbances.

Vegetative monocultures, such as vast cattail or reedgrass marshes, are considered to be of lower general value to wetland fauna than marshes interspersed with a variety of emergent aquatic plants. However, the same extensive uniform areas may be exceptionally valuable to a limited number of species. This points out the need for a subjective evaluation of ecological value associated with plant species diversity in any situation, a job which must be done by professional biologists familiar with the area.

*Analytical Methods*

*Baseline Data Needs.* Plant species diversity need only be evaluated in rough terms despite the existence of mathematical formulas to calculate species diversity of any community. A list of plant species present—with an assessment of their density in each vegetative zone, the frequency of occurrence, and percent cover—is satisfactory.

*Sampling and Measuring.* Most vegetative analysis investigations are concerned with sampling since it is impractical to measure in detail the vegetation on the entire area. Vegetative sampling normally is done by means of quadrats or simple plots. A discussion of the various considerations in design of a sampling scheme can be found in "Wildlife Management Techniques" (*16*), a manual published by the Wildlife Society. Size, shape, and number of sample plots are known to influence the efficiency and accuracy of the sampling.

*Data Sources.* Occasionally, detailed vegetative studies have been conducted in wetlands, but these can become quickly outdated. Conducting a thorough vegetative analysis for the impact assessment is recommended unless comparable recent data are available.

*Expertise Needed.* Limnology, plant taxonomy, autecology, synecology.

### Change in Wetland Class Composition

The distribution and abundance of wetland classes within a wetland will be referred to as its "wetland class composition." A shift in wetland class composition is a notable community level impact that may result from highway construction. This would nearly always occur in response to altered water levels, and may occur to a lesser degree from changes in periodicity, heavy sedimentation, or excavation and spoil disposal.

Wetland class composition is a major determinant of the wildlife values a wetland affords. Most terrestrial wildlife populations respond to gross structural features of the landscape, particularly life forms of vegetation. Major changes in the class composition of a wetland will induce a fairly predictable redistribution of wildlife species.

*Analytical Methods*

*Baseline Data Needs.* Measuring change in wetland class composition requires a recent (less than 5 years old) map of the wetland, which shows the arrangement of wetland classes within it. In addition, the dominant plant species in each class should be identified. For predicting the effect of water level changes, a map of the microtopography (contours of 1 ft) would be advantageous.

*Sampling and Measuring.* A map of wetland class composition can be prepared from a detailed vegetative cover map of the wetland. Vegetative cover maps, showing life forms of vegetation can be prepared from ordinary aerial photography by a professional interpreter. A limited amount of field observation by a person familiar with the local wetland flora is a practical means of identifying dominant plant species associations within each of the vegetative zones. This information may be used to produce a map of wetland class composition.

In the event that data on the microtopography of a wetland are not available, the distribution of water depths can be crudely interpreted from the existing vegetative distribution. In general, future areas of a given depth should support vegetation similar to that presently found in existing areas of that depth. One should be alert to two problems in this regard; water levels are not constant during the year or from year to year, so that hydrologic data are best if obtained over several years. Also, plant succession is a continual process, and most wetland classes represent early stages in the progression to a more complex structural form. Therefore, impacts of the highway activity should not be confused with natural successional events, and the predicted future of the wetland in either case should recognize that the present wetland may be in a period of significant transition.

*Data Sources.* Currently, the U.S. Fish and Wildlife Service is engaged in a natural wetlands inventory to map and classify wetlands using the interim classification of Wetlands and Aquatic Habitats of Cowardin et al. (*2*). The project will not be complete for several years, but some states have already completed such inventories, and the results are available. The highway planner should refer to "Existing State and Local Wetland Surveys (1965-1975)" (*17*) to determine the status of the respective state's wetland mapping program and for the source of any existing maps.

If these formal inventories do not indicate wetland class distinctions, commercial firms can be contacted to produce and interpret low altitude aerial photography. Where large wetland areas are affected, excellent high altitude imagery of the whole United States is available from satellites and other federal agency remote sensing programs. To obtain a complete listing of products available for a given location (by topographic coordinates), the Earth Resources Observation Service should be contacted at:

User Service Unit
EROS Data Center
Sioux Falls, South Dakota 57198

*Expertise Needed.* Aerial photogrammetry, plant synecology, plant taxonomy, wildlife management.

**Change in Wetland Primary Productivity**

The introduction of a highway into the wetland environment can result in a significant reduction of energy capture by green plants (primary productivity). Generally, the amount of energy fixed by wetland flora is affected by impacts on growth of existing species or by replacement with species of different potential productivity. Water quality impacts are likely to shift wetland productivity without apparent changes in species composition. For example, suspended solids limit primary productivity through reduction in the penetration of sunlight (turbidity) and by acting to precipitate phytoplankton to the bottom. Hydrologic impacts would tend to alter wetland productivity by disturbance of the species composition. The biological effect of plant species changes is qualitative, and usually involves a change in the whole community structure, so that net productivity changes are difficult to evaluate. However, where the altered productivity of existing species is the major effect, quantitative data on the wetland's primary productivity can be used for direct assessment of impacts.

The primary productivity of wetlands is important through its effects on the secondary productivity of the ecosystem and the rate of plant succession. The productivity of animal populations is greatly dependent on the amount of plant material available as food. The rate at which organic matter is produced and accumulated determines the rate of natural succession in wetlands, since water levels are progressively lowered over time. Physical impacts of highway construction that stimulate primary production (such as drainage which improves soil conditions for plant growth) may result in accelerated ecological succession.

Most herbaceous vegetation will respond to permanent physical impacts by substitution of species, whereas water quality or temporary physical disturbances may only reduce the growth of aquatic herbaceous plants. Likewise, algae and phytoplankton are sensitive to water quality impacts, and their productivity and diversity may be severely reduced by placement of a highway across a wetland. Woody vegetation is less capable of immediate shifts in plant species composition, so it is often practical to evaluate altered growth rates that may occur from physical impacts. Any shift in the environmental regime generally imposes conditions that are suboptimal for the presently dominant form. The existing species die back and are gradually replaced by better adapted species. This may include a reversion to earlier wetland successional stages such as open water or an emergent wetland, with a temporarily heavy loss of productivity until the later wetland types are established.

*Analytical Methods*

*Baseline Data Needs.* Assessment of change in primary productivity requires an estimate of the gross or net biomass production per unit of area (e.g., grams dry weight/square meter, pounds of dry weight/acre). This should be accomplished for each of the wetland classes, along with a determination of the net amount of organic material that is annually transported to or from the wetland site.

A quantitative assessment of primary productivity is probably only required when the wetland is known to be of commercial value. Salt marshes often form the energy base for most estuarine food chains supporting economically important fisheries. The productivity of wooded swamps may also be important if timber resources are involved. Impacts on fresh-water fishery resources may be predicted from assessments of altered phytoplankton and submergent vegetation. In general, however, predicted impacts on primary productivity, especially where species changes are occurring, cannot be readily interpreted from existing knowledge.

*Sampling and Measuring.* Primary productivity of herbaceous plants and benthic algae is normally determined on the basis of the standing crop of vegetation. Estimates of primary production by woody plants are usually interpreted from data on height and diameter growth rates, although production of leaves and fruit may be measured. Standing crop is not a useful measure of production of populations that are subject to rapid removal or short turnover, such as phytoplankton. In the latter case, a high standing crop does not necessarily mean that the ecosystem has a high rate of production. A knowledge of the phytoplankton composition at periodic intervals throughout the year should suffice to indicate general impacts on the aquatic community.

Unfortunately, satisfactory measurements of gross primary productivity have not been devised for wetlands which experience a considerable amount of organic matter exportation (e.g., tidal salt marshes). In the absence of such information, baseline data on net productivity must suffice for impact assessment.

*Data Sources.* Data on the primary productivity of wetlands are not generally available. However, estimates of primary productivity for several sites for which data have been gathered are as follows. The variability among these sites underscores the limitations in these data.

Estimates for the total phytosynthetic energy capture are:

1.0 gm/m$^2$/day in Lake Erie in winter;
9.0 gm/m$^2$/day in Lake Erie in summer; and
57.0 gm/m$^2$/day in a polluted Indiana stream in summer.

The rate of gross primary production in eutrophic lakes ranges from about .5 to 5.0 gm/m$^2$/day during favorable growing periods. In larger bodies of water, where the major contributions to primary productivity comes from the activity of phytoplankton, the productivity is comparable to the poorest kinds of terrestrial environments. In contrast, primary production by phytoplankton and macrophytes in wetlands often exceeds all other ecosystems. Conservative estimates of salt marsh productivity have been as high as 2500.0 gm/m$^2$/year.

*Expertise Needed:* Limnology, plant autecology, silvics.

**Change in Wetland Secondary Productivity**

Secondary productivity is the rate at which animal biomass is produced either as growth of individuals or growth of the population (reproduction). Highway construction can affect secondary productivity by altering the quantity of specific habitats (e.g., wetland class composition) or by disrupting the quality (suitability) of existing habitats for their natural fauna. The biological effects of these impacts range from insignificant change in population size to complete extirpation or introduction of species.

Most ecological impacts on fauna result from three aspects of the environmental disturbance; alteration of habitat composition, alteration of the abiotic environment, and food chain disruptions. Major changes in the vegetative community have widespread impacts on wetland fauna, because so many species are adapted to specific life form arrangements. These habitat associations have evolved out of the population's ability to find food and cover in those microenvironments, based on requirements for survival and reproduction. As habitat diversity declines, so does the diversity and productivity of consumer organisms over-all, but with a concentration of productivity by a few species. Such a situation is undesirable biologically, except when management is for a very special interest group.

The impacts of highways on the hydrology and water quality of wetlands have a significant potential for disturbing populations of aquatic and terrestrial fauna, even when vegetative response is minimal. Water often serves as the medium for feeding and travel, so that physical impacts can substantially influence a population's ability to obtain food or accomplish necessary daily or seasonal movements.

Food chain disruptions occur along with the foregoing biological effects, but deserve special recognition to ensure their consideration in the impact assessment. Essentially, this is the effect on animal populations of an altered prey (food) or consumer population. If the predominant food item in an organism's diet, whether plant or animal, is more or less available, the consumer population will respond in some way. There will be a consumer response if the availability of food is altered. If food were limited, the population is expected to be more productive with increased prey levels. As prey populations are reduced, the consumer population will decline in productivity, unless it can shift its diet to other sources. The specialization of species determines its ability to make such dietary changes, with the more general feeders capable of exploiting new prey items to maintain its productivity.

The dominant food chains in various wetlands are generally known, and most invertebrate fauna are comparatively more specialized feeders than are the vertebrates. In addition, any environmental impacts that affect predator habitat availability may result in an indirect effect on prey population productivity. The complexity of food chain disruptions makes quantitative impact predictions nearly impossible.

*Analytical Methods*

*Baseline Data Needs.* Baseline data should include an analysis of each animal population that occurs in the principal food chains of the wetland, or which is a unique or locally uncommon species. The analysis should include determining population size, habitats used, reproductive rates, and normal temporal variations in size (e.g., season to season, year to year). In addition, information on principal food items and predators should be provided.

*Sampling and Measuring.* Assessment of secondary productivity of animal populations involves very thorough field studies on the ecology of each population. Therefore, except where such information is obtainable, it is recommended that the impact assessment be based on size of each population. Sampling should include at least seasonal data gathering, timed during the day to obtain the most information. The size of an animal population may not reflect current productivity, because reproductive rates often vary inversely with population density, but is useful as an indicator of over-all habitat quality for the species.

There are numerous techniques available for estimating actual or relative population size of most groups of wetland fauna, but professional biologists should conduct these and interpret the impacts on the faunal community.

*Data Sources.* The sampling and measuring of animal populations should be designed, completed, and interpreted by professional biologists familiar with the wetland fauna. State wildlife, fishery, and aquatic biologists may also have some information and they can determine what is present by fairly standard procedures of inventory. Private consulting agencies are equally capable of performing the inventory of wetland fauna for the impact assessment.

*Expertise Needed.* Fisheries biology, limnology, wildlife biology.

**Sudden Mortality of Wetland Species**

The creation of temporary but extreme environmental conditions in a wetland often has very substantial effects on the existing biota. Local degradation of water quality by construction activities or chemical applications and spills can induce heavy mortality of aquatic fauna and flora with associated food chain effects. An important concern for sudden mortality of wetland species is the consideration of rare and endangered species, which are vulnerable to extirpation by short-term disturbances. Most other organisms will eventually recover or reinvade the habitats that supported them unless there are additional permanent impacts affecting them. Waterfowl may be subjected to heavy mortality by creation of stagnant shallow water areas where pathogenic bacteria causing diseases such as botulism may be favored and spread elsewhere. Undesirable conditions comparable to this should be avoided as permanent or temporary ecological effects.

In addition to the biological impact of sudden mortality is the aesthetic impact since the death and decay of wetland biota is often obvious to even the untrained observer.

*Analytical Methods*

*Baseline Data Needs.* Assessment of potential sudden mortality effects can be derived from information obtained for predicting impacts on primary and secondary productivity. The impact assessment should identify pre-

dominant plant and animal species, and determine the vulnerability of each to any temporary but extreme environmental impacts that are possible.

*Sampling and Measuring.* In addition to the sampling performed for effects on productivity, periodic observations and sampling for heavy mortality of vulnerable species should be made during the construction phase and immediately following. Afterwards, sudden mortality of species is likely to be recognized by the public in their normal use of the highway and the wetland environment. In the event of a sudden mortality of a population, environmental parameters should be measured to determine the cause.

*Data Sources.* Data sources for assessing sudden mortality of aquatic biota are primarily those employed for assessing secondary productivity, because plant species are less often affected. Observations during and after construction should be performed by the same professional personnel, especially where the predominant fauna are benthic, and would not appear at the surface or shores upon death.

*Expertise Needed.* Applied animal ecology, autecology, fisheries management, limnology.

### Barrier to Faunal Movements

The normal periodic movements of individuals and populations of animal species are often essential for their survival and productivity in all suitable habitats of a wetland. The construction of highways might create barriers to these faunal movements.

The location of highway fills is the principal consideration determining whether certain populations of animals will be affected.

Several aspects of culvert design can have adverse effects on the passage of fish. The most obvious is that of a culvert outfall above the elevation of the lower pool. The free fall of water from the culvert prevents migration. Another type of blockage occurs in a culvert that at first glance appears to be properly designed. Because of the relatively smooth interior of conduits, the velocity of the water may be increased to several times that of the natural channel upstream and downstream. This increased velocity may be intolerable to fish. Also, natural channels provide quiescent resting areas because of the roots and the presence of debris.

Trash racks installed at the upper ends of culverts can sometimes become barriers if not properly maintained. Debris sometimes collects against the trash rack and a small dam forms.

Terrestrial mammals vary in their requirements for travel between habitats. Deer often concentrate in specific wintering areas and undertake regular seasonal movements through established routes of passage. Predatory mammals travel distances following cover type borders. Where feasible, highways should be located so as to avoid crossing borders so as to reduce road-killing of animals. Movements by most bird populations are probably not affected by highway route selection, except that areas near the highway that are heavily used for feeding or resting during migration would pose a great hazard to birds and motorists.

Aquatic fauna also undertake seasonal migrations and daily movements, which are directly affected by the immediate hydrologic and water quality characteristics. Physical impacts of highways may make passage literally impossible, or may present invisible barriers by interference with normal hydrologic and chemical cues which stimulate movements of aquatic fauna.

#### *Analytical Methods*

*Baseline Data Needs.* Determination of effects on faunal movements requires a knowledge of all population movements that involve separated portions of the wetland or that indicate that outward dispersal of young is an important mechanism of population maintenance and growth.

There are several forms of fish migration of which the engineer should be aware. Perhaps, the most important is the spawning run. Certain types of mature fish return to the waters of their birth to deposit eggs and sperm. Some types of these fish die after spawning, while others migrate downstream to return again the next year. Passage during this spawning time is critical. If the adult fish are detained, the young fish will have little chance of survival.

To prevent this type of blockage, the engineer should ascertain the approximate time of the fish run and the swimming capabilities of the species. The migration time can be superimposed on the stream hydrograph to estimate the flow conditions occurring at the critical time. Velocities through the culvert must be limited to that which the fish are capable of swimming against. Since the swawning instinct is compelling, a design velocity of up to 4 m per sec can be used in some circumstances.

Another type of fish migration occurs after the spring freshet when large numbers of fish are swept downstream. After the flood waters recede, the fish return upstream. Their progress is less critical in this case, because a delay waiting for the high flow in a critical spot to recede is not as important as it is in the spawning run. Low flow conditions might be more important in this case.

A third type of migration is that of seeking out larger and deeper water bodies in the colder months. Fish that live in shallow water in the summer must move to warmer water as ice forms in the winter. Movement will occur at times other than peak flow.

The swimming capabilities of fish can be stated in two ways. Burst speed is that speed at which the fish can swim for a few seconds. It ranges from 8 to 12 body lengths per second. Sustained speed is that speed which is possible for extended periods of time (over 10 min). Burst speed is of primary importance in the design of trash racks and fishways, while sustained speed is important in the design of culverts of considerable length.

The downstream pool can cause problems if velocity is too great. The kinetic energy of water exiting the conduit must be dissipated to prevent scour. Continued scour can erode the bed to the point where a drop will occur. Suitable control devices are rip-rap, gabions, log cribs, or masonry stilling basins.

*Sampling and Measuring:* The results of seasonal population estimates along with sampling designed to detect regular movements prior to highway construction should

be used. Information on the ecology of species known to inhabit the area can also be applied to project potential barriers to fauna. This information should be provided by the same professional biologists involved with sampling, measuring, and interpreting effects on secondary productivity, because the two are closely interdependent.

*Data Sources:* The sampling and measuring of faunal movements should be designed, completed, and interpreted by professional biologists familiar with the wetland fauna. State wildlife, fishery, and aquatic biologists may also have some information and they can determine what is present by fairly standard procedures of inventory. Private consulting agencies are equally capable of performing the inventory of wetland fauna for the impact assessment.

*Expertise Needed:* Fisheries management, wildlife management.

#### Encouragement of Beaver Activity

Although natural channels often occur in wetlands, the placement of fills and culverts may create channelized flow where none existed before. Because water movement in channels is more erosive, channel creation may instigate more severe alteration of surface hydrology. Such channels encourage beaver activity.

#### Rare and Endangered Species

The Endangered Species Act of 1973 was passed to provide for the conservation, protection, and propagation of species or subspecies of fish and wildlife that are threatened with extinction or likely to become threatened with extinction. Under this Act, all federal departments and agencies are required to ensure that actions authorized, funded, regulated or administered by them do not jeopardize the continued existence of endangered species or result in destruction or modification of critical habitat of such species

According to the Endangered Species Act, species or subspecies of fish, wildlife, or plant shall be regarded as endangered whenever the continued existence of such, throughout all or a significant portion of its habitat or range, is either presently threatened with extinction or is likely within the foreseeable future to become threatened with extinction because of any of the following factors (as determined by the Secretary of the Interior):

1. The present or threatened destruction, modification or curtailment of its habitat or range.
2. Overutilization for commercial, sporting, scientific, or educational purposes.
3. Disease or predation.
4. Inadequacy of existing regulatory mechanisms.
5. Other natural or man-made factors affecting its continued existence.
6. The status of such species or subspecies is unknown.

The Secretary of the Interior must publish a list of endangered and threatened species in the Federal Register, not less than annually. The list includes scientific and common names of each; an indication of status as endangered, threatened, or unknown; and, in either case, over what portion of its range this condition exists. Protection may be extended to species of very similar appearance. Conversely, limited taking may be allowed if it is clearly shown to cause no damage to the population, or if it involves emergency cases involving human health and safety.

The director, U.S. Fish and Wildlife Service issues a list of endangered and threatened wildlife and plants. An annual publication of this list is required under the Endangered Species Act of 1973 (16 U.S.C. 1531-1543; 87 Stat. 884).

For further information, the following should be contacted:

Associate Director of Federal Assistance
Department of the Interior
Washington, D.C. 20240
(202-343-4646)

CHAPTER THREE

# AN EXAMPLE USE OF THE PROCEDURES

The use of the flow charts and biological effect matrix (Fig. 12 through 19) is illustrated in the following hypothetical example in which four alternative construction procedures for crossing the Swift Marsh Management and Refuge Area are compared in terms of the physical impacts and biological effects that may reasonably be expected to result from the use of each construction procedure. It is assumed that sufficient preliminary design data and information regarding the geophysical and hydrologic features of the site are available from which to determine the significant physical impacts of each alternative. On the basis of these assumptions, the impacts of each construction procedure are traced through the appropriate flow chart and recorded on the biological effect matrix.

For the purposes of this example, Swift Marsh is defined as a narrow-leaved emergent wetland that is fed by groundwater discharge at its northern end (see Fig. 21). Open water is present in the spring and early summer; both sur-

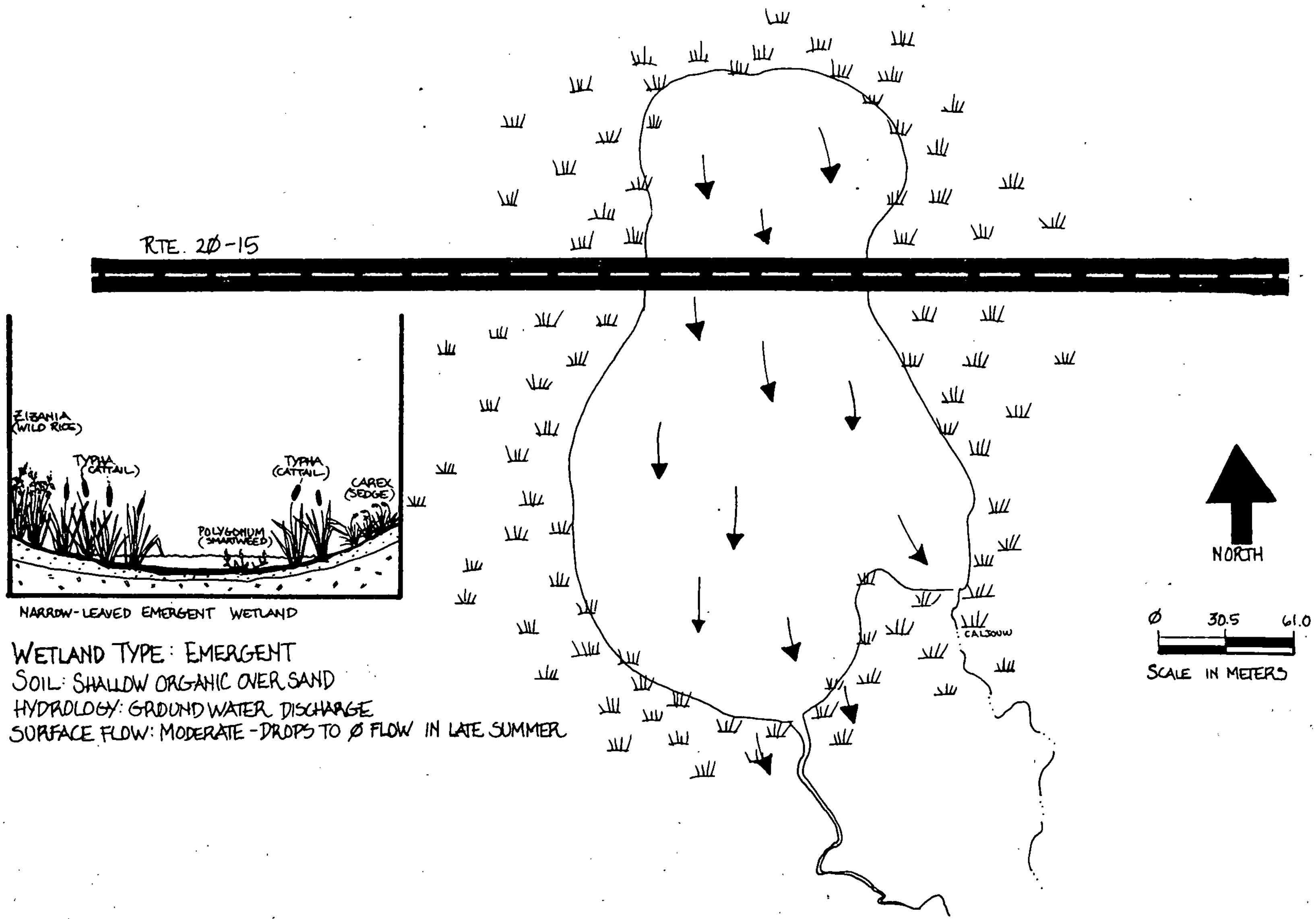



*Figure 21. Swift Marsh Management and Refuge Area.*

face and ground water flow in a southerly direction. During late summer in most years the water table is located below, but within 15 cm of, the bottom of the marsh. The soil profile at the site is shallow organic material over sand. The wetland supports hydrophytes throughout the growing season. Swift Marsh harbors no rare or endangered species, but does provide food and shelter for a variety of migratory waterfowl. It is assumed, for the purposes of this example, that the most feasible crossing of this marsh would be at its narrowest point. There are four alternative methods of construction that might be considered reasonable under the existing conditions. To determine how each construction method would affect the ecology of the wetland the flow charts for physical impacts and biological effect matrix are employed using pertinent site-specific data.

### CONSTRUCTION ALTERNATIVE 1—CONSOLIDATION (FIGS. 22, 23, 24)

As shown in Figure 22 consolidation involves three areas of primary concern: effect on subsurface flow; culvert design; and construction, maintenance, and use. In the Swift Marsh example, blockage of subsurface flow will lead to a significant alteration in the local water table with a concurrent minor effect on mean water level. Construction, maintenance, and use of the facility may lead to a variety of water quality effects, the extent and severity of which will depend primarily on the care with which construction and maintenance are carried out. In the present example, it is assumed that water quality impacts will be limited to a small amount of chemical pollution from gasoline, oil, and road salt.

The biological impacts that might be expected to result from each physical impact are displayed in the biological effects matrix of Figure 22. A potential biological impact is assumed to exist at each empty cell. For example, alteration of local water table level is assumed to lead to matrix effects on wetland size, plant species composition, wetland class, primary productivity, and secondary productivity. *The level of potential biological impacts in each cell should, in actual situations, be determined by a trained ecologist.*

The anticipated physical impacts of culvert capacity and placement are shown in Figures 23 and 24, respectively. In this case, it is assumed that the placement and capacity of the culverts are such that the only measurable impacts will be a possible major change in periodicity and a minor change in retention storage. The biological effects of these physical impacts are identified in the biological effects matrices in Figures 23 and 24. (It is assumed that in the Swift Marsh example the same culvert-related effects will also apply in alternatives 2 and 3.) The combined effects on Swift Marsh of consolidation and culvert design are shown along with alternatives 2, 3, and 4 in Figure 25.

### CONSTRUCTION ALTERNATIVE 2—DISPLACEMENT (FIG. 25)

The major differences in the physical effects resulting from displacement, as compared to consolidation, are assumed to fall mainly in the area of water quality. Displacement may result in excessive turbidity and in the potential for significant increases in chemical and biological oxygen demand from the displaced sediments. In addition, depending on the nature of the displaced material, heavy metals and other toxic substances may be released into the water column. In the Swift Marsh example, displacement is assumed to produce major increases in turbidity and sedimentation. No assumptions are made about the nature of the displaced sediments and the extent of chemical pollution is, therefore, specified as variable.

The physical and biological impacts that may be expected to result from the various physical effects produced by displacement are shown in Figure 25. It will be seen that the biological effects matrix, in contrast to the consolidation alternative, now shows the effects of increases in turbidity and sedimentation. Chemical pollution, although still shown as variable, would be expected to be more severe than in the previous case because construction as well as maintenance and use effects are now likely.

### CONSTRUCTION ALTERNATIVE 3—EXCAVATION AND REPLACEMENT WITH PERMEABLE FILL (FIG. 25)

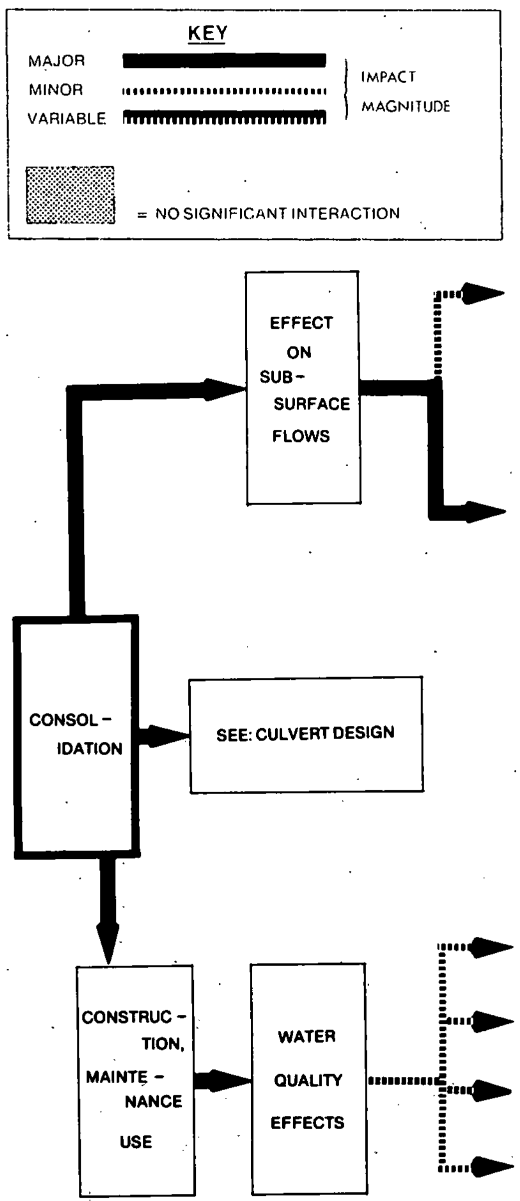
Alternative 3 involves excavation with upland disposal of the excavated material and replacement with permeable fill. As a consequence, the physical effects associated with the blockage of subsurface flows are avoided and chemical pollution stemming from reintroduction of excavated sediments into the wetland is minimized. The major physical effects resulting from excavation are increases in turbidity and sedimentation. As shown in Figure 25, the biological effects of these two physical impacts are assumed to be less severe than in the case of displacement.

### CONSTRUCTION ALTERNATIVE 4—PILE-SUPPORTED ROADWAY (FIG. 25)

It is assumed in this alternative that no significant impacts on surface or subsurface flows are created. Moderate degradation of water quality is anticipated as a consequence of construction-induced turbidity and sedimentation and as a result of chemical pollution introduced through road-salt and paint. Figure 25 shows possible major biological effects resulting from these physical and chemical impacts.

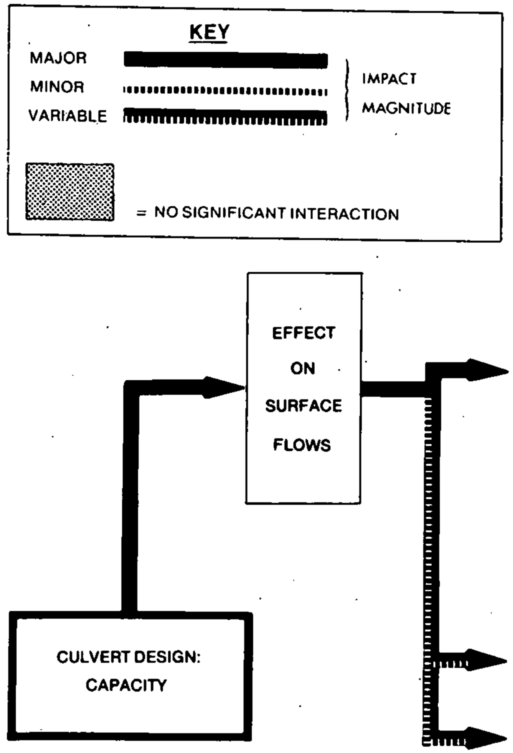
### SUMMARY

Comparison of the biological matrices shows that alternatives 3 and 4 are the methods which have the potential for causing less ecological impact, with alternative 4 causing the least. Unless this wetland is considered extremely important in its local context, economics would probably dictate alternative 3 (excavation and replacement with permeable borrow) as the method of choice.




| PHYSICAL IMPACTS / BIOLOGICAL EFFECTS | CHANGE IN WETLAND SIZE | CHANGE IN PLANT SPECIES COMPOSITION | CHANGE IN WETLAND CLASS COMPOSITION | CHANGE IN WETLAND PRIMARY PRODUCTIVITY | CHANGE IN WETLAND SECONDARY PRODUCTIVITY | SUDDEN MORTALITY OF AQUATIC SPECIES | BARRIER TO FAUNAL MOVEMENTS | ENCOURAGEMENT OF BEAVER ACTIVITY | RARE AND ENDANGERED SPECIES |
|---|---|---|---|---|---|---|---|---|---|
| CHANGE IN MEAN WATER LEVEL | Minor | Minor | Minor | Minor | Minor | | | | NA |
| CHANGE IN PERIODICITY | | | | | | | | | |
| MODIFICATION OF CIRCULATORY PATTERNS | | | | | | | | | |
| ALTERATION OF LOCAL WATER TABLE LEVELS | Major | Major | Major | Major | Major | | | | NA |
| DRAINAGE OF SURFACE WATERS | | | | | | | | | |
| ELIMINATION OF PERIODIC FLOODING AND FERTILIZATION | | | | | | | | | |
| CHANGE IN RETENTION STORAGE | | | | | | | | | |
| DAMPING OF TIDAL VARIATIONS | | | | | | | | | |
| ALTERATION OF SALINITY PATTERNS | | | | | | | | | |
| TURBIDITY | | | | | | | | | |
| SEDIMENTATION | | | | | | | | | |
| CHEMICAL POLLUTION | | Minor | | Minor | Minor | Minor | | | NA |
| TEMPERATURE | | | | | | | | | |

*Figure 22. Construction alternative 1—consolidation.*




| PHYSICAL IMPACTS / BIOLOGICAL EFFECTS | CHANGE IN WETLAND SIZE | CHANGE IN PLANT SPECIES COMPOSITION | CHANGE IN WETLAND CLASS COMPOSITION | CHANGE IN WETLAND PRIMARY PRODUCTIVITY | CHANGE IN WETLAND SECONDARY PRODUCTIVITY | SUDDEN MORTALITY OF AQUATIC SPECIES | BARRIER TO FAUNAL MOVEMENTS | ENCOURAGEMENT OF BEAVER ACTIVITY | RARE AND ENDANGERED SPECIES |
|---|---|---|---|---|---|---|---|---|---|
| CHANGE IN MEAN WATER LEVEL | | | | | | | | | |
| CHANGE IN PERIODICITY | | Major | Major | Major | Major | | Major | | NA |
| MODIFICATION OF CIRCULATORY PATTERNS | | | | | | | | | |
| ALTERATION OF LOCAL WATER TABLE LEVELS | | | | | | | | | |
| DRAINAGE OF SURFACE WATERS | | | | | | | | | |
| ELIMINATION OF PERIODIC FLOODING AND FERTILIZATION | | | | Var. | Var. | | | | NA |
| CHANGE IN RETENTION STORAGE | | | | | | Var. | | | NA |
| DAMPING OF TIDAL VARIATIONS | | | | | | | | | |
| ALTERATION OF SALINITY PATTERNS | | | | | | | | | |
| TURBIDITY | | | | | | | | | |
| SEDIMENTATION | | | | | | | | | |
| CHEMICAL POLLUTION | | | | | | | | | |
| TEMPERATURE | | | | | | | | | |

*Figure 23. Construction alternative 1—culvert design capacity.*

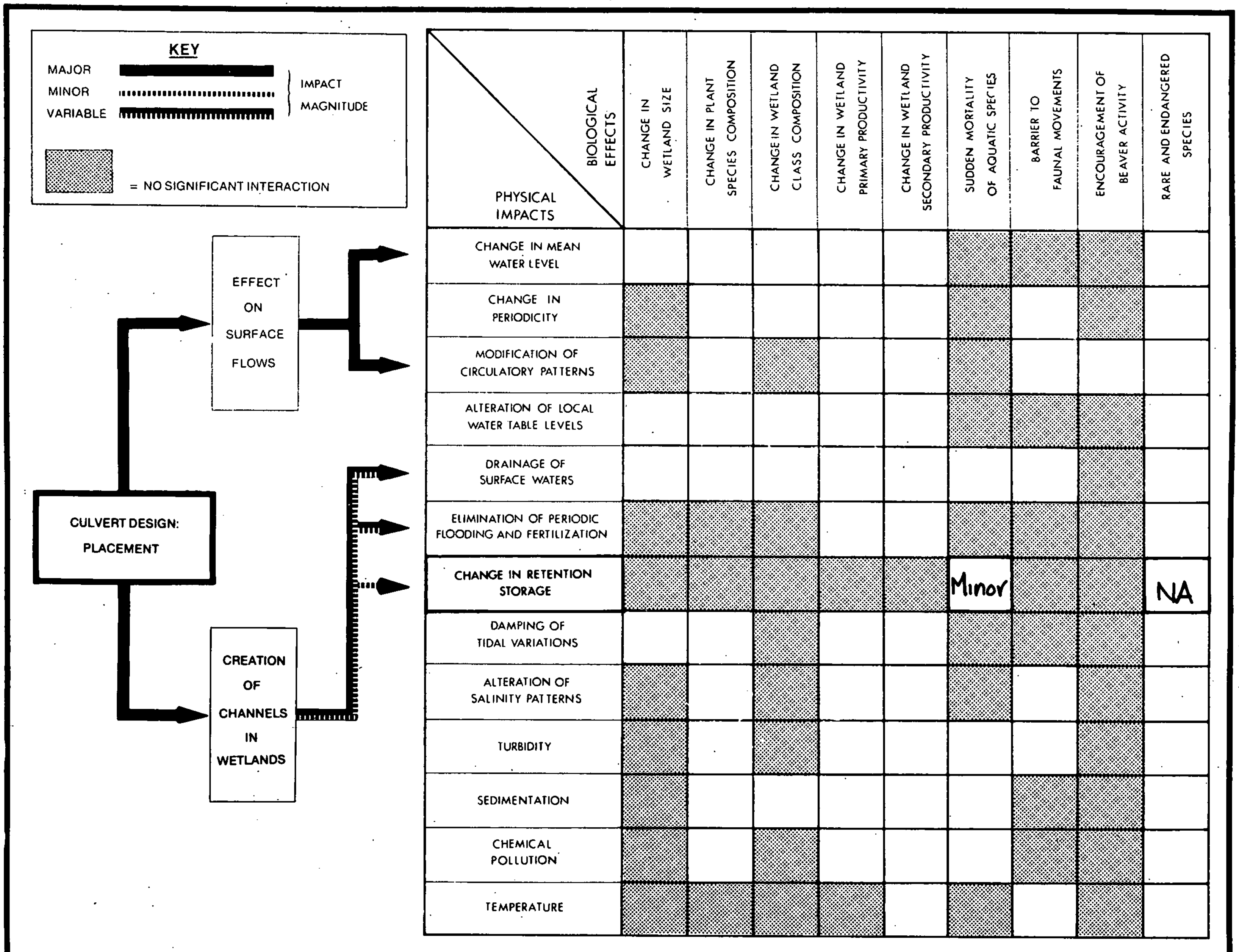



*Figure 24. Construction alternative 1—culvert design placement.*

| PHYSICAL IMPACTS \ BIOLOGICAL EFFECTS | CHANGE IN WETLAND SIZE | CHANGE IN PLANT SPECIES COMPOSITION | CHANGE IN WETLAND CLASS COMPOSITION | CHANGE IN WETLAND PRIMARY PRODUCTIVITY | CHANGE IN WETLAND SECONDARY PRODUCTIVITY | SUDDEN MORTALITY OF AQUATIC SPECIES | BARRIER TO FAUNAL MOVEMENTS | ENCOURAGEMENT OF BEAVER ACTIVITY | RARE AND ENDANGERED SPECIES |
|---|---|---|---|---|---|---|---|---|---|
| CHANGE IN MEAN WATER LEVEL | Minor | Minor | Minor | Minor | Minor | | | | NA |
| CHANGE IN PERIODICITY | | Major | Major | Major | Major | | Major | | NA |
| MODIFICATION OF CIRCULATORY PATTERNS | | | | | | | | | |
| ALTERATION OF LOCAL WATER TABLE LEVELS | Major | Major | Major | Major | Major | | | | |
| DRAINAGE OF SURFACE WATERS | | | | | | | | | |
| ELIMINATION OF PERIODIC FLOODING AND FERTILIZATION | | | | Var. | Var. | | | | |
| CHANGE IN RETENTION STORAGE | | | | | | Minor | | | NA |
| DAMPING OF TIDAL VARIATIONS | | | | | | | | | |
| ALTERATION OF SALINITY PATTERNS | | | | | | | | | |
| TURBIDITY | | | | | | | | | |
| SEDIMENTATION | | | | | | | | | |
| CHEMICAL POLLUTION | | Minor | | Minor | Minor | Minor | | | NA |
| TEMPERATURE | | | | | | | | | |

ALTERNATIVE 1

| PHYSICAL IMPACTS \ BIOLOGICAL EFFECTS | CHANGE IN WETLAND SIZE | CHANGE IN PLANT SPECIES COMPOSITION | CHANGE IN WETLAND CLASS COMPOSITION | CHANGE IN WETLAND PRIMARY PRODUCTIVITY | CHANGE IN WETLAND SECONDARY PRODUCTIVITY | SUDDEN MORTALITY OF AQUATIC SPECIES | BARRIER TO FAUNAL MOVEMENTS | ENCOURAGEMENT OF BEAVER ACTIVITY | RARE AND ENDANGERED SPECIES |
|---|---|---|---|---|---|---|---|---|---|
| CHANGE IN MEAN WATER LEVEL | Minor | Minor | Minor | Minor | Minor | | | | NA |
| CHANGE IN PERIODICITY | | Major | Major | Major | Major | | Major | | NA |
| MODIFICATION OF CIRCULATORY PATTERNS | | | | | | | | | |
| ALTERATION OF LOCAL WATER TABLE LEVELS | Major | Major | Major | Major | Major | | | | NA |
| DRAINAGE OF SURFACE WATERS | | | | | | | | | |
| ELIMINATION OF PERIODIC FLOODING AND FERTILIZATION | | | | Var. | Var. | | | | NA |
| CHANGE IN RETENTION STORAGE | | | | | | Minor | | | NA |
| DAMPING OF TIDAL VARIATIONS | | | | | | | | | |
| ALTERATION OF SALINITY PATTERNS | | | | | | | | | |
| TURBIDITY | | Major | | Major | Major | Major | Major | | NA |
| SEDIMENTATION | | Major | Major | Major | Major | Major | | | NA |
| CHEMICAL POLLUTION | | Var. | | Var. | Var. | Var. | | | NA |
| TEMPERATURE | | | | | | | | | |

ALTERNATIVE 2

| PHYSICAL IMPACTS \ BIOLOGICAL EFFECTS | CHANGE IN WETLAND SIZE | CHANGE IN PLANT SPECIES COMPOSITION | CHANGE IN WETLAND CLASS COMPOSITION | CHANGE IN WETLAND PRIMARY PRODUCTIVITY | CHANGE IN WETLAND SECONDARY PRODUCTIVITY | SUDDEN MORTALITY OF AQUATIC SPECIES | BARRIER TO FAUNAL MOVEMENTS | ENCOURAGEMENT OF BEAVER ACTIVITY | RARE AND ENDANGERED SPECIES |
|---|---|---|---|---|---|---|---|---|---|
| CHANGE IN MEAN WATER LEVEL | | | | | | | | | |
| CHANGE IN PERIODICITY | | Major | Major | Major | Major | | Major | | NA |
| MODIFICATION OF CIRCULATORY PATTERNS | | | | | | | | | |
| ALTERATION OF LOCAL WATER TABLE LEVELS | | | | | | | | | |
| DRAINAGE OF SURFACE WATERS | | | | | | | | | |
| ELIMINATION OF PERIODIC FLOODING AND FERTILIZATION | | | | Var. | Var. | | | | NA |
| CHANGE IN RETENTION STORAGE | | | | | | Var. | | | |
| DAMPING OF TIDAL VARIATIONS | | | | | | | | | |
| ALTERATION OF SALINITY PATTERNS | | | | | | | | | |
| TURBIDITY | | Var. | | Var. | Var. | Var. | Var. | | NA |
| SEDIMENTATION | | Var. | Var. | Var. | Var. | Var. | | | NA |
| CHEMICAL POLLUTION | | Var. | | Var. | Var. | Var. | | | NA |
| TEMPERATURE | | | | | | | | | |

ALTERNATIVE 3

| PHYSICAL IMPACTS \ BIOLOGICAL EFFECTS | CHANGE IN WETLAND SIZE | CHANGE IN PLANT SPECIES COMPOSITION | CHANGE IN WETLAND CLASS COMPOSITION | CHANGE IN WETLAND PRIMARY PRODUCTIVITY | CHANGE IN WETLAND SECONDARY PRODUCTIVITY | SUDDEN MORTALITY OF AQUATIC SPECIES | BARRIER TO FAUNAL MOVEMENTS | ENCOURAGEMENT OF BEAVER ACTIVITY | RARE AND ENDANGERED SPECIES |
|---|---|---|---|---|---|---|---|---|---|
| CHANGE IN MEAN WATER LEVEL | | | | | | | | | |
| CHANGE IN PERIODICITY | | | | | | | | | |
| MODIFICATION OF CIRCULATORY PATTERNS | | | | | | | | | |
| ALTERATION OF LOCAL WATER TABLE LEVELS | | | | | | | | | |
| DRAINAGE OF SURFACE WATERS | | | | | | | | | |
| ELIMINATION OF PERIODIC FLOODING AND FERTILIZATION | | | | | | | | | |
| CHANGE IN RETENTION STORAGE | | | | | | | | | |
| DAMPING OF TIDAL VARIATIONS | | | | | | | | | |
| ALTERATION OF SALINITY PATTERNS | | | | | | | | | |
| TURBIDITY | | Var. | | Var. | Var. | Var. | Var. | | NA |
| SEDIMENTATION | | Var. | Var. | Var. | Var. | Var. | | | NA |
| CHEMICAL POLLUTION | | Major | | Major | Major | Major | | | NA |
| TEMPERATURE | | | | | | | | | |

ALTERNATIVE 4

*Figure 25. Biological effects matrices resulting from construction alternatives 1-4.*

CHAPTER FOUR

# MITIGATION

Prediction of the impacts that are likely to result from a proposed course of action is a necessary step in the planning and design of a highway facility. But the process cannot stop there; consideration must also be given to what might be done to mitigate the deleterious effects that are predicted.

There are two fundamental approaches to impact mitigation. The first approach is to plan or design highways to avoid or minimize the probable occurrence of potential impacts. This approach lies at the heart of the National Environmental Policy Act and other related impact assessment laws and regulations. The second approach stems from the fact that some degree of impact is often unavoidable regardless of the care and creativity applied during the planning, design, and construction of a highway. Mitigation in these instances may take the form of attempting to reconstruct the basic ecological features that were disturbed by the construction of the facility. Such mitigation may include the restoration of original hydrologic systems and the replacement of certain species of plants.

Mitigation may also take the form of creating alternative ecosystems that offer environmental values equivalent to or more desirable than those of the impacted system. It may be possible, for example, to use the highway structure deliberately to create new wetlands in one area as a substitute for areas destroyed or diminished elsewhere. Borrow pits may be located and designed so as to create new wetland habitat. The opportunities for creative design in this regard both on and off the immediate right-of-way are many and growing.

Practices that are selected in order to mitigate adverse impacts should be evaluated for their effectiveness. Among the practices typically employed to mitigate adverse impacts are the following:

1. Erosion control practices.
2. Careful selection of borrow areas.
3. Avoidance of encroachment on sensitive areas of stream.
4. Creative use of dredged materials.
5. Use of culverts and other devices to maintain hydrologic conditions.
6. Construction of sedimentation pools.
7. Avoidance of encroachment on sensitive wetland areas.
8. Adoption of good practices in use of herbicides and mowing along the right-of-way.
9. Minimum use of deicing salts.
10. Use of containment structures to minimize risk from accidental spillage in sensitive areas.
11. Avoidance of disruption of nesting sites and migration routes for wildlife.
12. Avoidance of construction during particularly sensitive seasons for fish and wildlife (*18*).

In a similar manner, practices and design features may be adopted to enhance and/or create positive impacts that may result from the highway project. Some of these practices might include the following:

1. Maintenance of low understory along right-of-way to enhance edge effects.
2. Increasing edge effects by use of "islands" of tree stands.
3. Location of highway along natural ridges and benches.
4. Provisions in highway corridor to facilitate animal migrations.
5. Use of borrow pits for sports fishery resource.
6. Modification of impoundment features created by highway to include low-flow augmentation and creation of new wetlands habitat.
7. Design of drainage control systems and stream diversions to include low flow augmentation for ephemeral and intermittent streams.
8. Enhancement of fisheries through use of culverts for migration, provisions for low flow augmentation, and enhancement of habitat diversity by use of rip-rap on stream bed.

Careful consideration of terrain, regional hydrology, regional flora and fauna, and highway design requirements will often permit considerable latitude for creative design options to reduce adverse impacts and create or enhance positive impacts (*18*).

## MITIGATION PROCEDURES

### Location

The location of a highway is a complex process involving trade-offs among many factors including: directness of route; economy of construction, operation, and maintenance; and concern for the social and natural environment. The balance among these several determinants has shifted over the years with the development of large and efficient earthmoving equipment, the introduction of higher safety and operating design standards, and the growing scarcity of available low-cost land. More recently, greater awareness of the impacts that highway construction can have on the natural environment has led to a much greater emphasis on ecological factors in the formulation and evaluation of location alternatives. Wetlands, as a particularly sensitive natural environment, now enjoy special protection under a variety of federal and state laws and regulations. The

result of these changes is that what once might have been viewed as the least contentious of potential highway locations is now often the most controversial.

The most obvious way of mitigating the impact on a wetland is to avoid it completely. However, what is most obvious is not necessarily most feasible, and less absolute solutions must often be sought. The options available to the highway agency are often restricted by institutional constraints, however. Perhaps most restricting is the relatively advanced stage in the planning and design process in which most current highway projects are found. Options for these so-called "pipeline" projects may be limited to minor design or locational modifications within an already committed (and acquired) right-of-way. A second institutional constraint is brought about by engineering standards associated with federal and state aid. Such standards, particularly those dealing with curvature, width, and grade of highways, often restrict the engineer's flexibility in selecting an environmentally benign alignment.

The location of a highway is often the single most important decision that can be made affecting the impact that a given facility will have on the environment through which it passes. Environmental consideration must, therefore, be incorporated into the decision-making process at the earliest possible stage. Since many of the potential impacts of alternative locations may not be apparent to the engineer, the active participation of ecologists and other natural scientists in the planning and route location process is essential.

#### Erosion and Sedimentation Control

Erosion and sediment control measures are instituted both during and after construction not only to protect affected wetlands from pollution, but also to ensure the continuing integrity of the highway structure and the unimpeded operation of drainage appurtenances. The federal government—principally through the Environmental Protection Agency—and many states have placed increased emphasis on the need to control sediment laden runoff resulting from erosion at construction sites.

#### Field Construction Techniques

Soil erosion is a major contributor to environmental degradation. The rate of erosion produced by a highway project is generally greatest during construction, when the disturbance of the natural ground cover is at a maximum. However, significant erosion may also continue throughout the life of the project, especially if the initial design of the facility is faulty or if erosion control devices are not properly maintained.

Various devices and construction procedures, including berms, sediment basins and traps, mulching, and revegetation, are employed by highway agenices to limit the extent of erosion and to mitigate its impact on the environment. A balance is generally sought between the extent and cost of erosion-control features on the one hand and the sensitivity of the potentially impacted environment on the other. Culverts and other drainage features should be installed as early in the construction process as possible so as to provide the maximum degree of protection. Typical erosion control practices used by the New York State Department of Transportation (*19*) to ensure the integrity of highway structures and to protect affected wetlands are described as follows:

1. *Mulching and seeding cut and fill slopes*—One of the most effective ways to control surface soil erosion is to establish a vegetative cover, usually grass, on recently graded earth areas. This work can be accomplished by permanent seeding or by temporary seeding and mulching, depending on whether or not final grade has been reached. Permanent seeding should be done as soon as the final grading is completed. Temporary seeding should be used where the final grade and trimming cannot be accomplished and the exposed earth would be left unprotected for a considerable length of time.
2. *Construction of side-slope berms*—Berms are steps or benches in steep slopes. They are modifications of and serve much the same purpose as diversions. Properly located and designed, they reduce slope lengths and divide the volume of runoff water into workable slugs that are more easily handled. Capacity to carry the volume of water is obtained by grading the berm so that the outside edge is higher than the edge adjacent to the cut slope. Runoff water may be removed from the berm by use of paved waterways or buried pipe.
3. *Fill slope drains*—Where large fills closely parallel streams, bodies of water, or developed property, a berm at the top of the slope may be used to channel water to a location where it may be removed by a slope drain. Slope drains should be used with care, as any ponding created by berms will soften the fill.
4. *Cut-fill transitions*—This is a particularly difficult area for temporary erosion control installation. As the fill area is brought to grade with material from the cut, the point of change from fill section to cut section moves uphill. During the construction phase, before the permanent drainage system is in place, runoff from the cut sections is confined to movement along the roadway and not allowed to leave until it reaches the fill section. Because this transition section is moving uphill, erosion control measures must be moved with it, or other provisions for sediment removal must be made downstream.
5. *Toe of fill protection*—Hay bales are often placed at the toe of the fill to contain sediments within the highway right-of-way. This procedure is effective as a temporary measure if the rate flow off the fill slope is low. Where substantial flows are anticipated, either from the fill slope itself or from other sources, side ditches with appropriate erosion control devices will be necessary.
6. *Channel protection materials*—Areas of concentrated flow require protection commensurate with anticipated volumes of flow, slope, soil type, and related site characteristics. Usual practices include:
    a. Installation of permanent protection where possible.
    b. Stone fill is used both to protect the underlying soil from erosion and to help to dissipate the kinetic energy of the flowing water. The appropriate size, shape, and grading of the stone will

depend, among other things, on the nature of the soil to be protected. Fine sands and silts tend to erode beneath the stone cover, allowing the stone fill to drop into the resulting depressions and leading to a continuing cycle of erosion and depression. In such soils, a filter material or well graded mix should be used rather than a uniformly sized stone.

c. Plastic sheets, plastic filter cloth, and flexible plastic pipe are effective and relatively inexpensive. These materials require inlet and outlet controls and are placed with hand labor.

d. Jute mesh, excelsior mats, and asphalt and chemical stabilizers have been used with variable results.

7. *Check dams in ditches*—Either an impermeable or permeable dam may be built. Permeable dams of hay, rock, or wood are preferred. A frequent shortcoming of the hay bale check dam is that it does not extend high enough up the ditch side. This causes the impounded water to flow around the ends of the dam, causing washouts.

Impermeable check dams may be built of soil, rock and soil, or plastic sheets and soil. These should have a formed spillway to prevent washout around the dam at high flow conditions. A downstream apron is also required in highly erodible soils.

8. *Sediment traps in ditches*—The simplest trap is the pit trap, which is merely a pit or hole in the ditch bottom. Little information is available about the design of pit traps. Length and depth are dependent on soil type, watershed area, gradient, rainfall estimates, and planned frequency of clean-out. Experience has shown that sediment traps in ditches are ineffective. High flows pass over with little or no effect. Although they are easy to construct and maintain, they may leave soft, soggy areas when removed.

9. *Sediment basins*—These are the largest and most complex of the temporary erosion controls. The use of sediment basins should be reserved for critical situations (such as drainage into surface water supplies), and should be considered a backup safety device if other controls on the project fail. Sediment basins permit sedimentation of coarse soils only, as silt and clay sized particles remain in suspension. The use of chemical flocculating agents (generally alum) to remove the discoloration from the remaining water in the basins is not recommended, as overtreatment can be damaging to the water quality downstream, trading physical discoloration for chemical pollution.

10. *Borrow pits and spoil areas*—When operations on a portion of a borrow pit or spoil area are completed, that portion should be seeded and mulched without waiting for the entire borrow or spoil operation to be completed. If, for some reason, all or portions of borrow pits or spoil areas must remain "open" for a period of time, such as through the winter or because of delays in the contract operation, the exposed pit or spoil area should be rough graded and protected by temporary or permanent erosion control measures. Seeding and mulching should be done whenever possible and, depending on the exposure of the area, should be used in conjunction with other methods, such as sediment basins and traps.

11. *Turnouts on wetland crossings*—If there are no firm places for equipment parking or turn around during construction of a wetland crossing greater than about a kilometer in length, a contractor frequently finds it expedient to construct an area for this purpose. This area is located at the side of the design roadway at the beginning of the wetland crossing, near the major stream crossing, or at some intermediate point where it is feasible and convenient. When such areas are the beginning of the crossing, they are convenient locations for arresting ditch drainage and catching the sediment before it enters the wetland. If turnouts are not planned as part of the original design, location is often not well controlled and potential future beneficial uses may not be attained. *Ad hoc* construction by the contractor may lead to unplanned environmental impacts that may subject the construction to legal delay if limits imposed by preconstruction environmental review or permit procedures are exceeded.

#### Adverse Impacts on Wildlife

A comprehensive and detailed set of recommendations with respect to correcting habitat degradation in streams, lakes, and wetlands is provided in the Forest Service Handbook (*20*).

Some of these recommendations for habitat improvement may be implemented in the design and construction of a highway facility. For example, categories of wetland improvement include construction of potholes and islands, maintenance of marsh habitat, and development of "greentree reservoirs"—wooded swamps with regulated flooding periods. Habitat improvement in streams and lakes include development of impoundments, manipulation of water levels, treatment of stream channels and streamsides, regulating streamflow, and maintaining and improving water quality.

Stream improvement is concerned mostly with fish habitats. The major categories of improvements are: treating channels directly, treating streamsides, maintaining a regulated streamflow, maintaining and improving water quality, and improving food production.

#### Adverse Effects on Aquatic Biota

In the preparation of highway design alternatives, wetland crossings require special considerations for protecting the resident aquatic species. Since most aquatic biota are restricted to the aquatic environment alone, any barrier to their migration and free movement through the water can be harmful. The discussion provided here is drawn heavily from information provided by the Federal Water Pollution Control Administration (*21*).

Natural tidal movements in estuaries and downstream movement of planktonic organisms and aquatic invertebrates in flowing fresh-water are important factors in the repopulation of areas and the general economy of the area. Many species make local migrations for spawning, escape, and feeding, while several may travel long distances to reach annual spawning areas. It is essential that adequate passageways be provided at all times for the movement of drift of these biota.

Water quality criteria favorable to the aquatic com-

munity must be maintained at all times in these passageways, including the absence of any chemical or physical barriers. The width of the zone of passage and the volume of flow in it will depend on the character and size of the stream or estuary. Area, depth, and volume of flow must be sufficient to provide a usable and desirable passageway.

The Idaho Fish and Game Department has recognized that free access to spawning areas for trout, salmon, and steelhead is necessary to prevent the loss of valuable fisheries in that state. In response, the Department has prepared a publication (*22*) which identifies potential problems of culvert installations relating to fish passage. Specifications for culvert design—gradient, water velocity, length, baffles, etc.—are discussed in detail and should be useful in highway planning. In Idaho, and perhaps in other states as well, it is the responsibility of the regional fisheries management biologist to determine if it is necessary to provide for fish passage at a culvert.

## CREATION OF NEW HABITAT

The use of highway construction to create new wetland habitat is becoming increasingly common, as highway agencies recognize the benefits derived from such practices to both highway users and our wetland resources. In addition, highway agencies may be required to provide compensatory habitat acquisition and management for wetlands lost to filling and drainage (e.g., Federal easement wetlands). Many highway features and construction activities may be useful in this compensatory effort.

Of these activities, construction of borrow areas, dredged material disposal, and installation of surface water control structures appear to offer the most viable opportunities for habitat creation and improvement. However, early and continuing coordination between highway agencies and natural resource departments is essential if the full benefits from the creation or improvement of wetland habitats are to be realized.

### U.S. Fish and Wildlife Service Procedures

The U.S. Fish and Wildlife Service has developed a manual of procedures for determining the extent of habitat improvement measures needed to compensate for losses due to water resource development projects. The concept and structure of these procedures will be briefly discussed here, in addition to other methods used to determine mitigation for habitat losses.

The U.S. Fish and Wildlife Service has developed a quantitative methodology for evaluating the suitability of wetlands and other habitat types for fish and wildlife species. This method, the Habitat Evaluation Procedures (HEP), combines both wetland quality and quantity in a single index value that can be used to rank present wetland values and compare baseline conditions with land-use changes for selected target years. The HEP provides decision-makers with a methodology to inventory baseline wetland habitat conditions, formulate land-use plans, evaluate alternate sites and plans, and determine mitigation (compensation) requirements. The procedures are designed to be understandable by a wide cross section of individuals and organizations and at the same time are detailed and accurate enough to make a significant contribution to all phases of resource planning at all levels of decision-making (*23*).

### Methods and Guidelines

This section describes the basic categories of wetland creation and improvement. Included are broad specifications and examples of prior implementation. The details in any instance are variable, and will be determined largely by the desires of the interest group (e.g., landowners) involved. Therefore, efforts to create or improve wetland habitats should be done in cooperation with professional biologists.

#### *Acquisition/Watershed Management*

Wetland habitats are greatly affected by adjacent land uses, much of which may relate to secondary effects of highway construction. Where highway agencies are required to provide mitigation for habitat losses, it may be sufficient to acquire other wetland acreages for protection from future development. Often, however, this is not sufficient, since these other wetlands existed prior to the highway, and compensation for habitat loss requires creation of new or improvement of existing wetland habitats. In any case, purchase for preservation and extensive control of pollution from highway maintenance and use may reduce the amount of mitigation required, and is encouraged.

#### *Excavation of Borrow Areas*

In the process of removing borrow material, excavations can be designed to generate into productive wetland habitats. There has been very little investigation to determine what physical features are most important in successful creation of wetlands. However, these guidelines are provided for excavations designed to enhance wetland productivity based on some general concepts of wetland ecology, along with the limited documentation available.

Depth of the excavations is the most critical parameter, because it relates to the eventual water levels in the borrow area. The growth of aquatic vascular plants is dependent on the extent of shallow areas in a wetland. To provide for emergent marshes, excavations should result in water depths of 15 to 60 cm (during the growing season) over most of the basin. Areas ranging from 0.5 to 2 m deep provide suitable zones for submergent aquatic plants. Scattered pits exceeding 3 m deep are also desirable, since they contribute to the diversity of aquatic habitats and ensure deep water areas required by many aquatic organisms at various times during the year. A wetland design with variable bottom elevations is best accomplished by excavation of deep areas first, concentrating rain water, allowing the remainder to be excavated.

The location of an excavation for wetland development has a complex influence on its eventual productivity. Soil types are principally dictated by borrow needs and will not be considered in most cases. Because of the nature of borrow pits, the bottom sediments would normally contribute little to wetland fertility. However, replacement of topsoil after excavation can improve conditions for establishment

and growth of aquatic vegetation. Upland seepage and runoff exert a major control over water chemistry. The pH of the ground-water should be between 5.0 and 10.0, while a cultivated area would be better than a fallow or wooded situation because of the increased fertility. Soil moisture is related to the success of wetland development as well as the suitability of borrow material. Borrow areas at lower topographic elevations (and shallower depth to water table) are preferable because higher soil moisture conditions there reduce the amount of water necessary for compaction.

The productivity of artificially excavated marshes has not been adequately compared to natural wetlands in most regions. However, any contribution to wetland productivity should be recognized as a valuable effort, and many improvements by borrow excavation have been successful. Examples of these exist in Massachusetts, North Dakota, and Minnesota—to name but a few states.

*Dredged Material Disposal*

Dredged material can originate from excavation prior to placement of fills or pilings, and from removal of material overlying borrow areas. In many cases this material should be placed on upland disposal sites to avoid adverse effects on water quality. However, recent efforts have determined that dredge material disposal in wetlands can be managed to improve habitats for selected wildlife species. In particular, spoil banks create microelevations where woody vegetation can become established within extensive marsh or open water areas, providing a greater diversity of habitats. Guidelines for the placement of dredge material are currently being prepared by the U.S. Army Corps of Engineers.

*Hydrologic Management*

More than 20 years ago, Delaware, Michigan, New York, and Pennsylvania initiated cooperative efforts between their highway and natural resource agencies to improve or create wetland habitats by implementing structures for hydrologic management. Actual specifications for water control structures (e.g., dikes, floodgates, spillwarps, impoundments) were decided on mutually by highway and wildlife agencies to accomplish successful hydrologic management. The advantage in this approach is that the resource agency has the benefit of the complete fill as a surface water regulator, at the cost of a few water control structures.

Briefly, hydrologic management is desirable for wetland improvements because surface waters can be manipulated to affect vegetative composition and productivity. The habitat manager is interested in creating interspersion of open water with marsh-land, and creating conditions favorable to waterfowl, mammals, and fishes. The specific objectives which wildlife biologists may seek through hydrologic management associated with highways include expanding wetland acreage by impoundment, regulation of water levels to stimulate waterfowl food plants or eliminate nuisance species, maintenance of minimum levels to protect fauna during critical dry periods, and flooding of mast-producing (nut and fruit) timber species to provide waterfowl feeding areas.

*Other Techniques*

Wetland managers use a variety of site-specific techniques for improving fish and wildlife habitats. Mitigation by highway agencies may include funding of these habitat improvements. For example, planting waterfowl foods has been widely practiced; also, artificial nesting structures can be placed in suitable habitats to enhance productivity of Canada Geese and Wood Ducks. Where purchase of wetlands is not completely satisfactory compensation, and where the habitat is already highly productive, improvements of this sort or creation of habitat may be a reasonable alternative.

### INTERDISCIPLINARY TEAMS FOR MITIGATING ADVERSE IMPACTS

The National Environmental Policy Act of 1969 (NEPA) provided an action-forcing procedure in Section 102(A) which states that all agencies of the federal government shall:

> Utilize a systematic interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and decision-making which may have an impact on man's environment.

CHAPTER FIVE

# SOURCES OF EXPERTISE

In most instances, major universities and smaller colleges would be the principal sources from which to select biological experts. Because many of the specialized fields require high laboratory and/or field equipment overhead, major universities would be considered the primary source. Also, because most such specialists are oriented towards experimentation, it is less likely that museums and other natural history interpretive institutions would have such persons on their staff. Additional agencies, such as the National Institute of Health and the Agricultural Experi-

ment Stations, would be logical sources for seeking assistance of such experts. The major areas are listed as follows:

*AERIAL PHOTOGRAMMETRY*—The science of making reliable measurements by the use of photographs and especially aerial photographs.

*AGRICULTURAL ECONOMICS*—The branch of economics concerned with the efficient use of resources in agriculture, the technology of food and fiber production, the distribution of farm products, and the income and welfare of farm populations.

*ANIMAL GEOGRAPHY* (Zoogeography)—The science that attempts to describe and explain the distribution of animals through space and time. This is accomplished by inventory and analysis of genetic and environmental factors of the organism. The primary difference between zoogeography and ecology is merely one of scale.

*AUTECOLOGY*—Ecology dealing with individual organisms or individual kinds of organisms.

*BIOCHEMISTRY*—The study of the substances that occur in living organisms, the processes by which the substances enter into or are formed in the organisms and react with each other and the environment, and the methods by which the substances and processes are identified, characterized, and measured. A biochemist is familiar with the substances that occur naturally in organisms and with the amounts that are normal for the organisms.

*BIOCLIMATOLOGY*—The study of the effects of the climatic environment on living organisms.

*BIOGEOGRAPHY*—The study of the geographical distribution of plants and animals. The studies are concerned with learning the manner in which living organisms are arranged on the earth and the (possible) causal factors of this arrangement.

*BIOMETRICS*—The application of mathematical and statistical methods to describe and analyze data concerning the variation of biological characteristics obtained from observation or experiment.

*BIOPHYSICS*—A hybrid science involving the overlap of physics, chemistry, and biology, using the ideas and methods of physics and chemistry to study and explain the structures of living organisms and the mechanisms of life processes. The study is applied to human diseases and human adaptations to new environmental stress, such as that produced by space travel and nuclear radiation. *Molecular biophysics* has to do with the study of large molecules and particles of comparable size which play important roles in biology. *Physiological biophysics* is concerned with functioning of living organisms or parts of living organisms and with the response of living organisms to physical forces. One area of research is the changes in normal functioning of organisms, including the human body, when the physical environment is changed. *Mathematical and theoretical biophysics* deals primarily with the attempt to explain the behavior of living organisms on the basis of mathematics and physical theory.

*BOTANY*—The study of plants and plant life. The studies range from microscopic observations of small plants and the life processes taking place within them to the relationships among plants and their geographic distribution. The former area includes plant anatomy, chemistry, cytology (study of cells), genetics, evolution, morphology (structure), and physiology. The latter studies plant ecology and plant geography.

*ECOLOGY*—The study of the interrelations between organisms and their environments. It is based on the premise that life and environment are inseparable parts of a greater whole. Subfields include:

*Anatomy*—The study of the internal structure of the organism, from the cellular to the skeletal level. The study is often carried out on a comparative basis within a class of animals such as vertebrates. Comparisons illuminate evolutionary trends and specializations within that class.

*Ethology*—The study of animal behavior. It differs from psychology in that the interest is in behavior that occurs in a natural context. The ethologist focuses on the adaptive value of behavior and studies the animal in its natural or simulated natural environment.

*Animal Evolution*—The theory that modern animals are the modified descendants of animals that formerly existed and that these earlier organisms descended from still earlier and different forms.

*Physiology*—The study of the basic activities of living organisms that occur in most cells and tissues, using physical and chemical methods.

*Synecology*—A branch of ecology that deals with the structure, development, and distribution of ecological communities.

*GEOLOGY*—The study of earth, primarily of the rocks that compose the earth's crust. Subfields include:

*Coastal Geology*—The study of the characteristic features and patterns of land in a coastal zone subject to marine and subaerial processes of erosion and deposition.

*Economic Geology*—The application of geology to the description, discovery, and exploitation of rocks and minerals that are usable as metals, fuels, or industrial minerals.

*Engineering Geology*—The application of geologic knowledge to solve geological problems posed by civil engineering structures. Taken broadly, engineering geology can be considered as a form of impact assessment (i.e., the geological resources of an area are evaluated in terms of their ability to bear a proposed project and in terms of the impact that project would have on the geologic features). A team of geologists can provide the same information as an engineering geologist.

*Environmental Geology*—An applied field of geology in which knowledge of geological resources and conditions is applied to land-use planning. The effect of landfills on ground water, ground-water development, and the effect of underground mining on the landscape are three of the problem areas that require the environmental geologists' expertise. Because this is a relatively new field, environmental geologists are not numerous. The hydrologist and

engineering geologist should be consulted if an environmental geologist is not available.

*Geomorphology*—The study of the forms that compose the earth's surface: mountains, valleys, hills, streams, their evolution and the erosional processes which act upon them. The forces causing slope erosion, compaction and subsidence of the earth, landslides, and avalanches are studied. The study of fluvial processes includes flow regimes, the relationship between flow velocity and the width, depth, and slope of the stream channel, bank erosion, and the rate of sediment deposit. From this information a prediction of impact by a dam or channel alteration on the morphology, flow rate, and siltation rate of a stream can be derived. For this reason a geomorphologist or hydraulics engineer should be consulted on any project involving a stream change.

*Glaciology*—Study of the effects of glacial erosion of the surface of the earth. A knowledge of glacial deposits is of great importance in engineering geology, hydrogeology, hydrology, and soil science.

*Hydrology*—The study of the earth's waters; their occurrence, circulation and distribution; their chemical and physical properties; and their reaction with the environment, including their relation to living things. The application of hydrological knowledge grows in importance as ground-water development becomes an increasingly viable water supply alternative. Hydrologists can provide answers to the following questions: Where and in what quantity does ground water occur? What is the safe daily yield of ground-water basins? How can the basins be developed as water supplies, and how can they be preserved? Furthermore, water in the foundation material under a structure may produce undesirable uplift pressures on the base of the structure. Prior knowledge of the location of such water would be the basis for predictions of the interaction between such material and a proposed structure.

*Limnology*—The study of the chemical, physical, meteorological, and biological aspects of fresh waters.

*Microbiology*—The study of microorganisms (those organisms only visible through a microscope).

*Oceanography*—The study of the shape and structure of ocean basins; physical and chemical properties of sea water; ocean currents, waves and tides; thermodynamics of the oceans; and the relation of these factors to the organisms that live in the sea.

*Plant Geography*—The study of the development and natural distribution of plants and plant communities. Because all animals are dependent in the final analysis on plants to supply food, the distribution of plant life is the basic component of biogeography. The function of plant geography is to record the observed, empirical facts of plant distribution and also to understand and interpret these facts. Where possible, the study includes the prediction and control of distributional phenomena, especially as these relate to plant pests and to the introduction and spread of desirable species and vegetation types. Such practical aspects are pertinent to the fields of forestry, agriculture, range and pasture management, wild-life habitat management, horticulture, and soil and water conservation. The understanding and interpretation of floras and of their distribution have been predominantly in terms of their history and ecology. Ecological factors include the contemporary roles played by precipitation, humidity, water levels, temperature, wind, soil, animals, and man. Vegetational plant geography has emphasized the mapping of so-called vegetation regions, and the interpretation of these in terms of environmental or ecological influences. A plant geographer familiar with the project region would most likely know of any rare, unique, or otherwise significant plant communities in that area.

*PLANT SCIENCE*—The study of plants, including the aspects studied by botanists, but the focus is on plants of economic value to man.

*Plant Bioclimatology*—The study of the natural climatic values, such as air temperature, precipitation, and wind speed and its variations, and the effect of these agents on the plant. The bioclimatologist can assist in the development and/or interpretation of data related to both micro- and macro-changes in climate resulting from program or project activities. Such climatic impacts would be significant in terms of change distribution and life-cycle factors of all manner of plant, animal, and microbiological organisms as well as the environment of man.

*Plant Breeding*—The study of genetic topics peculiar to plants and of the methods and problems of the plant bred.

*Post-Harvest Physiology*—The study of physical and chemical processes of plants before and after harvest and the influence of environmental, chemical, and storage factors on the processes.

*Agrostology*—The establishment and maintenance of turf grasses used on athletic fields, highways, and airports.

*Silvics*—The study of the life history, characteristics, and ecology of forest trees, especially in stands.

*SEDIMENTOLOGY*—The study of the origin and deposition of sediments. This includes the weathering processes that act mechanically and chemically to break up pre-existing rocks, and processes of transportation of the material, and the processes by which the sediment is compacted and hardened to rock. Knowledge of sediment transportation and deposition can be applied to the problem of predicting the siltation rate of a body of water.

*SOIL SCIENCE*—The study of the origin and classification of soils, their physical and chemical properties, and soil management and conservation. Properties of soils have effects on agricultural productivity, and important implications for land-use planning. The purpose of a soil survey, after mapping the boundaries between kinds of soils, is to "correlate and predict adaptability of soils to various land uses: agricultural, highway location, sub-

urban or urban development. This survey is an important element of soil conservation and management practices. The soil conservationist seeks to minimize the erosion of soils caused by human activity by advocating land uses that are compatible with the soil type. Accelerated erosion may have consequences that reach far beyond the lands on which the erosion takes place. Rural farm communities may suffer severe economic depression if the land has lost its productive capacity. Dust storms may incur losses in neighboring communities. An entire watershed may be adversely affected by excessive upstream topsoil erosions and slope denudation that results in heavy sediment load and the lowering of flow during dry seasons.

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# APPENDIX A

## CLASSIFICATION OF WETLANDS

Appendix A is taken from the "Classification of Wetlands and Deep-Water Habitats of the United States (An Operational Draft)" by Cowardin et al. At the time of the printing of this manual, final revisions to the Cowardin classification system are in press. (Additional graphics for this appendix were done by Caren Caljouw.)

# THE CLASSIFICATION SYSTEM

The structure of this classification is hierarchical, progressing from systems and subsystems, at the most general levels, to classes, subclasses and dominance types. Modifiers for water regime, water chemistry and soils are applied to classes, subclasses and dominance types. Figures 3-7 illustrate the classification structure within each of the five ecological systems. Special modifiers are also included to describe wetlands and deep-water habitats either created or highly modified by man or beavers.

## HIERARCHICAL STRUCTURE

### Systems and Subsystems

The term SYSTEM refers here to a complex of wetland and deepwater habitats that share the influence of one or more dominant hydrologic, geomorphologic, chemical, or biological factors. We have chosen to subdivide systems into more specific categories called SUBSYSTEMS.

The characteristics of the five major systems have been discussed at length in the scientific literature and the concepts are well-recognized, but there is frequent disagreement as to which attributes should be used to bound the systems in space. For example, both the limit of tidal influence and the limit of ocean-derived salinity have been proposed for bounding the upstream end of the Estuarine System (Caspers 1967). As Bormann and Likens (1969) pointed out, boundaries of ecosystems are defined to meet pragmatic needs.

1. MARINE

Definition.--The Marine System (Figure 3) consists of the open ocean overlying the continental shelf and its associated high-energy coastline. Marine habitats are exposed to the waves and currents of the open ocean and the water regimes are determined primarily by the ebb and flow of oceanic tides. Salinites exceed 30°/₀₀ (parts per thousand), with little or no dilution except opposite mouths of estuaries. Shallow coastal indentations or bays without appreciable fresh-water inflow, and coasts with exposed rocky islands that provide the mainland with little or no shelter from wind and waves, are also considered part of the

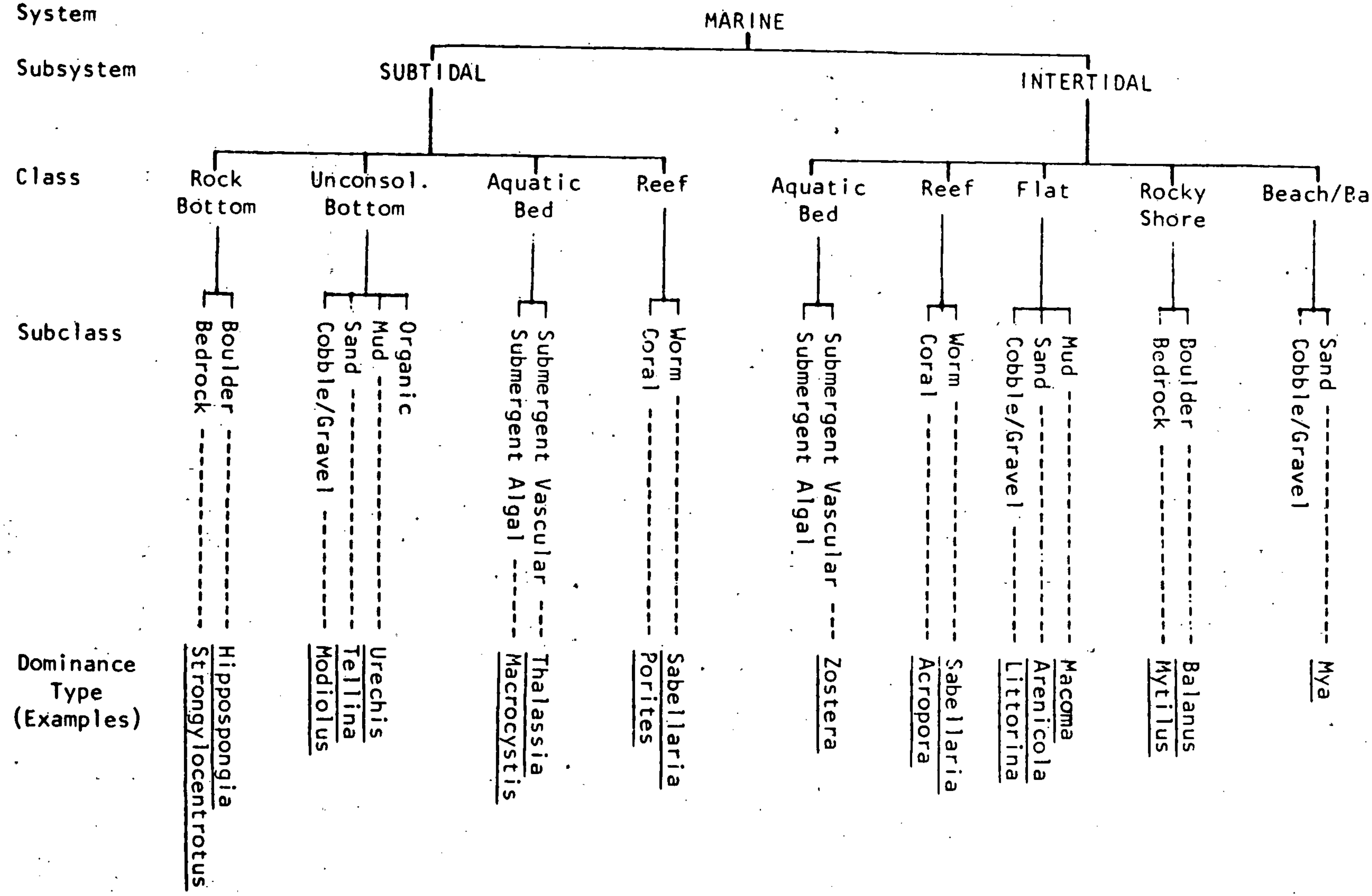


Figure 3. DIAGRAM OF THE CLASSIFICATION HIERARCHY FOR THE MARINE SYSTEM

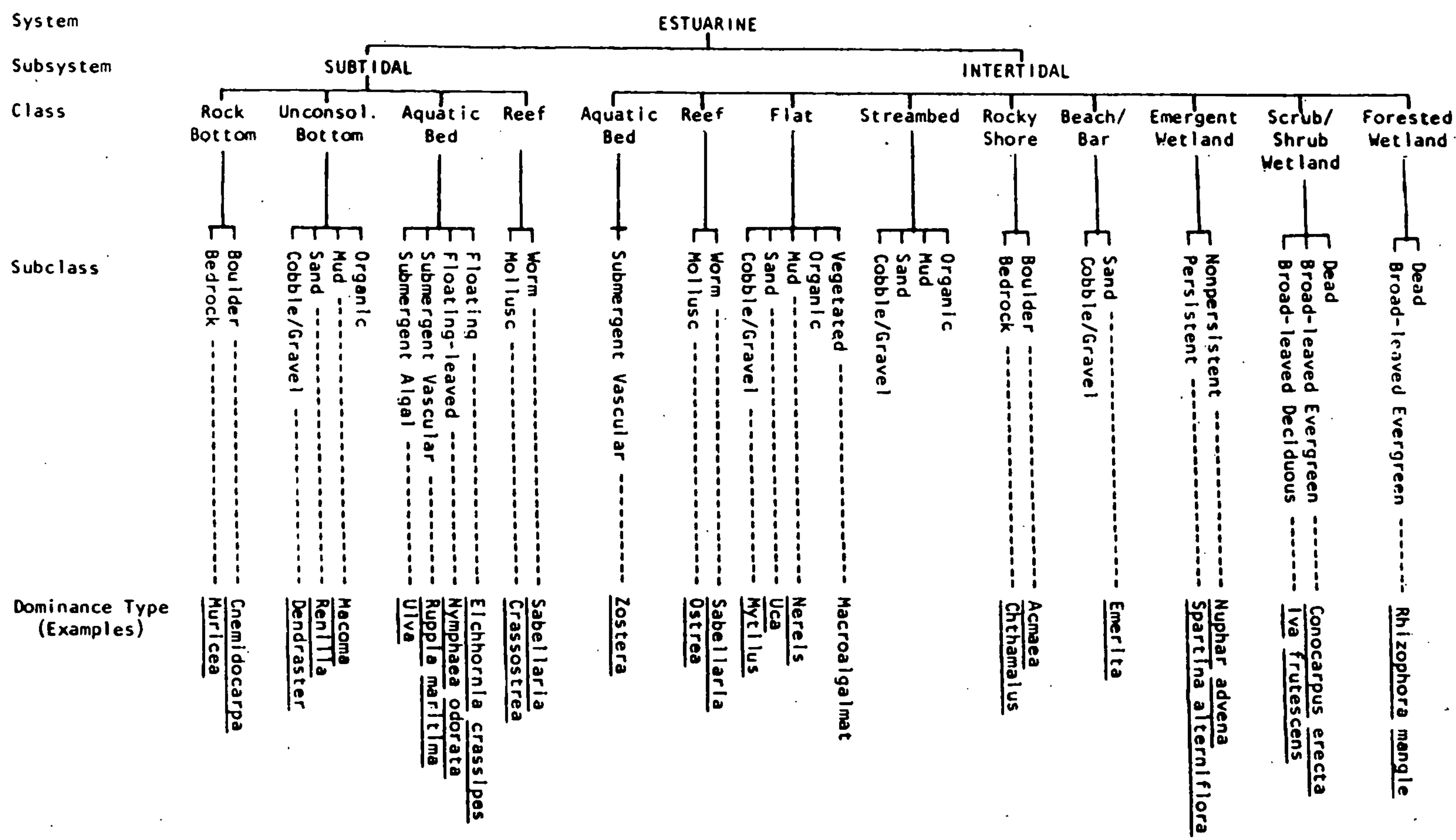


Figure 4. DIAGRAM OF THE CLASSIFICATION HIERARCHY FOR THE ESTUARINE SYSTEM.

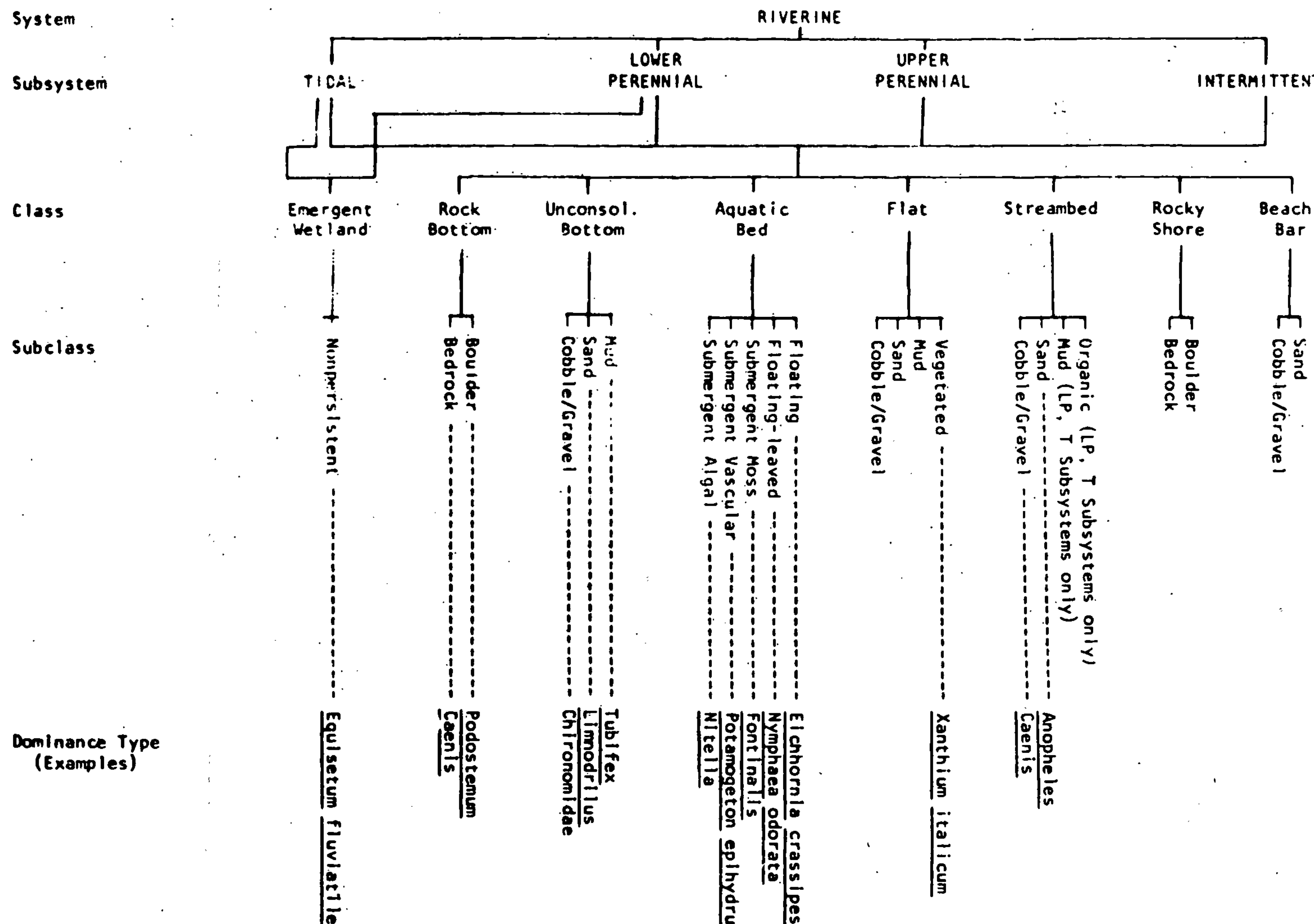


Figure 5. DIAGRAM OF THE CLASSIFICATION HIERARCHY FOR THE RIVERINE SYSTEM.

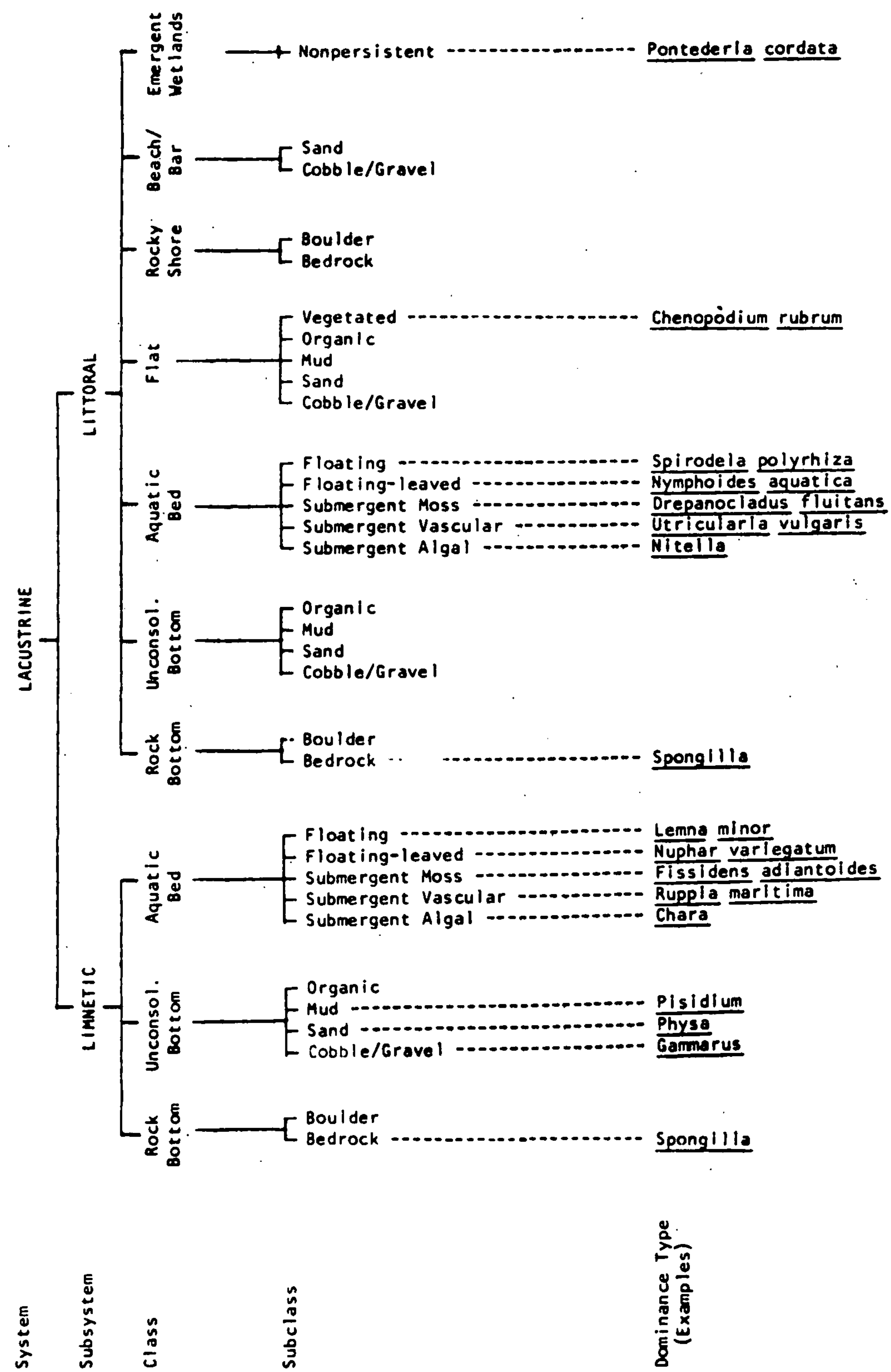


Figure 6. DIAGRAM OF THE CLASSIFICATION HIERARCHY OF THE LACUSTRINE SYSTEM.

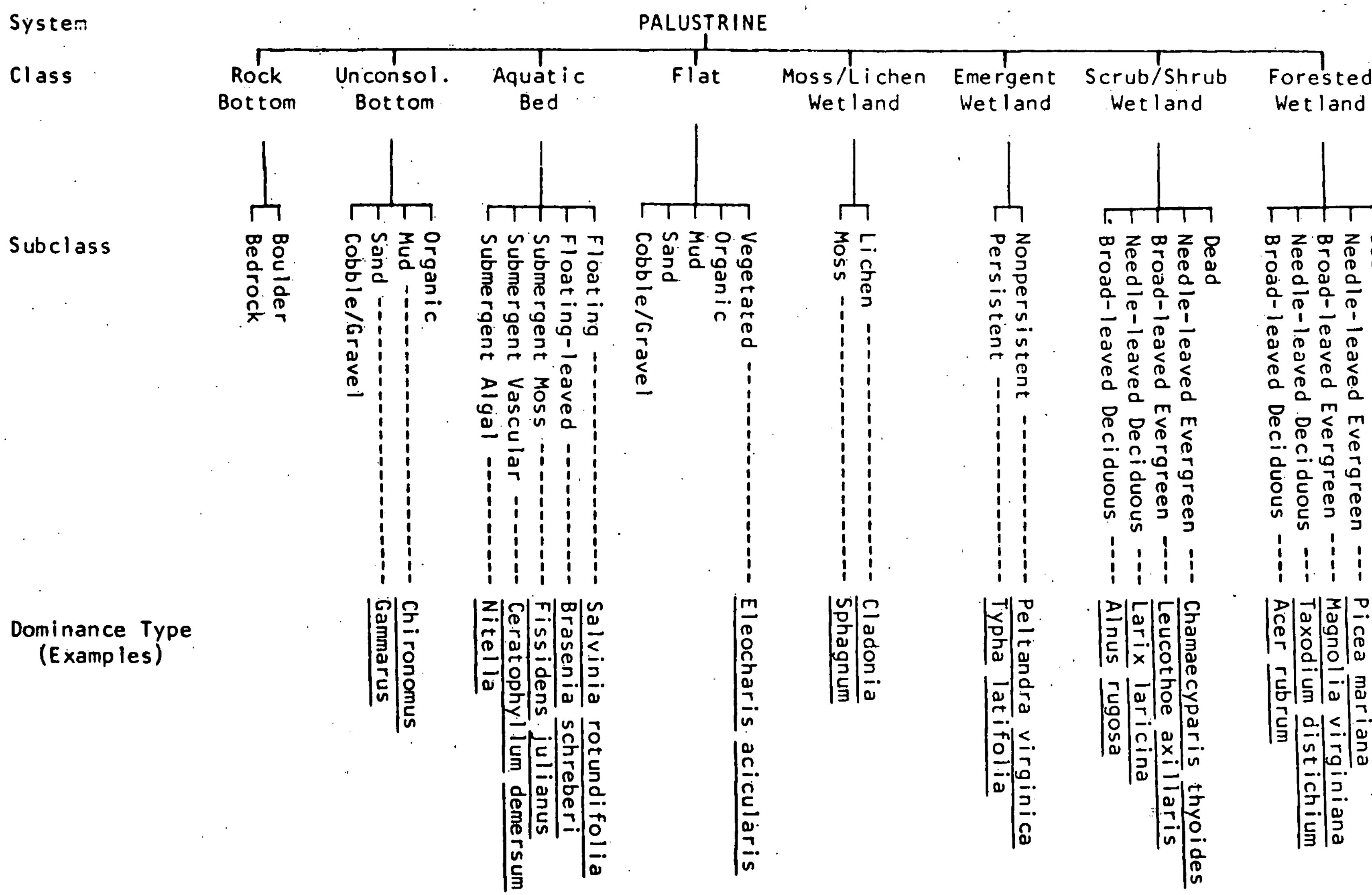


Figure 7. DIAGRAM OF THE CLASSIFICATION HIERARCHY OF THE PALUSTRINE SYSTEM.

Marine System because they generally support typical marine biota.

Limits.--The Marine System extends from the outer edge of the continental shelf to: 1) the landward limit of tidal inundation (extreme high water of spring tides: EHWS) including the splash zone from breaking waves; 2) the seaward limit of wetland emergents, trees or shrubs where they extend into open ocean waters; or 3) the seaward limit of the Estuarine System where this limit is determined by factors other than vegetation. Deep-water habitats lying beyond the seaward limit of the Marine System are outside of the scope of this classification system.

Description.--The distribution of plants and animals in the Marine System primarily reflects differences in: 1) degree of exposure of the site to waves; 2) the texture and physico-chemical nature of the substrate; 3) the amplitude of the tides; and 4) latitude, which governs water temperature, the intensity and duration of solar radiation, and the presence or absence of ice.

Subsystems

(1) Subtidal. This includes that part of the Marine System in which the substrate is continuously submerged.

(2) Intertidal. This includes that part of the Marine System in which the substrate is exposed and flooded by tides. It also includes the associated splash zone.

Classes.--Rock Bottom, Unconsolidated Bottom, Aquatic Bed, Reef, Flat, Rocky Shore and Beach/Bar.

2. ESTUARINE

Definition.--The Estuarine System (Figure 4) consists of deep-water tidal habitats and adjacent tidal wetlands which are usually semi-enclosed by land, but have open, partially obstructed, or sporadic access to the open ocean and in which ocean water is at least occasionally diluted by fresh water runoff from the land. The salinity may be periodically increased above that of the open ocean by evaporation. Along some low energy coastlines there is appreciable dilution of sea water. Those offshore areas with typical estuarine plants and animals,

such as mangroves (Rhizophora mangle) and oysters (Crassostrea virginica), are also included in the Estuarine System even though they are not semi-enclosed by land.[1]

Limits.--Estuaries extend upstream and landward to the place where ocean-derived salts measure less than 0.5°/oo during the period of average annual low flow. The seaward limit of the Estuarine System is: 1) a line closing the mouth of a river, bay or sound; 2) a line enclosing an offshore area of diluted sea-water with typical estuarine flora and fauna; or 3) the seaward limit of wetland emergents, shrubs or trees where these plants grow seaward of the line closing the mouth of a river, bay, or sound.

Description.--The Estuarine System includes both estuaries and lagoons. It is more strongly influenced by its association with land than the Marine System. In terms of wave action, estuaries are generally considered to be low energy systems.

Estuarine water regimes and water chemistry are affected by one or more of the following forces: oceanic tides, precipitation, freshwater runoff from land areas, evaporation and wind. Estuarine salinities range from hyperhaline to oligohaline (Table 1). The salinity may be variable (poikilohaline), as in the case of hyperhaline lagoons (e.g., Laguna Madre, Texas) and most brackish estuaries (e.g., Chesapeake Bay, Virginia-Maryland); or it may be relatively stable (homoiohaline), as in the case of sheltered euhaline embayments (e.g., Chincoteague Bay, Maryland) or brackish embayments with partially obstructed access or small tidal range (e.g., Pamlico Sound, North Carolina). (For an extended discussion of estuaries and lagoons see Lauff [1967]).

Subsystems

(1) Subtidal. This includes that part of the Estuarine System in which the substrate is continuously submerged.

(2) Intertidal. This includes that part of the Estuarine

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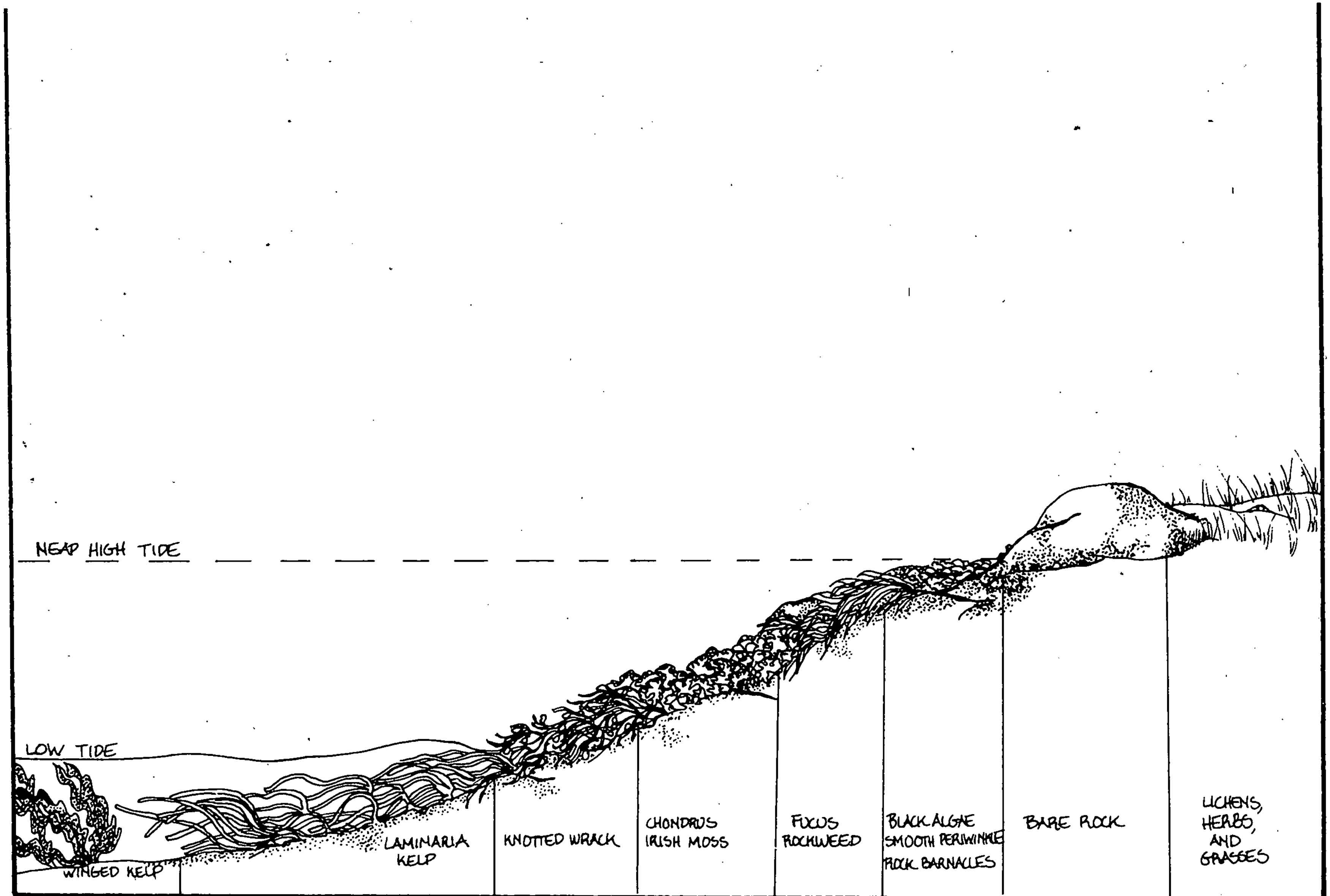
[1]The Coastal Zone Management Act of 1972 defines an estuary as, "that part of a river or stream or other body of water having unimpaired connection with the open sea, where the sea water is measurably diluted with fresh water derived from land drainage." The Act further states that, "the term includes estuary-type areas of the Great Lakes." However, in this system we will not classify areas of the Great Lakes as estuarine.




ADAPTED FROM R.L. SMITH, ECOLOGY AND FIELD BIOLOGY, HARPER AND ROW 1966.

FIGURE **A1**. A ROCKY SHORE IS A HIGH ENERGY ENVIRONMENT. THE LARGE ROCKS PROVIDE A STABLE SUBSTRATE FOR THE ATTACHMENT AND GROWTH OF MANY INVERTEBRATES, ALGAE, AND LICHENS.

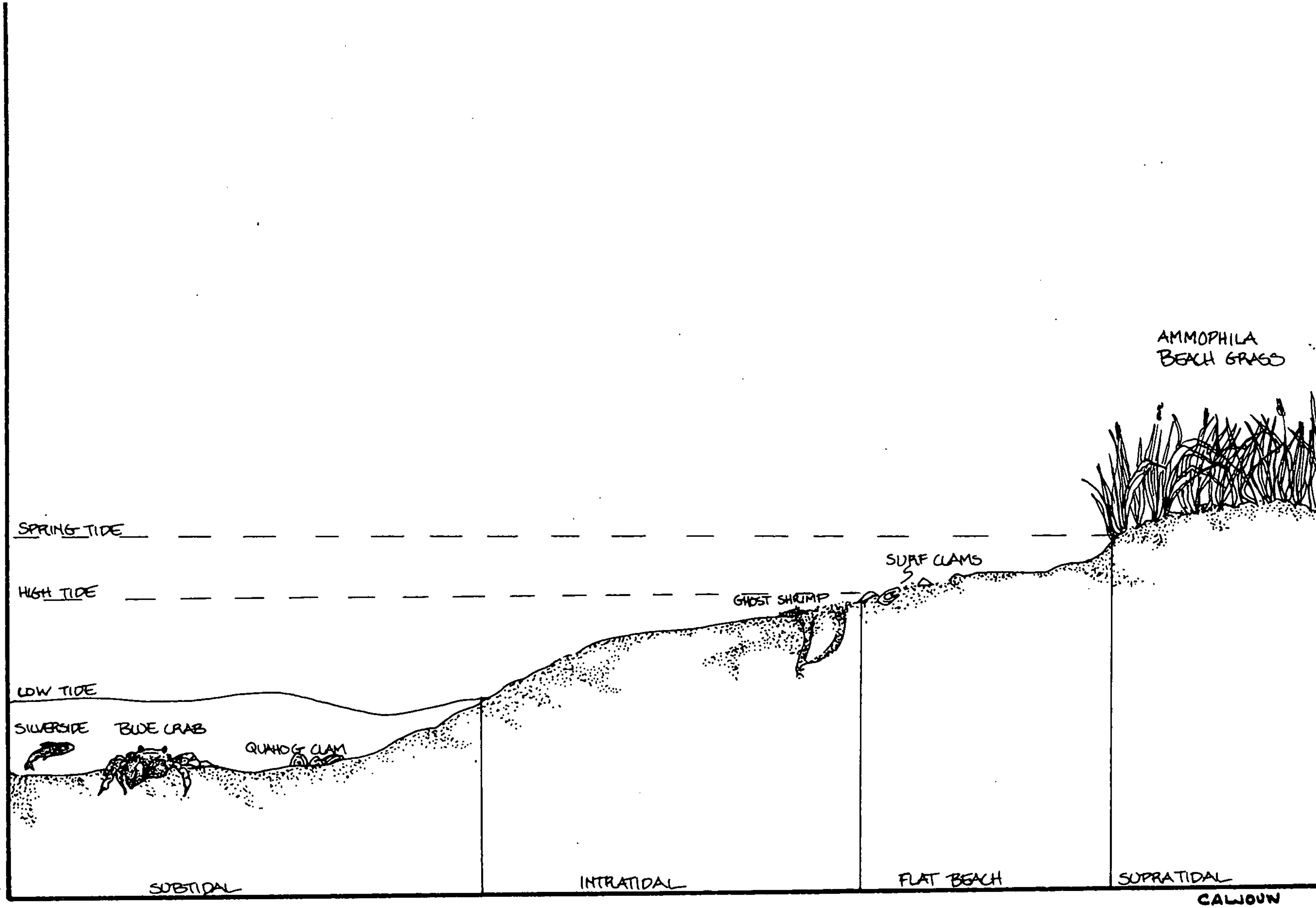



FIGURE **A2**. A SANDY BEACH. THIS ECOSYSTEM PRODUCES VERY LITTLE OF ITS OWN FOOD. SPECIES MUST ADAPT TO THE CONSTANT STRESS OF POUNDING WAVES AND SHIFTING SANDS.

System in which the substrate is exposed and flooded by tides. It also includes the associated splash zone.

Classes.--Rock Bottom, Unconsolidated Bottom, Aquatic Bed, Reef, Flat, Streambed, Rocky Shore, Beach/Bar, Emergent Wetland, Scrub/Shrub Wetland and Forested Wetland.

3. RIVERINE

Definition.--The Riverine System (Figure 5) includes all wetlands and deep-water habitats contained within a channel, except: 1) wetlands dominated by trees, shrubs, persistent emergents, nonaquatic mosses or lichens, and 2) habitats with waters containing ocean-derived salts in excess of 0.5°/₀₀. A channel is, "an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water" (Langbein and Iseri 1960:5).

Limits.--The Riverine System is bounded on the landward side by upland, by the channel bank (including natural or man-made levees), or by wetland dominated by trees, shrubs, persistent emergents, nonaquatic mosses or lichens. In braided streams, the system is bounded by the banks forming the outer limits of the depression within which the braiding occurs.

The Riverine System terminates at the downstream end where the concentration of ocean-derived salts in the water exceeds 0.5°/₀₀ during the period of annual average low flow, or where the channel enters a lake. It terminates at the upstream end where tributary streams originate, whether their flow is perennial or intermittent, or where the channel leaves a lake. Springs discharging into a channel are considered part of the Riverine System.

Description.--Water is usually, but not always, flowing (lotic) in the Riverine System. Upland islands or Palustrine wetlands may occur in the channel but they are not included in the Riverine System. Palustrine Forested Wetlands, Emergent Wetlands, Scrub/Shrub Wetlands, and Moss/Lichen Wetlands may occur adjacent to the Riverine System, often

on a flood plain. Many biologists have suggested that all the wetlands occurring on the river flood plain should be a part of the Riverine System because they consider their presence to be the result of river flooding. However, we concur with Reid and Wood (1976:72,84) who state, "The floodplain is a flat expanse of land bordering an old river. . . . Often the floodplain takes the form of a very level plain occupied by the present stream channel, and it may never, or only occasionally, be flooded. . . . It is this subsurface water [the ground water] that controls to a great extent the level of lake surfaces, the flow of streams, and the extent of swamps and marshes."

Subsystems.--The Riverine System is divided into four subsystems: the Tidal, the Lower Perennial, the Upper Perennial, and the Intermittent. Each is defined in terms of water permanence, gradient, water velocity, streambed composition and the extend of flood plain development. The subsystems have characteristic water temperatures, flora, and fauna (see Reid 1961, Illies and Botosaneau 1963, Hynes 1970). All four subsystems are not necessarily present in all rivers, and the order of occurrence may be other than that given below.

(1) Tidal. In this subsystem, the gradient is low and water velocity fluctuates under tidal influence. The streambed is mainly mud with occasional patches of sand. Oxygen deficits may occur at times and the fauna is similar to that in the Lower Perennial Subsystem. The flood plain is typically well-developed and water temperatures approximate those of the Lower Perennial Subsystem.

(2) Lower Perennial. This includes those channels that contain nontidal flowing water throughout the year. The flow is slow and the substrate consists mainly of sand and mud. Oxygen deficits may occur at times, the fauna is composed mostly of species that reach their maximum abundance in still water, and true planktonic organisms are common. The gradient is low compared to that of the Upper Perennial Subsystem and the flood plain is well-developed. Generally, the average of mean monthly water temperatures is more than 20°C, and in tropical latitudes, the average of the monthly means during the summer may reach 25°C (Illies and Botosaneau 1963).

(3) Upper Perennial. This includes channels that contain flowing water throughout the year. The flow is fast and the substrate consists of rock, cobbles, or gravel with occasional patches of sand. The natural dissolved oxygen concentration is normally near saturation; the fauna is characteristic of running water, and there are few or no planktonic forms. The gradient is high compared to the Lower Perrenial Subsystem, and there is very little flood plain development. Generally, the average of mean monthly water temperatures is about 20 C (Illes and Botosaneau 1963).

(4) Intermittent. This includes those channels that contain flowing water only part of the time. During those periods when the water is not flowing, it may remain in isolated pools or surface water may be absent.

Classes.--Rock Bottom, Unconsolidated Bottom, Aquatic Bed, Flat, Streambed, Rocky Shore, Beach/Bar, and Emergent Wetland (nonpersistent).

4. LACUSTRINE

Definition.--The Lacustrine System (Figure 6) includes wetlands and deep-water habitats with all of the following characteristics: 1) situated in a topographic depression or a dammed river channel; 2) lacking trees, shrubs, persistent emergents, nonaquatic mosses or lichens with greater than 30 percent areal coverage; and 3) greater than 8 hectares (20 acres) in size. Similar wetlands and deep-water habitats smaller than 8 ha are also included in the Lacustrine System if an active wave-formed or bedrock shoreline feature forms all or part of the boundary, or if the water depth in the deepest part of the basin is greater than 2 m at low water. Lacustrine waters may be tidal or nontidal, but ocean-derived salinity is always less than 0.5°/₀₀.

Limits.--The Lacustrine System is bounded by upland or by wetland dominated by trees, shrubs, persistent emergents, nonaquatic mosses or lichens. Lacustrine systems formed by damming a river channel are bounded by the contour approximating the normal spillway

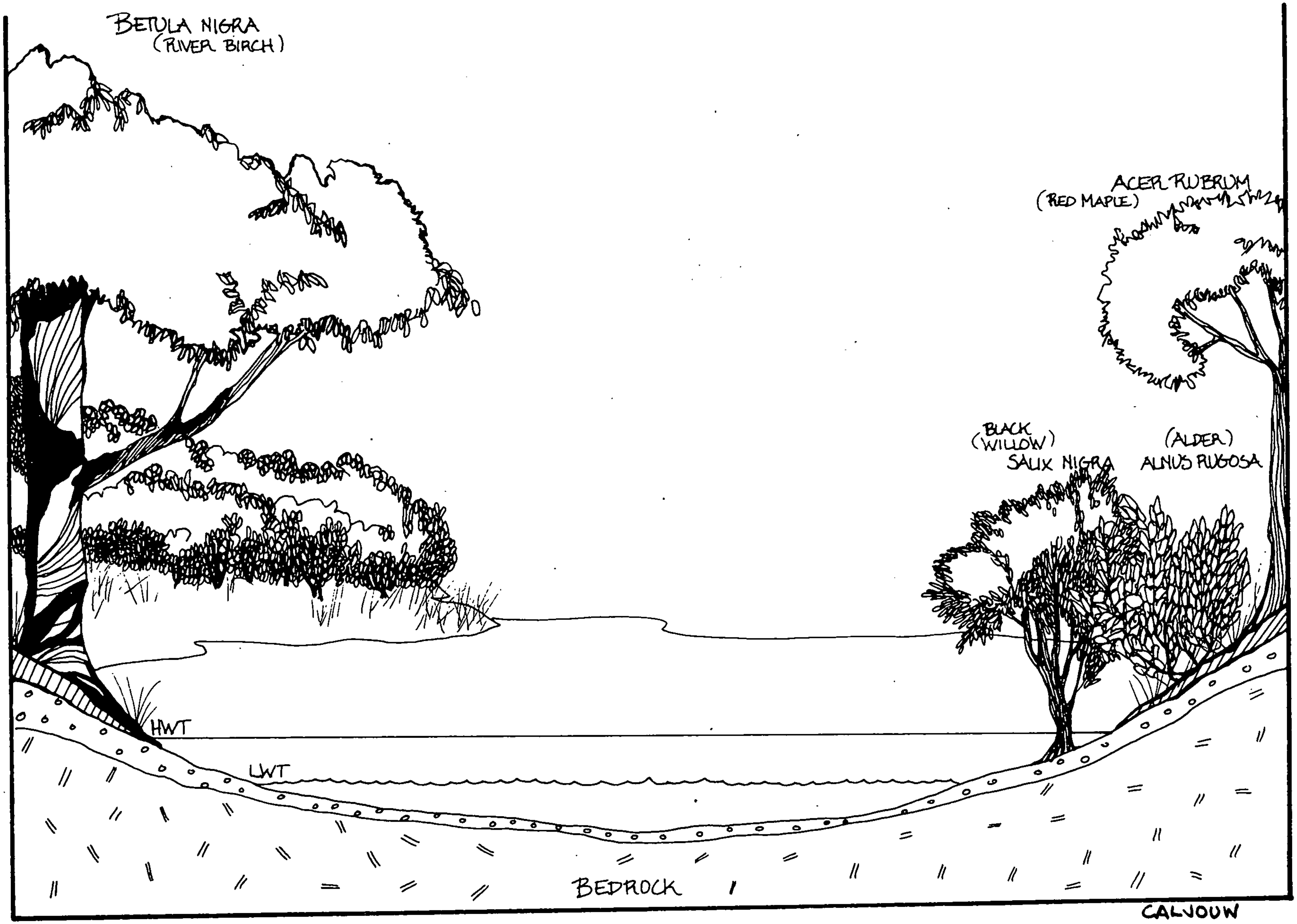



FIGURE **A3.**

A TYPICAL BROAD-LEAVED DECIDUOUS FORESTED WETLAND

elevation or normal pool elevation except where Palustrine wetlands extend lakeward of that boundary. Where a river enters a lake, the extension of the lacustrine shoreline forms the Riverine/Lacustrine boundary.

Description.--The Lacustrine System includes permanently flooded lakes and reservoirs (e.g., Lake Superior), intermittent lakes (e.g., playa lakes) and tidal lakes with ocean-derived salinities below 0.5°/₀₀ (e.g., Lake Maurapas, Louisiana). Typically, this system contains extensive areas of deep water and exhibits considerable wave action. Islands of Palustrine wetland may lie within the boundaries of the Lacustrine System.

Subsystems

(1) Limnetic. This subsystem includes all deep-water habitats within the Lacustrine System. Many small Lacustrine Systems have no Limnetic Subsystem.

(2) Littoral. This subsystem includes all wetland habitats that fall within the Lacustrine System. It extends from the shoreward boundary of the system to a depth of 2 m below low water or to the maximum extent of nonpersistent emergents if these grow beyond the 2 m depth.

Classes.--Rock Bottom, Unconsolidated Bottom, Aquatic Bed, Flat, Rocky Shore, Beach/Bar, and Emergent Wetland (nonpersistent).

5. PALUSTRINE

Definition.--The Palustrine System (Figure 7) includes all nontidal wetlands dominated by trees, shrubs, persistent emergents, nonaquatic mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5°/₀₀. It also includes wetlands lacking such vegetation, but with all the following characteristics: 1) size less than 8 hectares; 2) absence of an active wave-formed or bedrock shoreline feature; 3) water depth in the deepest part of basin less than 2 m at low water; and 4) salinity due to ocean-derived salts less than 0.5°/₀₀.

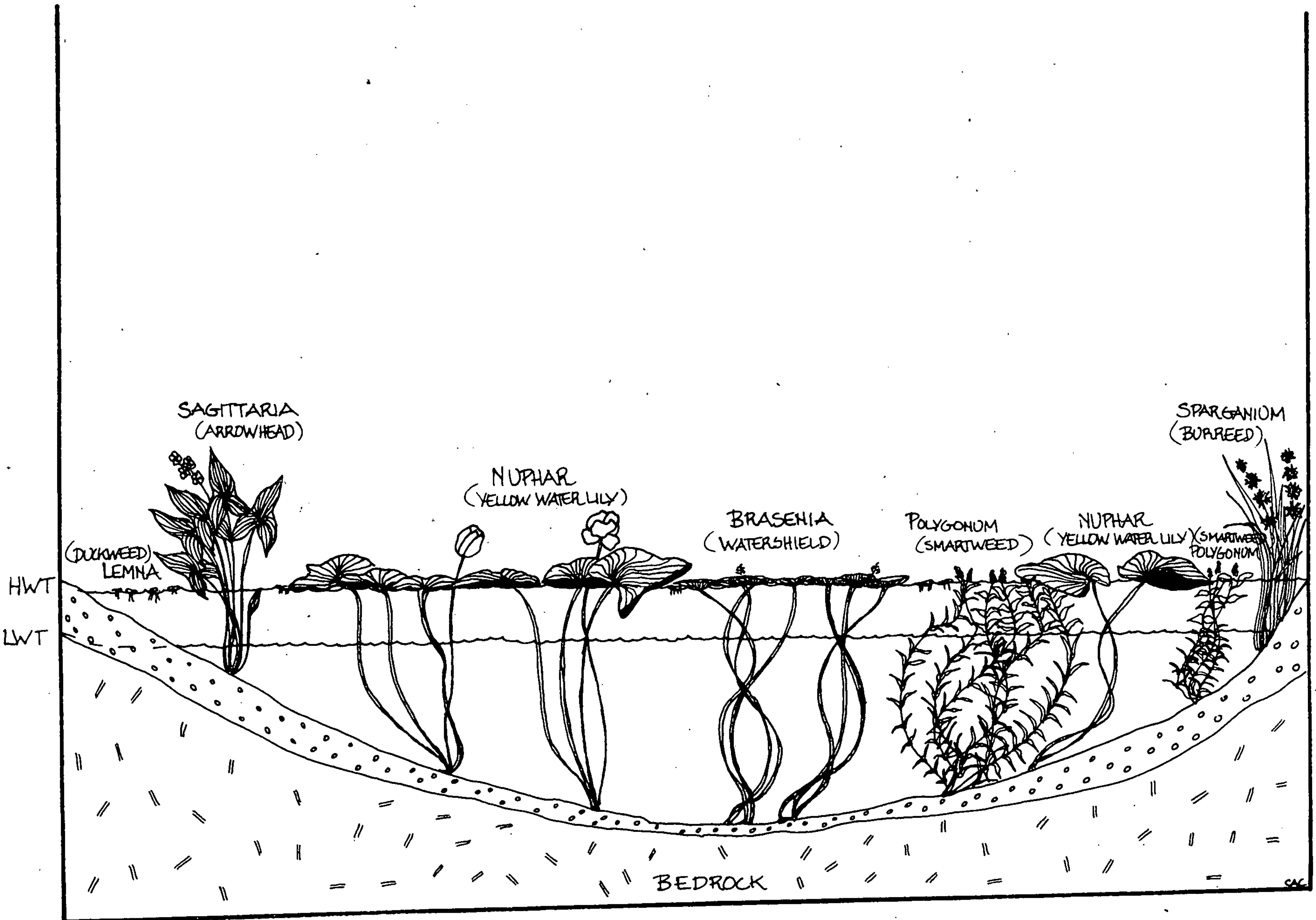



FIGURE A4.
A TYPICAL FLOATING-LEAVED AQUATIC BED (AN INLAND WETLAND).

Limits.--The Palustrine System is bounded by upland or by any of the other four systems.

Description.--The Palustrine System was developed to group the extensive vegetated wetlands traditionally called by such names as marsh, swamp, bog, fen, and prairie which are found throughout the country. It also includes small, shallow permanent or intermittent water bodies, often called ponds. Palustrine wetlands may be situated shoreward of lakes, river channels or estuaries; on river flood plains; in isolated catchments; or on slopes. They may also occur as islands in lakes or rivers. The erosive forces of wind and water are of minor importance except in times of severe flood.

The emergent vegetation adjacent to rivers and lakes is often referred to as "the shore zone" or the "zone of emergent vegetation" (Reid and Wood 1976), and is generally considered a separate community from that of the river itself. As an example, Hynes (1970:85) says in reference to riverine habitats, "We will not here consider the long list of emergent plants which may occur along the banks out of the current, as they do not belong, strictly speaking, to the running water habitat." There are often great similarities between wetlands lying adjacent to lakes or rivers and isolated wetlands of the same class in basins without open water.

Subsystems.--No subsystems are recognized for the Palustrine System.

Classes.--Rock Bottom, Unconsolidated Bottom, Aquatic Bed, Flat, Moss/Lichen Wetland, Emergent Wetland, Scrub/Shrub Wetland and Forested Wetland.

## Classes, Subclasses and Dominance Types

The CLASS is the highest taxonomic unit below the subsystem level. It describes the general appearance of the habitat in terms of either plant life form or physiography and composition of the substrate,

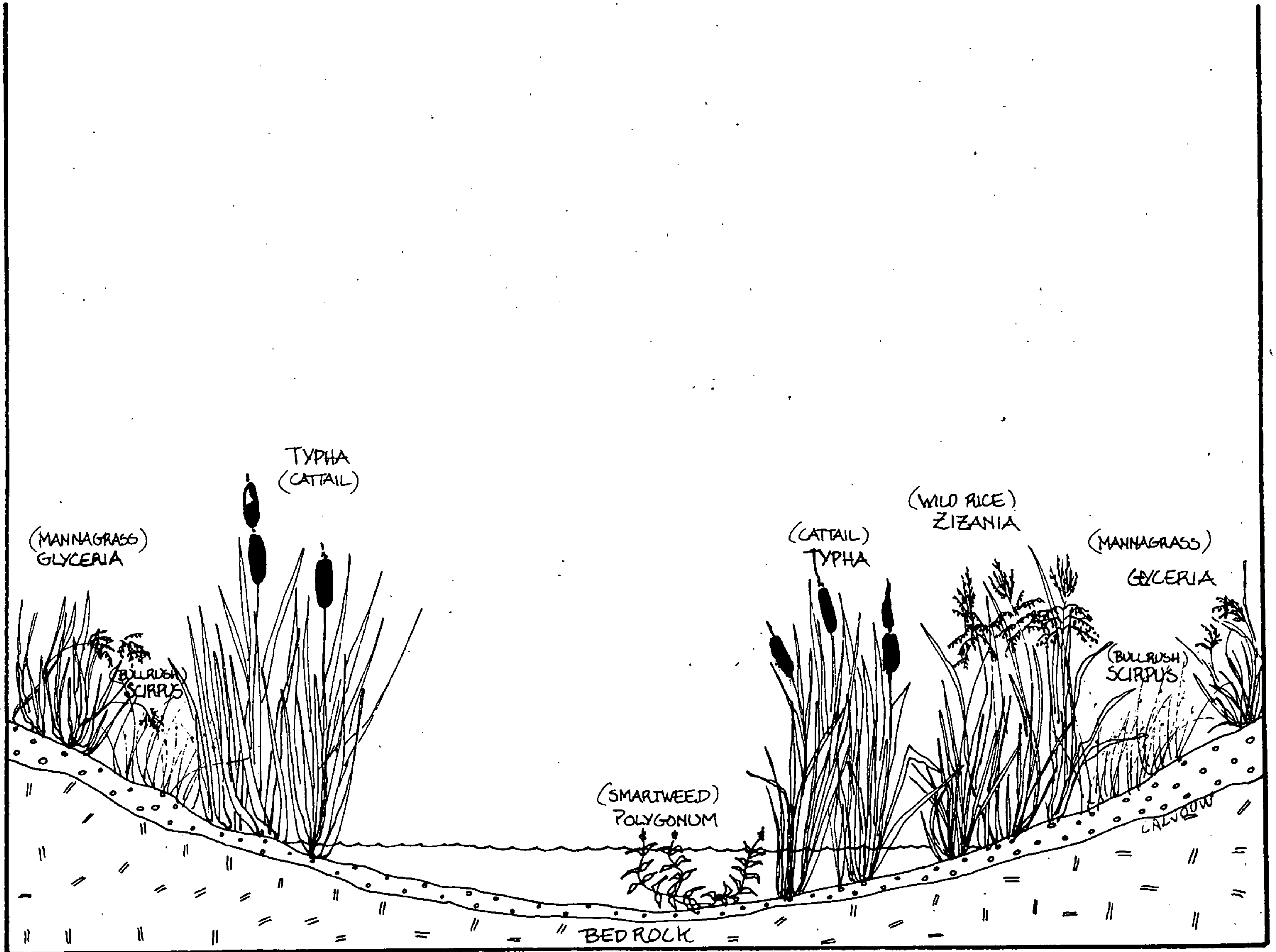



FIGURE A5.
NARROW-LEAVED EMERGENT WETLAND

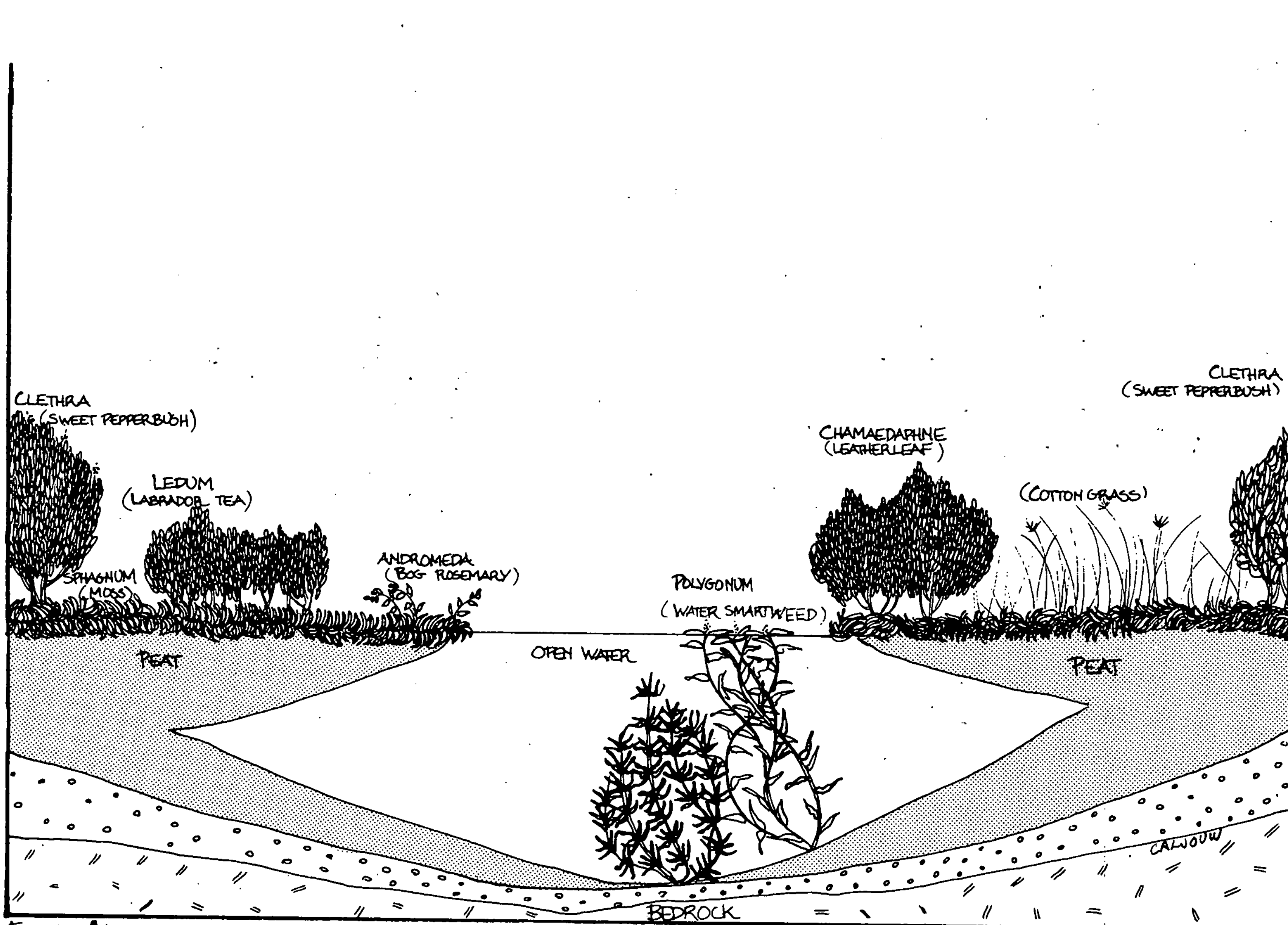



FIGURE A6.
A TYPICAL BROAD-LEAVED EVERGREEN SCRUB/SHRUB WETLAND

features which can be recognized without the aid of detailed environmental measurements.[1]

Use of life forms at the class level has two major advantages: 1) it does not require a high level of biological expertise to distinguish between various life forms, and 2) it has been established that various life forms are easily recognizable on a great variety of remote sensing products (e.g., Radforth 1962, Anderson et al. 1976). If plants cover more than 30 percent of the substrate, we distinguish classes on the basis of the life form of the plants which constitute the uppermost layer of vegetation and possess an areal coverage greater than 30 percent. For example, an area with 50 percent areal coverage of trees over a shrub layer with a 60 percent areal coverage would be classified as a Forested Wetland; an area with 20 percent areal coverage of trees over the same (60 percent) shrub layer would be classified a Scrub/Shrub Wetland. Finer differences in life forms are recognized at the SUBCLASS level. For example, Forested Wetland is divided into Broad-leaved Deciduous, Needle-leaved Deciduous, Broad-leaved Evergreen, Needle-leaved Evergreen, and Dead Subclasses. Subclasses are named on the basis of the predominant life form.

If plants cover less than 30 percent of the substrate, the physiography and composition of the substrate are the principal characteristics used to distinguish classes. The nature of the substrate reflects regional and local variations in geology and the influence of wind, waves, and currents upon erosion and deposition of substrate materials. Rocky Shores have been recognized as a separate class, also based on substrate, even though these habitats may support more than 30 percent cover of macrophytic algae. Similarly, we decided to characterize beaches and flats on the basis of substrate, although, in some cases, macrophytic algae or "pioneer" vegetation may cover more than

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[1] Our attempts to use familiar terms such as marsh, swamp, bog, and meadow at the class level were unsuccessful primarily because of wide discrepancies in the use of these terms in various regions of the United States. In an effort to resolve that difficulty, we decided to base the classes upon the fundamental components (life form, water regime, substrate type, water chemistry) which give rise to such terms. We believe that this approach will greatly reduce the misunderstandings and confusion that result from the use of the common terms.

30 percent of the substrate. Reefs are a unique class in which the substrate itself is composed primarily of living and dead animals.

Most classes based on substrate have been divided into subclasses according to the texture or composition of the substrate; for example, four subclasses of unconsolidated bottoms are recognized: Cobble/Gravel, Sand, Mud and Organic. In the special case of coral reefs, subclasses are designated on the basis of the type of organism that has formed the reef.

The DOMINANCE TYPE forms the taxonomic category subordinate to subclass. Dominance types are determined on the basis of dominant plant species (e.g., Jeglum et al. 1974), dominant sedentary or sessile animal species (e.g., Thorson 1957) or dominant plant and animal species (e.g., Stephenson and Stephenson 1972). A dominant plant species has traditionally meant one that has control over the community (Weaver and Clements 1938:91), and this plant is also usually the predominant species (Cain and Castro 1959:29). When the subclass is based on life form we name the dominance type for the dominant species or combination of species (codominants) in the same layer of vegetation used to determine the subclass.[1] For example, a Needle-leaved Evergreen Forested Wetland with 70 percent areal coverage of *Picea mariana* and 30 percent areal coverage of *Larix laricina* would be designated as a *Picea mariana* Dominance Type. When the relative abundance of codominant species is approximately equal, the Dominance Type consists of a combination of species names. For example, an Emergent Wetland with approximately equal areal coverage of broad-leaved cattail (*Typha latifolia*) and hardstem bulrush (*Scirpus acutus*) would be designated as *Typha latifolia*/*Scirpus acutus* Dominance Type.

When the subclass is based on substrate material, the Dominance Type is named for the predominant plant or sedentary or sessile macroinvertebrate species without regard for life form. In the Marine and

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[1]Percent areal cover will seldom be measured in the application of this system, but the term must be related to a frame of reference. We suggest $2m^2$ for herbaceous and moss layers, $16m^2$ for shrub layers and $100m^2$ for tree layers (Meuller-Dombois and Ellenberg 1974:74). When percent areal cover is the key for establishing boundaries between units of the classification, it may be necessary to make cover measurements occasionally on plots in order to maintain uniformity of ocular estimates made in the field, or interpretations made from aerial photographs.

Estuarine Systems, sponges, alcyonarians, molluscs, crustaceans, worms, ascidians and echinoderms may all be part of the community represented by the Macoma Dominance Type. Sometimes it is necessary to designate two or more codominant species as a Dominance Type. Thorson (1957) has recommended guidelines and suggested definitions for establishing community types and dominants on level bottoms.

1. ROCK BOTTOM

Definition.--In the Marine and Estuarine Systems the class Rock Bottom includes all deep-water (subtidal) habitats with rock substrates. In the Lacustrine, Palustrine and Riverine Systems, Rock Bottom includes all wetlands and deep-water habitats with rock substrates and permanently flooded, intermittently exposed, and semipermanently flooded water regimes. This class does not include those habitats classified as Aquatic Beds.

Description.--The solid rock substrate of the rocky benthic or bottom zone is one of the most important factors in determining the abundance, variety and distribution of organisms. The stability of the bottom allows a rich assemblage of plants and animals to develop. Rock bottoms are usually high energy habitats with well-aerated waters. Temperature, salinity, current and light penetration are also important factors in determining the composition of the benthic community. Animals that live on the rocky surface are generally firmly attached by hooking or sucking devices although they may move about over the substrate in search of food. Some may be permanently attached by cement. A few animals hide in rocky crevices and under rocks, some move rapidly enough to avoid being swept away, and others burrow into finer substrates between boulders. Plants are also firmly attached (e.g., by holdfasts) and, in the Riverine System, they are commonly streamlined or flattened in response to high water velocities.

Subclasses and Dominance Types.--Rock Bottom has been divided into two subclasses, Bedrock and Boulder. The Dominance Types for both subclasses are similar.

(1) Bedrock. These bottoms consist of stable bedrock

surfaces. Grooves and crevices, when present, provide shelter and microhabitats.

(2) Boulder. These bottoms consist predominantly of relatively stable, rock fragments larger than 256 mm (10 in) in diameter (Wentworth 1922). Often, finer material is mixed with these boulders.

Examples of Dominance Types for the Marine and Estuarine Systems are *Hippospongia* encrusting sponges and *Cnemidocarpa*, *Strongylocentrotus*, *Pisaster*, *Muricea*, and *Laminaria*. Examples of Lacustrine and Riverine Dominance Types are *Spongilla*, *Lymnaea*, *Caenis*, Chironomidae, and *Hydrosyche*.

2. UNCONSOLIDATED BOTTOM

Definition.--In the Marine and Estuarine Systems, Unconsolidated Bottom includes all deep-water (subtidal) habitats with unconsolidated substrates. In Lacustrine, Palustrine and Riverine Systems, the class includes all unconsolidated substrates with permanently flooded, intermittently exposed and semipermanently flooded water regimes. This class does not include habitats classified as Aquatic Beds.

Description.--Unconsolidated Bottoms are characterized by the lack of large stable surfaces for plant and animal attachment. They are usually found in lower energy areas than Rock Bottoms, and may be very unstable. Exposure to wave and current action, temperature, salinity and light penetration determine the composition and distribution of organisms.

Most macroalgae attach to the substrate by means of basal holdfast cells or discs; however, in sand and mud, algae penetrate the substrate and higher plants can successfully root if wave action and currents are not too strong. The majority of animals in unconsolidated sediments live within the substrate, e.g., *Macoma* and *Mellita*. Some, such as *Chaetopterus*, maintain permanent burrows, and others may live on the surface, especially in coarse-grained sediments.

In the Marine and Estuarine Systems, Unconsolidated Bottom communities are relatively stable. They vary from the Arctic to the tropics, depending largely on temperature, and from the open ocean to the upper

end of the estuary depending upon salinity. Thorson (1957) has summarized and described characteristic types of level bottom communities in detail.

In the Riverine System, the substrate type is, to a great extent, determined by current velocity, and plants and animals exhibit a high degree of morphologic and behavioral adaptation to flowing water. Some species are confined to specific substrates and others are at least more abundant in one type of substrate than they are in others. According to Hynes (1970:208), "The larger the stones, and hence the more complex the substratum, the more diverse is the invertebrate fauna." In Lacustrine and Palustrine Systems, there is usually a high correlation, within a given water body, between the nature of the substrate and the number of species and individuals. For example, in the profundal bottom of eutrophic lakes where light is absent, oxygen content is low and carbon dioxide concentration is high, the sediments are ooze-like organic materials and species diversity is low. Each substrate type typically supports a relatively distinct community of organisms (Reid 1961:307).

Subclasses and Dominance Types.--The class Unconsolidated Bottom has been divided into four subclasses: Cobble/Gravel, Sand, Mud, and Organic. Differences in grain size and interstitial space in unconsolidated substrates greatly affect the species composition of the benthic flora and fauna.

(1) Cobble/Gravel. The substrate is predominantly cobble and gravel although finer sediments may be intermixed. An example of a Dominance Type for the Marine System is *Modiolus* and for the Estuarine System, *Dendraster*. Examples for the Lacustrine, Palustrine and Riverine Systems are *Diamesa*, *Nemoura*/*Eukiefferiella* (Slack et al. 1977). *Chironomus*/*Hydrosyche*/*Physa* (Krecker and Lancaster 1933), *Limnea*, *Baetis*, *Spongilla*, *Lumbriculus*, and *Gammarus*.

(2) Sand. The substrate is predominantly sand, although finer or coarser sediments may be intermixed. The Sand Bottom has a more limited fauna and flora than either Mud or Cobble/Gravel Bottom. Examples of Dominance Types in the Marine System are *Pecten*, *Tellina*, *Penaeus*, and *Spatangus* and for the Estuarine System, *Tellina*, *Arenicola*,

*Dendraster*, and *Renilla*. Examples for the Lacustrine, Palustrine and Riverine Systems are *Physa*, *Gammarus*, Chironomidae, *Limnodrilus*, and *Ephemera*.

(3) *Mud*. The substrate is predominantly silt and clay although coarser sediments or organic material may be intermixed. Organisms living in mud must often be able to adapt to rather low oxygen concentrations. Examples of Dominance Types for the Marine and Estuarine Systems include *Amphiura*, *Macoma*, *Echinocardium*, and *Urechis*. Examples of Dominance Types for the Lacustrine, Palustrine and Riverine Systems are *Tubifex*, *Anodonta*, *Pisiduim*, *Chaoborus*, and *Chironomus*.

(4) *Organic*. The substrate is predominantly composed of organic material. These habitats have a limited number of species and are very low in faunal productivity (Welch 1952).

3. AQUATIC BED

*Definition*.--The class Aquatic Bed represents wetlands and deepwater habitats that the majority of the time are dominated by submergent plants, floating-leaved plants or floating plants for the majority of the growing season in most years. Water regimes are restricted to subtidal, irregularly exposed, permanently flooded, intermittently exposed, and semipermanently flooded.

*Description*.--Aquatic Beds represent a diverse group of plant communities that require surface water for optimum growth and reproduction. They are best developed in relatively permanent water.

*Subclasses and Dominance Types*

(1) *Submergent Algal*. These habitats occur in both tidal and nontidal locations, but they are far more diverse and widespread in the Marine and Estuarine Systems. In these coastal areas, algal beds occupy rock substrates and unconsolidated substeates characterized by a wide range of sediment depths and textures. They may extend to water depths of 30 m (98 ft). Coastal algal beds are most luxuriant along the rocky shores of the northeast and the west. *Macrocystis* beds are especially well-developed on the Pacific Coast. Along both coasts,

*Fucus* and *Laminaria* may dominate dense Submergent Algal Beds. In tropical regions, this subclass is characterized by green algae, including forms containing calcareous particles; *Halimeda* and *Penicillus* are common examples. *Caulerpa* and *Laurencia* also may form large Submergent Algal Beds. Other plants, such as *Enteromorpha* and *Ulva*, are tolerant of fresh water and flourish in some estuaries.

Inland Submergent Algal Beds are represented by plants such as the *Chara* and *Nitella* which look much like vascular plants and may grow in similar situations. However, *Chara* meadows may be found in Lacustrine waters as deep as 40 m (131 ft) (Zhadin and Gerd 1963), where hydrostatic pressure limits the survival of vascular submergents (Welch 1952).

(2) *Submergent Vascular*. In the Marine and Estuarine Systems this subclass has been referred to by others as temperate grass flats (Phillips 1974); tropical marine meadows (Odum 1974); eelgrass beds, turtlegrass beds and seagrass beds (Akins and Jefferson 1973, Eleuterius 1973, Phillips 1974). Submergent Vascular Beds extend to depths greater than 10 m (33 ft) in clear marine waters. The greatest numbers of plant species occur in shallow, clear, tropical or subtropical waters of moderate current strength in the Caribbean and along the Florida and Gulf Coasts. Principal Dominance Types in these areas include *Thalassia testudinum*, *Halodule beaudettei*, *Syringodium filiformis*, *Ruppia maritima*, *Halophila* and *Vallisneria americana*.

Five major species dominate the Submergent Vascular Beds along the temperate coasts of North America: *Halodule beaudettei*, *Phyllospadix scouleri*, *P. torreyi*, *Ruppia maritima* and *Zostera marina*. *Zostera* beds have the most extensive distribution, but they are limited primarily to the more sheltered estuarine environment. In the lower salinity zones of estuaries, stands of *Ruppia*, *Potamogeton* and *Vallisneria* often occur, along with *Najas* and *Myriophyllum*.

Submergent Vascular Beds in the Riverine, Lacustrine and Palustrine Systems occur at all depths within the photic zone. Typical inland genera include *Potamogeton*, *Ceratophyllum*, *Myriophyllum*, *Najas*, *Ruppia*, *Utricularia* and *Vallisneria*.

(3) *Submergent Moss*. These Aquatic Beds are far less abundant than Algal or Vascular Beds. They occur primarily in the

Riverine System and in permanently flooded and intermittently exposed parts of some Lacustrine Systems. The most important Dominance Types include genera such as Fissidens, Drepanocladus and Fontinalis. The latter may grow to depths as great as 120 m (392 ft) (Hutchinson 1975). For simplicity, aquatic liverworts of the genus Marsupella are included in this subclass.

(4) Floating-leaved. These Aquatic Beds are characterized by floating-leaved plants. They are found in all systems except the Marine. These beds typically occur in sheltered areas where there is little water movement (Wetzel 1975). Typical dominants include Nymphaea, Nuphar, Potamogeton natans and Brasenia schreberi. Plants such as Nuphar advena and Polygonum amphibium, which may stand erect above the water surface or substrate, may be considered emergents or floating-leaved plants, depending upon the life form adopted at a particular site.

(5) Floating. This subclass is characterized by genera which float freely on the water surface, such as: Lemna, Spirodela, Pistia, Eichhornia, Trapa, Salvinia and Azolla. These plants are found primarily in protected portions of slow-flowing rivers and in the Lacustrine and Palustrine Systems. Floating Beds are dynamic habitats; they are easily moved about by wind or water currents. They cover a large area of water in some parts of the country, particularly the southeast.

4. REEF

Definition.--The class Reef includes ridge- or mound-like structures formed by the colonization and growth of sedentary invertebrates.

Description.--Reefs are characterized by their elevation above the surrounding substrate and their interference with normal wave flow; they are primarily subtidal, but parts of some Reefs may be intertidal as well. Although corals, oysters and tubeworms are the most visible organisms and are mainly responsible for Reef formation, other molluscs, foraminifera, corralline algae and other forms of life also contribute substantially to Reef growth. Frequently, Reefs contain an abundance

of dead skeletal material and shell fragments, in comparison to the amount of living matter.

Subclasses and Dominance Types

(1) Coral. Coral Reefs are widely distributed in shallow waters of warm seas. They are found in Hawaii, Puerto Rico, the Virgin Islands, and southern Florida. They are characterized by Odum (1971) as stable, well-adapted, highly diverse and highly productive ecosystems with a great degree of internal symbiosis. Coral Reefs lie almost entirely within the Marine Subtidal Subsystem, although the upper part of some reefs is sometimes exposed. Examples of Dominance Types are *Porites*, *Acropora* and *Montipora*; the distribution of these types primarily reflects elevation, wave exposure, and the age of the Reef.

(2) Mollusc. This subclass occurs in both the Estuarine Intertidal and Subtidal Subsystems. These Reefs are found on the Pacific, Atlantic, and Gulf Coasts and in Hawaii and the Carribbean. Mollusc Reefs may become extensive, affording a substrate for sedentary and boring organisms and a shelter for many others. Reef molluscs are adapted to great variations in water level, salinity and temperature, and these same factors control their distribution. Examples of Dominance Types for this subclass are the oysters (*Ostrea*, *Crassostrea*).

(3) Worm. Worm Reefs are constructed by large colonies of sabellariid worms living in individual tubes constructed from cemented sand grains. Although they do not support as diverse a biota as do Coral and Mollusc Reefs, they provide a distinct habitat which may cover large areas. Worm Reefs are generally confined to tropical waters, and are most common along the coasts of Florida, Puerto Rico, and the Virgin Islands. They occur in both the Marine and Estuarine Systems where the salinity approximates that of sea water. The Dominance Type for this subclass is *Sabellaria*.

5. FLATS

Definition.--The class Flat refers to level landforms composed of unconsolidated sediments. Normally, Flats occur only in areas sheltered from strong currents and wave action. They may be irregularly shaped or elongate and continuous with the shore, whereas Bars generally are

elongate, parallel to the shoreline, and separated from the shore by water. Water regimes are restricted to irregularly exposed, regularly flooded, irregularly flooded, seasonally flooded, temporarily flooded and intermittently flooded.

Description.--Estuarine and Marine Flats occur in the intertidal zone. The distribution of fauna is dependent on substrate texture, current and wave action, and salinity; temperature and salinity may be extremely variable. Regularly flooded Flats support diverse populations of tube-dwelling and burrowing invertebrates including worms, clams and crustaceans (Gray 1974). These invertebrates are mostly detritus feeders. Irregularly flooded Flats have been called salt flats, pans or pannes. They are typically high in salinity and are usually surrounded by, or lie on the landward side of, Emergent Wetland (Martin et al. 1953, Type 15). Flats are also commonly colonized by algae and diatoms and there may be an algal crust or mat.

The distribution of organisms in Riverine and Lacustrine Flats is dependent upon substrate material, current and wave action, and the frequency of inundation. Lacustrine Flats may include the entire basin of a lake. Palustrine Flats are generally the result of high salinity, removal of vegetation by man, animals, or fire, or the discharge of thermal waters or pollutants. In many arid areas, Palustrine and Lacustrine Flats are crusted or saturated with salt. Martin et al. (1953) called these habitats inland saline flats (Type 9); they are also called alkali flats, salt flats, and salt-pans. Faunal diversity and abundance caries with salinity, duration of inundation and temperature.

Subclasses and Dominance Types

(1) Cobble/Gravel. The Flats are composed predominantly of cobbles or gravel, often with shell fragments or finer sediments intermixed. Unlike Rocky Shores, Cobble/Gravel Flats are not stable and communities are more transitory. Examples of Dominance Types in the Marine and Estuarine Systems are: *Balanus*, *Patella*, *Littorina*, *Thais*, and *Mytilus*.

(2) Sand. Sand Flats are composed predominantly of sand,

often with particles of other sizes intermixed. Although population density may be very high, species diversity is usually comparatively low. In the Marine and Estuarine Systems, some examples of Dominance Types are Mya, Macoma, Tellina, Arenicola, Uca, Leptosynapta, and Paractis.

(3) Mud. Mud Flats are composed predominantly of silt and clay, and tend to be anaerobic below the surface. They usually have a higher organic content than Cobble/Gravel and Sand Flats. In the Marine and Estuarine Systems some examples of Dominance Types are: Uca, Callianassa, Nassarius, Macoma, Nereis, Amphitrite, Cerianthiopsis and Thyone.

(4) Organic. These Flats consist of exposed organic soils of formerly vegetated wetlands. In the Estuarine System, Organic Flats are often dominated by microinvertebrates such as foraminifera or smaller snails (Cerithium).

(5) Vegetated Flats. Some Flats are exposed for a sufficient period to be colonized by herbaceous annuals or seedling herbaceous perennials (pioneer plants). When these plants cover more than 30 percent of the substrate, the area is classified as a Vegetated Flat. This vegetation is usually killed by rising water levels and may be removed before the beginning of the next growing season. Examples of Dominance Types are Xanthium italicum, Chenopodium rubrum, Echinochloa crusgalli, and Eleocharis acicularis.

6. STREAMBED

Definition.--The class Streambed is restricted to the Riverine and Estuarine Systems. It includes all parts of channels that are not included in any of the other classes. Streambed may have the classes Beach/Bar and Flat included within it, but in the Intermittent Subsystem of the Riverine System the entire channel frequently contains only the class Streambed.

Description.--Streambeds vary greatly in substrate and form depending on the gradient of the channel and the velocity of the water. In the Riverine System, material on the bed is continually being moved downstream; in Estuarine streambeds, material may be moved upstream or

downstream according to the direction of tidal flow. Frequently Bars occur on the convex side of single channels or they may be included as islands within the bed of braided streams (Crickmay 1974). Flats and Beaches are particularly common adjacent to Streambed, particularly in the Lower Perennial and Tidal Subsystems of larger rivers and in estuarine streams where wave action is especially strong. In estuarine areas, Streambed is the proper class for the entire channel of tidal creeks that are dewatered at low tide. In most cases, Streambeds are not vegetated because of the scouring effect of the moving water, but, like Flats, they may be colonized by "pioneering" annuals during periods of low flow or they may have perennial emergents and shrubs that are too scattered to classify as Emergent Wetland or Scrub/Shrub Wetland.

Subclasses and Dominance Types

(1) Cobble/Gravel. This subclass is characteristic of Upper Perennial and Intermittent Subsystems of the Riverine System. When water flows over this material, the surface is frequently broken in areas called riffles. Cobble/Gravel Streambeds are particularly common in streams with braided channels. Examples of Dominance Types in Intermittent Cobble/Gravel Streambeds are *Limnodrilus*, *Caenis*, *Chironomus*, *Anopheles* (Stehr and Branson 1938). An example for the Upper Perennial is *Agrenia/Hypogastrura* (Slack et al. 1977).

(2) Sand. This subclass is also characteristic of the Upper Perennial and Intermittent Subsystems of the Riverine System. Frequently, Sand Streambeds are interspersed with Cobble/Gravel Streambeds. Examples of Dominance Types in Intermittent Sand Streambeds are *Gammarus*, *Physa*, *Chironomus* (Stehr and Branson 1938).

(3) Mud. This subclass is characteristic of the Lower Perennial and Tidal Subsystems of the Riverine. Mud Streambeds are frequently associated with large Mud Flats.

(4) Organic. This is not a common subclass in the Riverine System but it occurs along the edge of streams flowing over deep peat deposits, usually in the Lower Perennial Subsystem. Organic Streambeds are common in creeks draining Estuarine Emergent Wetlands with organic soils.

7. ROCKY SHORE

Definition.--The class Rocky Shore includes wetland environments characterized by stable bedrock surfaces or relatively stable, large rock fragments. Water regimes are restricted to irregularly exposed, regularly flooded, irregularly flooded, seasonally flooded, temporarily flooded and intermittently flooded.

Description.--In Marine and Estuarine Systems, Rocky Shores are generally high energy habitats which lie exposed as a result of continuous erosion by wind-driven waves or strong currents. The substrate is stable enough to permit the attachment and growth of sessile or sedentary invertebrates and attached algae or lichens. Rocky Shores usually display a vertical zonation which is a function of tidal range, wave action and degree of exposure to the sun. In the Lacustrine and Riverine Systems, Rocky Shores support sparse plant and animal communities.

Subclasses and Dominance Types.--The class Rocky Shore is divided into two subclasses, Bedrock and Boulder. The Dominance Types are similar for both subclasses.

(1) Bedrock. These wetlands consist of stable bedrock surfaces.

(2) Boulder. These wetlands consist of relatively stable rock fragments larger than 256 mm in diameter.

Communities or zones of Marine and Estuarine Rocky Shores have been studied in detail (Lewis 1964, Ricketts and Calvin 1968, Stephenson and Stephenson 1972). Each zone supports a rich assemblage of invertebrates and algae. Dominance Types of the Rocky Shore often can be characterized by one or two dominant genera from these zones.

The uppermost zone (termed the Littorine/Lichen Zone) is dominated by periwinkles (*Littorina* and *Nerita*) and lichens. This zone frequently takes on a dark, or even black appearance, although abundant lichens may lend a colorful tone. These organisms are rarely submerged, but are kept moist by sea spray. Frequently, this habitat is invaded from the landward side by semi-marine genera such as *Lygia*.

The next lower zone (the Balanoid Zone) is commonly dominated by

molluscs, green algae and barnacles of the balanoid group. From a distance, the zone appears white. Dominance Types such as Balanus, Chthamalus and Tetraclita may form an almost pure sheet of barnacles, or these animals may be interspersed with molluscs, tubeworms and algae such as Pelvetia.

The transition between the littorine/lichen and balanoid zones is frequently marked by the replacement of the periwinkles with both true and false limpets such as Acmaea and Siphonaria. The limpet band approximates the upper limit of the regularly flooded intertidal zone.

In the middle and lower intertidal areas, which are flooded and exposed by tides at least once daily, lie a number of other communities which can be characterized by dominant genera. Mussels (Mytilus) and gooseneck barnacles (Mitella) form communities exposed to strong wave action. The Fucus and Laminaria Dominance Types lie slightly lower, just above the coralline algae (Lithothamnion) Dominance Type. The Laminaria Dominance Type approximates the lower end of the Intertidal Subsystem; it is generally exposed at least once daily. The Lithothamnion Dominance Type forms the transition to the Subtidal Subsystem and is exposed only irregularly.

We have not identified Dominance Types for the Lacustrine and Riverine Systems.

8. BEACH/BAR

Definition.--The class Beach/Bar consists of sloping landforms generated by waves and currents and composed predominantly of unconsolidated sand, gravel or cobbles. They have less than 30 percent vegetative cover. Beaches are generally continuous with the shore, extending landward to a distinct break in landform or substrate type (e.g., a foredune, cliff or bank) or to the point where vegetation covers 30 percent or more of the substrate. Bars are elongate ridges, banks or mounds which are bordered by water on at least two sides. Water regimes are restricted to irregularly exposed, regularly flooded, irregularly flooded, seasonally flooded, temporarily flooded and intermittently flooded.

Description.--Beaches and Bars are characterized by a shifting, unstable substrate with high permeability, variable surface moisture,

and relatively low organic matter content. The surface layer has a high oxygen content and there is a deeper anaerobic layer (Hedgpeth 1957, Ranwell 1972). They may be sparsely vegetated and populated by a diversity of specialized burrowing invertebrates such as molluscs, crustaceans and polychaetes. Faunal distribution is controlled by waves, currents, interstitial moisture, salinity and sediment grain size. In Marine and Estuarine Beaches and Bars the fauna is usually more diverse than in Lacustrine or Riverine Beaches and Bars (Hedgpeth 1957, Riedl and McMahan 1974).

Subclasses and Dominance Types

(1) Cobble/Gravel. Cobble/Gravel Beaches and Bars typically form where wave action is especially strong so that sand and silt particles are largely eroded and transported from the Beach or Bar and deposited in deeper waters. While cobbles and gravel predominate, sand is usually mixed with these larger particles. Some of the larger cobbles and occasional boulders found on these Beaches may support sedentary organisms such as *Balanus*.

(2) Sand. Sand Beaches and Bars are composed predominantly of calcareous or terrigenous sand. Examples of Dominance Types in the Marine and Estuarine Systems are *Donax*, *Mya*, *Tivela*, *Oliva*, *Thoracophelia*, *Haustorius*, *Orchestia*, *Chiredotea*, *Emerita*, *Ocypode* (Hedgpeth 1957, Riedl and McMahan 1974). Examples of Dominance Types in the Riverine, Lacustrine, and Palustrine Systems are *Parastenocaris*, *Phyllognathus*, and *Pristina* (Neel 1948).

9. MOSS/LICHEN WETLAND

Definition.--The Moss/Lichen Wetland class includes areas where mosses or lichens cover the substrate and where other plants such as emergents, shrubs or trees comprise less than 30 percent of the areal cover.

Description.--Mosses and lichens are important components of the flora in many wetlands, especially in the north, but these plants usually form a ground cover under a dominant layer of trees, shrubs or emergents. In some instances higher plants are uncommon and mosses or

lichens dominate the flora. Such Moss/Lichen wetlands are not common, even in the northern United States where they occur most frequently.

Subclasses and Dominance Types

(1) Moss. These wetlands are most abundant in the far north. Areas covered with *Sphagnum* spp. are usually called bogs (Golet and Larson 1974, Jeglum et al. 1974, Zoltai et al. 1975), whether *Sphagnum* or higher plants are dominant. In Alaska, mosses such as *Drepanocladus* and the liverwort *Chiloscyphus fragilis* may dominate shallow pools with impermanent water; *Sphagnum*, *Campylium stellatum*, *Desmatodon heimii*, *Aulacomnium palustre* and *Oncophorus wahlenbergii* are typical of wet soil in this region (Britton 1957, Drury 1962).

(2) Lichen. These wetlands are also a northern subclass. *Cladonia* forms the most important Dominance Type. Pollett and Bridgewater (1973) described areas with mosses and lichens as bogs or fens, the distinction being based on the availability of nutrients and the particular plant species present. Sjörs (1959) and Jeglum et al. (1974) mentioned the presence of Lichen Wetlands in the Hudson Bay Lowlands and in Ontario, respectively.

10. EMERGENT WETLAND

Definition.--The Emergent Wetland class is characterized by erect, rooted, herbaceous hydrophytes, excluding mosses and lichens. This vegetation is present for most of the growing season in most years. These wetlands are usually dominated by perennial plants.

Description.--In areas with relatively stable climatic conditions, Emergent Wetlands maintain the same appearance year after year. In other areas, such as the prairies of the central United States, violent climatic fluctuations cause Emergent Wetlands to revert to an open water phase in some years (Stewart and Kantrud 1972). They are found throughout the United States and occur in all systems except the Marine. Emergent Wetlands are known by many names including marsh, meadow, fen, prairie pot hole, and slough. Areas that are dominated by pioneer plants that become established during periods of low water are not Emergent Wetlands and should be classified as Vegetated Flats.

Subclasses and Dominance Types

(1) Persistent. Wetlands in this subclass are dominated by species that normally remain standing at least until the beginning of the next growing season. This subclass is found only in the Estuarine and Palustrine Systems.

Persistent Emergent Wetlands dominated by *Spartina alterniflora*, *S. patens*, *S. cynosuroides*, *Juncus roemerianus*, *Typha angustifolia*, and *Zizaniopsis miliacea* are major components of the Estuarine Systems of the Atlantic and Gulf Coasts of the United States. On the Pacific Coast, *Salicornia pacifica*, *Suaeda californica*, *Triglochin maritima* and *Spartina foliosa* are common dominants.

Palustrine Persistent Emergent Wetlands contain a vast array of grass-like plants such as *Typha* spp., *Scirpus* spp., *Cladium jamaicens* *Carex* spp., and true grasses such as *Phragmites communis*, *Glyceria* spp., *Beckmania syzigachne* and *Scolochloa festucacea*. There is also a variety of broad-leaved persistent emergents such as *Lythrum salicaria*, *Rumex mexicanus*, *Decodon verticillatus*, and many species of *Polygonum*.

(2) Nonpersistent. Wetlands in this subclass are dominated by plants which fall to the surface of the substrate or below the surface of the water at the end of the growing season so that, at certain seasons of the year, there is no obvious trace of emergent vegetation. For example, *Zizania aquatica* in the north central states does not become apparent until mid-summer and fall when it forms dense emergent stands. Nonpersistent emergents also include species such as *Peltandra virginica*, *Pontederia cordata* and *Sagittaria* spp. Movement of ice in Riverine and Lacustrine Systems often removes all traces of emergent vegetation during the winter. Where this occurs, the area should be classified as Nonpersistent Emergent Wetland.

11. SCRUB/SHRUB WETLAND

Definition.--The class Scrub/Shrub Wetland includes areas dominated by woody vegetation less than 6 mm (20 ft) in height. The species include true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions.

Description.--Scrub/Shrub Wetlands may represent a successional

stage leading to Forested Wetland, or they may be relatively stable communities. They occur only in the Estuarine and Palustrine Systems, but are one of the most widespread classes in the country (Shaw and Fredine 1956). Scrub/Shrub Wetlands are known by many names such as shrub swamp (Shaw and Fredine 1956), shrub carr (Curtis 1959), bog (Heinselman 1970), and pocosin (Kologiski 1977). For practical reasons we have also included forests composed of young trees less than 6 m tall in this class.

Subclasses and Dominance Types

(1) Broad-leaved Deciduous. These are wetlands where deciduous trees or shrubs less than 6 m high represent more than 50 percent of the total areal cover. In the Estuarine System they are dominated by such plants as *Baccharis halmifolia*, and *Iva frutescens*. *Alnus* spp., *Salix* spp., *Cephalanthus occidentalis*, *Zenobia pulverulenta*, *Betula pumila* and young trees such as *Acer rubrum* are typical Dominance Types in the Palustrine System.

(2) Needle-leaved Deciduous. This subclass is found only in the Palustrine System where it is represented by young or stunted trees such as *Larix laricina* or *Taxodium distichium*.

(3) Broad-leaved Evergreen. These wetlands are found in both the Estuarine and Palustrine Systems. In the Estuarine System, vast acreages are dominated by mangroves (*Rhizophora mangle*, *Langunculeria racemose*, *Conocarpus erecta*, *Avicennia germinans*) that are less than 6 m in height. In the Palustrine System, the broad-leaved evergreen species are typically found on organic soils. In the north, typical representatives are *Ledum groenlandicum*, *Andromeda glaucophylla*, *Kalmia polifolia*, and the semi-evergreen *Chamaedaphne calyculata*. In the south, *Lyonia lucida* and *Leucothoe axillaris* are characteristic broad-leaved evergreen species.

(4) Needle-leaved Evergreen. These wetlands are found only in the Palustrine System. The dominant species are young or stunted trees such as *Picea mariana* or *Pinus serotina*.

(5) Dead. These wetlands are dominated by dead woody vegetation less than 6 m in height. They are usually produced by a

relatively abundant, particularly along rivers and in the mountains. They occur only in the Palustrine and Estuarine Systems. Palustrine Forested Wetlands normally possess an overstory of trees, an understory of young trees or shrubs and an herbaceous layer. Forested Wetlands in the Estuarine System are restricted to the mangrove forests of Florida, Puerto Rico and the Virgin Islands.

Subclasses and Dominance Types

(1) Broad-leaved Deciduous. These wetlands are found throughout the country, but reach their greatest abundance in the south and east. Dominant trees typical of this subclass include: *Acer rubrum*, *Ulmus americana*, *Fraxinus pennsylvanica*, *F. nigra*, *Nyssa sylvatica*, *N. aquatica*, *Quercus bicolor*, *Q. lyrata*, and *Q. michauxii*. Wetlands in this subclass generally occur on mineral soils or highly decomposed organic soils.

(2) Needle-leaved Deciduous. These wetlands are represented by a limited group of species. *Larix laricina* is characteristic of the Boreal Forest Region where it occurs as a dominant on organic soils. The southern representatives of this subclass include *Taxodium distichum* and *T. ascendens* which are noted for their ability to tolerate long periods of surface inundation.

(3) Broad-leaved Evergreen. These wetlands reach their greatest development in the southeast where *Persea borbonia*, *Gordonia lasianthus* and *Magnolia virginiana* are prevalent, especially on organic soils. This subclass also includes *Rhizophora mangle*, *Avicennia nitida* and *Laguncularia racemosa* which are adapted to varying levels of salinity. prolonged rise in the water table, which often results from the activities of man or beavers, but they may result from other natural causes such as fire, salt spray which often accompanies severe coastal storms, and insect infestations; and from air pollution or man's use of herbicides.

12. FORESTED WETLAND

Definition.--The class Forested Wetland is characterized by woody vegetation that is 6 m or more in height.

Description.--Forested Wetlands are most common in the eastern United States and in those sections of the west where moisture is

(4) Needle-leaved Evergreen. These wetlands are widespread in the north where *Picea mariana*, growing on organic soils, represents a major dominant. Whereas *P. mariana* is common on nutrient-poor soils, *Thuja occidentalis* dominates northern wetlands on more nutrient-rich sites. Along the Atlantic Coast, *Chamaecyparis thyoides* is one of the most common dominants on organic soils. *Pinus serotina* is a common needle-leaved evergreen found in the southeast in association with dense stands of broad-leaved evergreen and deciduous shrubs.

(5) Dead. These wetlands are dominated by dead woody vegetation greater than 6 m in height. Like Dead Scrub/Shrub Wetlands, they are most common in, or around the edges of, man-made impoundments and in beaver ponds. The same factors that produce Dead Scrub/Shrub Wetlands also produce Dead Forested Wetlands.

# APPENDIX B

## FLOW CHARTS AND MATRICES FORMS

Figures B-1 through B-8 are representations of the flow charts and matrices provided for the purpose of making duplicates for field use.

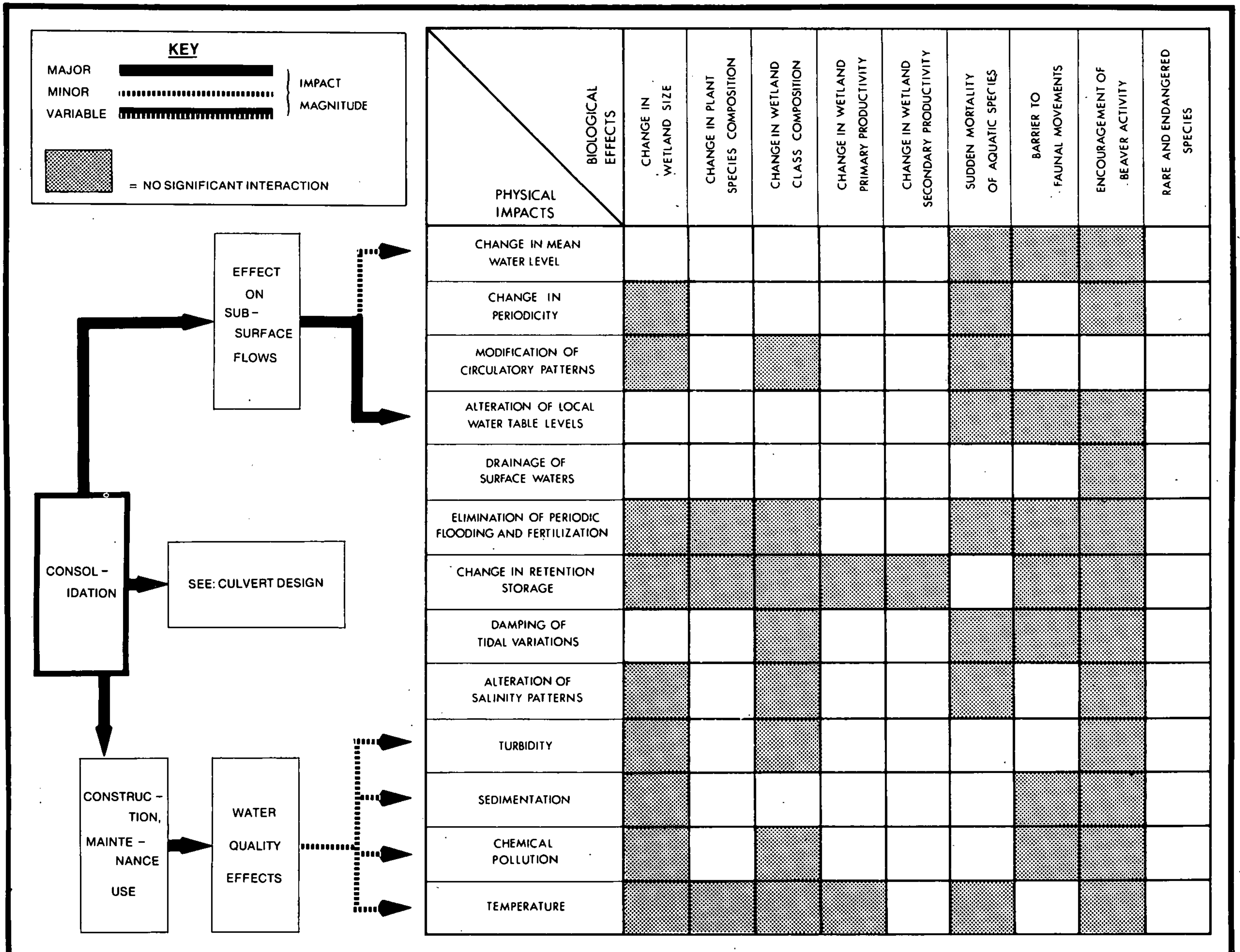
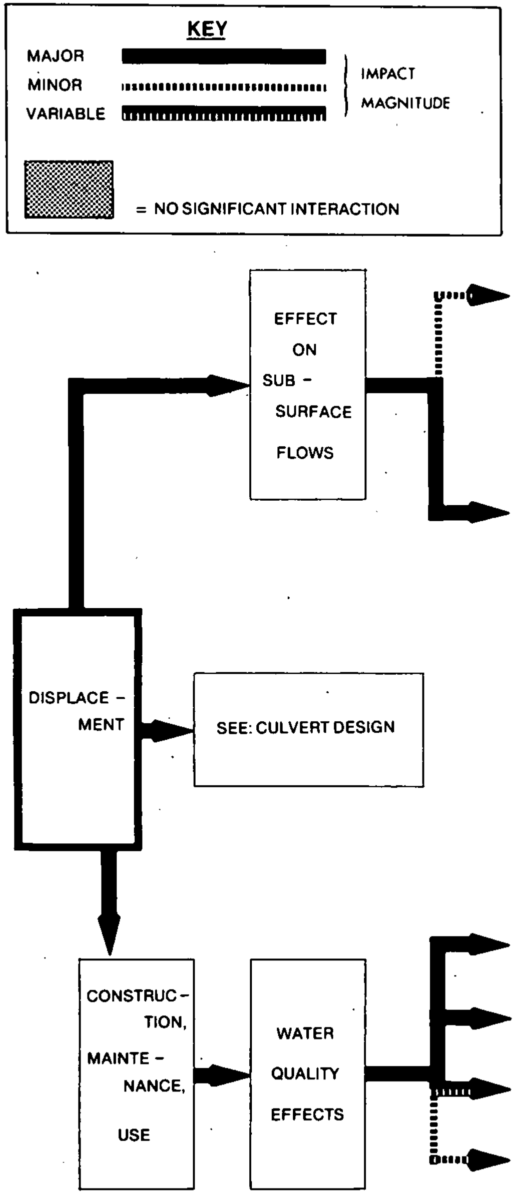



*Figure B-1. Physical impacts flow chart and biological effects matrix form.*




| PHYSICAL IMPACTS \ BIOLOGICAL EFFECTS | CHANGE IN WETLAND SIZE | CHANGE IN PLANT SPECIES COMPOSITION | CHANGE IN WETLAND CLASS COMPOSITION | CHANGE IN WETLAND PRIMARY PRODUCTIVITY | CHANGE IN WETLAND SECONDARY PRODUCTIVITY | SUDDEN MORTALITY OF AQUATIC SPECIES | BARRIER TO FAUNAL MOVEMENTS | ENCOURAGEMENT OF BEAVER ACTIVITY | RARE AND ENDANGERED SPECIES |
|---|---|---|---|---|---|---|---|---|---|
| CHANGE IN MEAN WATER LEVEL | | | | | | ■ | ■ | ■ | |
| CHANGE IN PERIODICITY | ■ | | | | | ■ | | ■ | |
| MODIFICATION OF CIRCULATORY PATTERNS | ■ | | ■ | | | ■ | | | |
| ALTERATION OF LOCAL WATER TABLE LEVELS | | | | | | ■ | ■ | ■ | |
| DRAINAGE OF SURFACE WATERS | | | | | | | | ■ | |
| ELIMINATION OF PERIODIC FLOODING AND FERTILIZATION | ■ | ■ | ■ | | | ■ | ■ | ■ | |
| CHANGE IN RETENTION STORAGE | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | |
| DAMPING OF TIDAL VARIATIONS | | | ■ | | | ■ | ■ | ■ | |
| ALTERATION OF SALINITY PATTERNS | ■ | | ■ | | | ■ | | ■ | |
| TURBIDITY | ■ | | ■ | | | | | ■ | |
| SEDIMENTATION | ■ | | | | | | ■ | ■ | |
| CHEMICAL POLLUTION | ■ | | ■ | | | | ■ | ■ | |
| TEMPERATURE | ■ | ■ | ■ | ■ | | ■ | | ■ | |

*Figure B-2. Physical impacts flow chart and biological effects matrix form.*

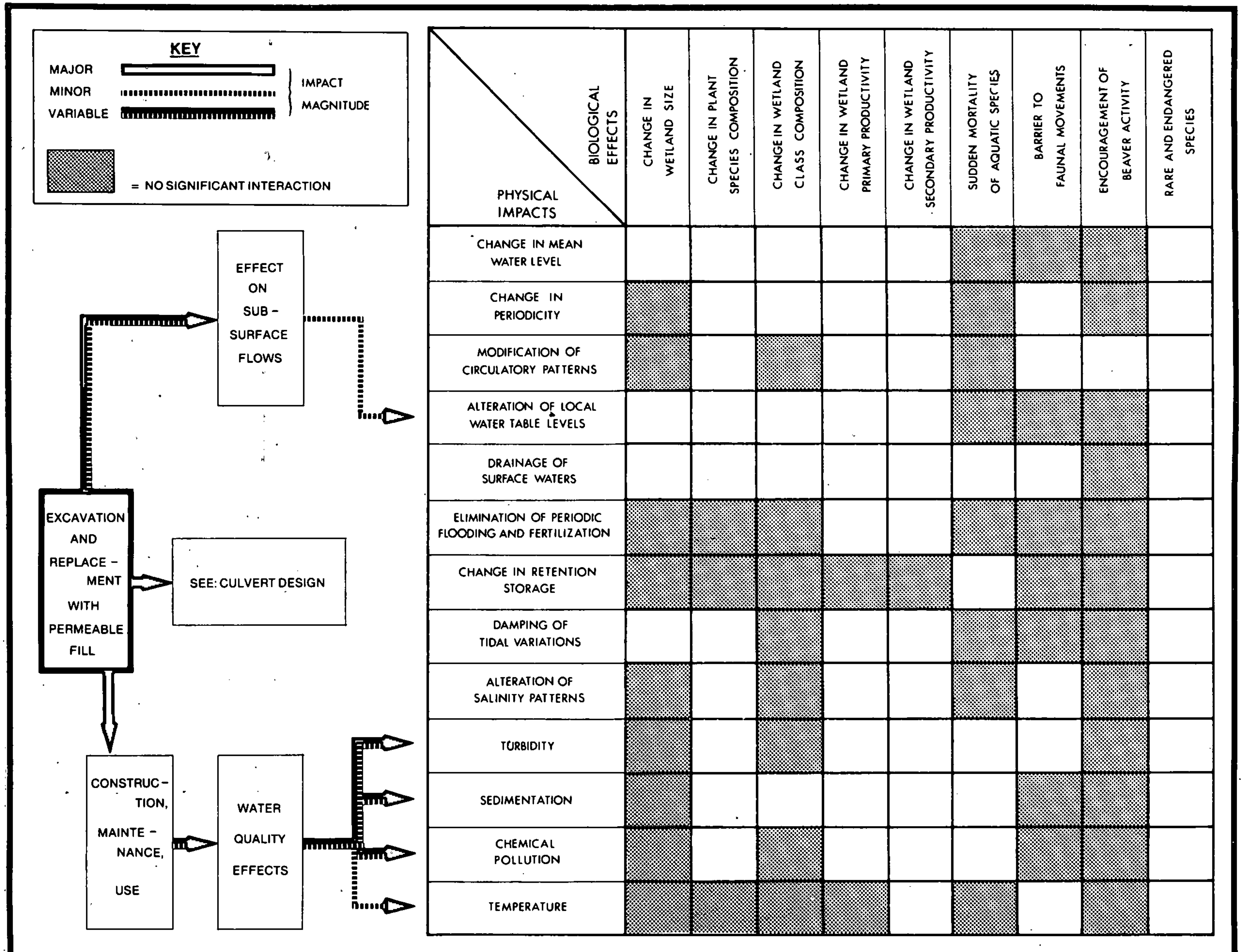



*Figure B-3. Physical impacts flow chart and biological effects matrix form.*

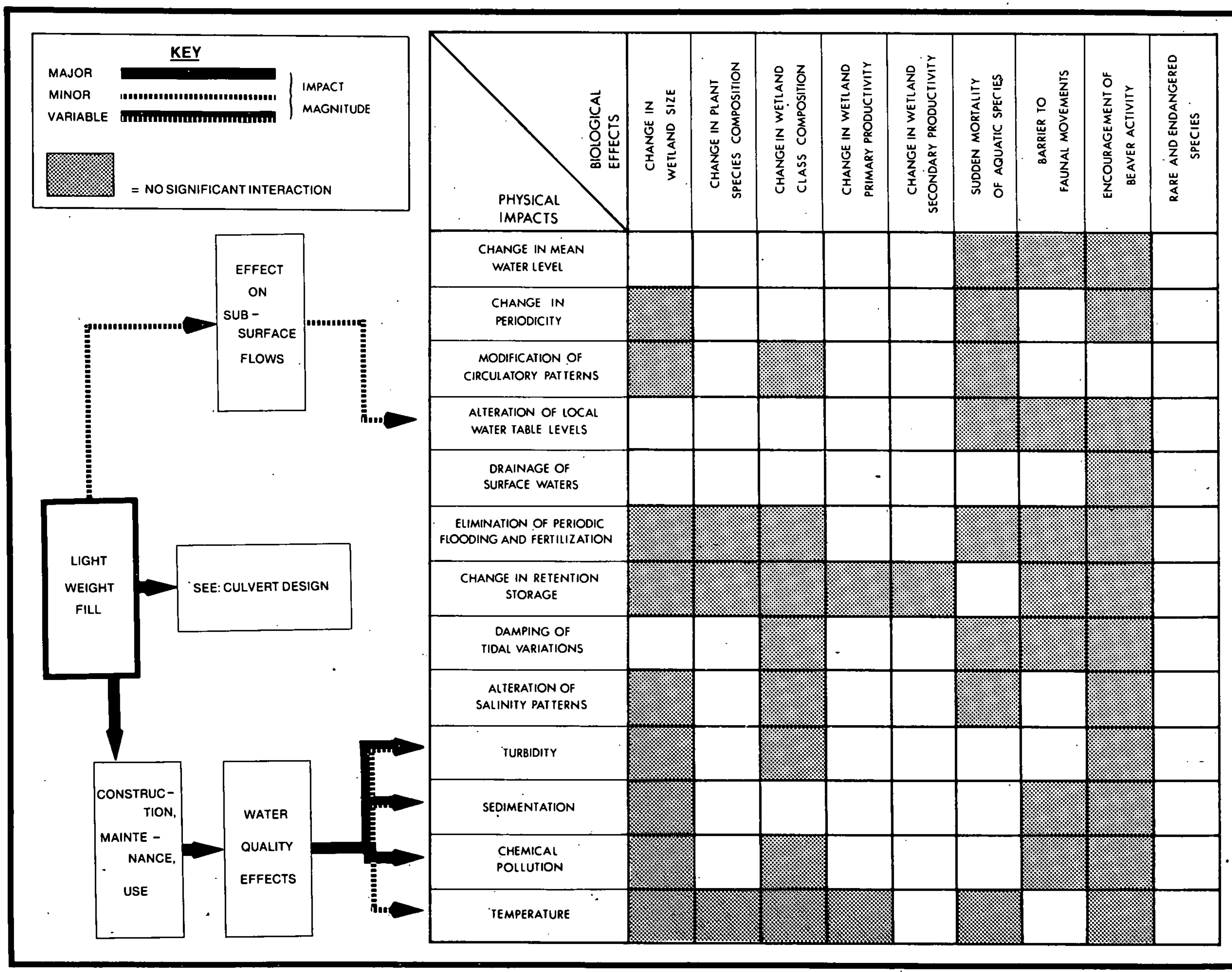



*Figure B-4. Physical impacts flow chart and biological effects matrix form.*

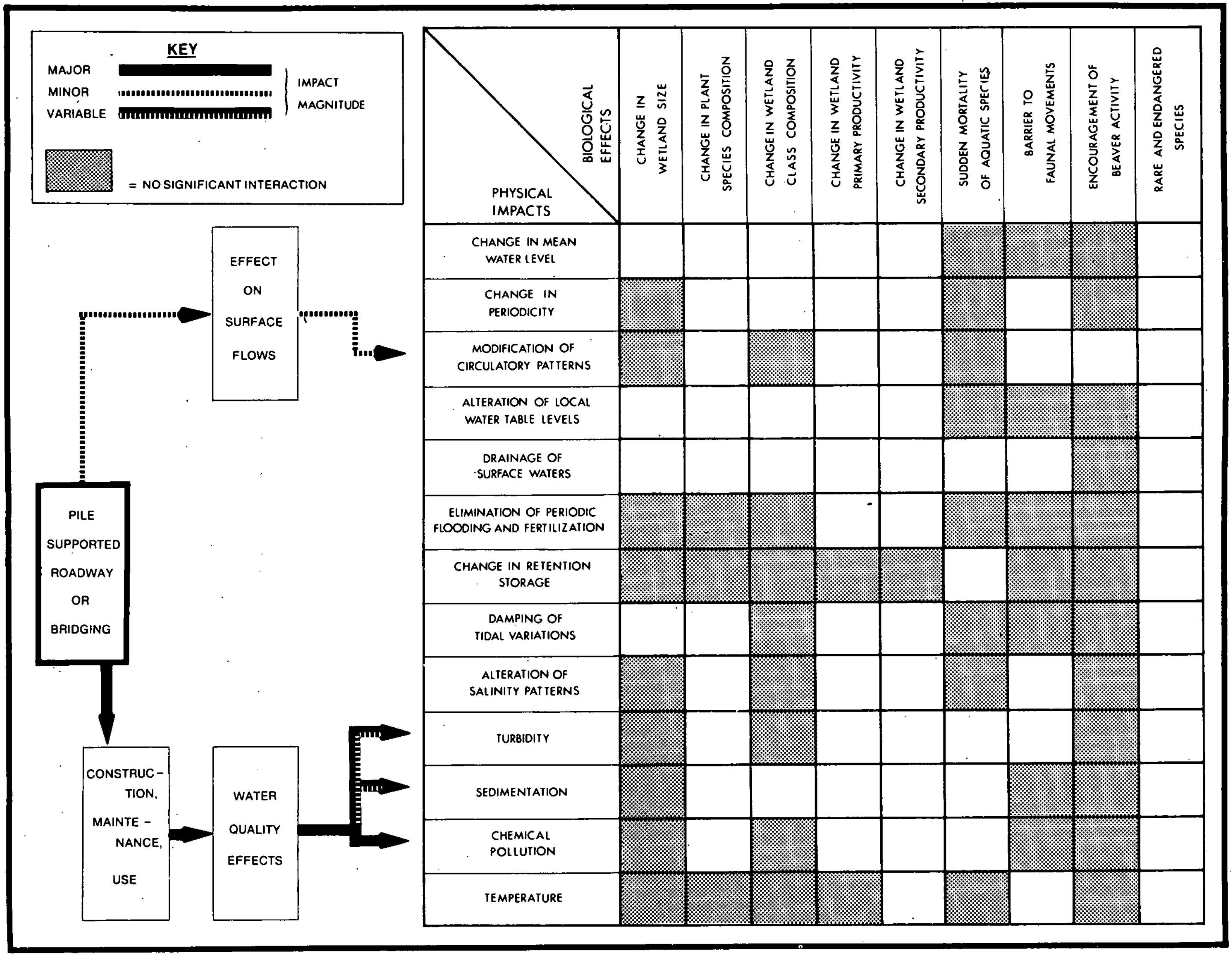



*Figure B-5. Physical impacts flow chart and biological effects matrix form.*

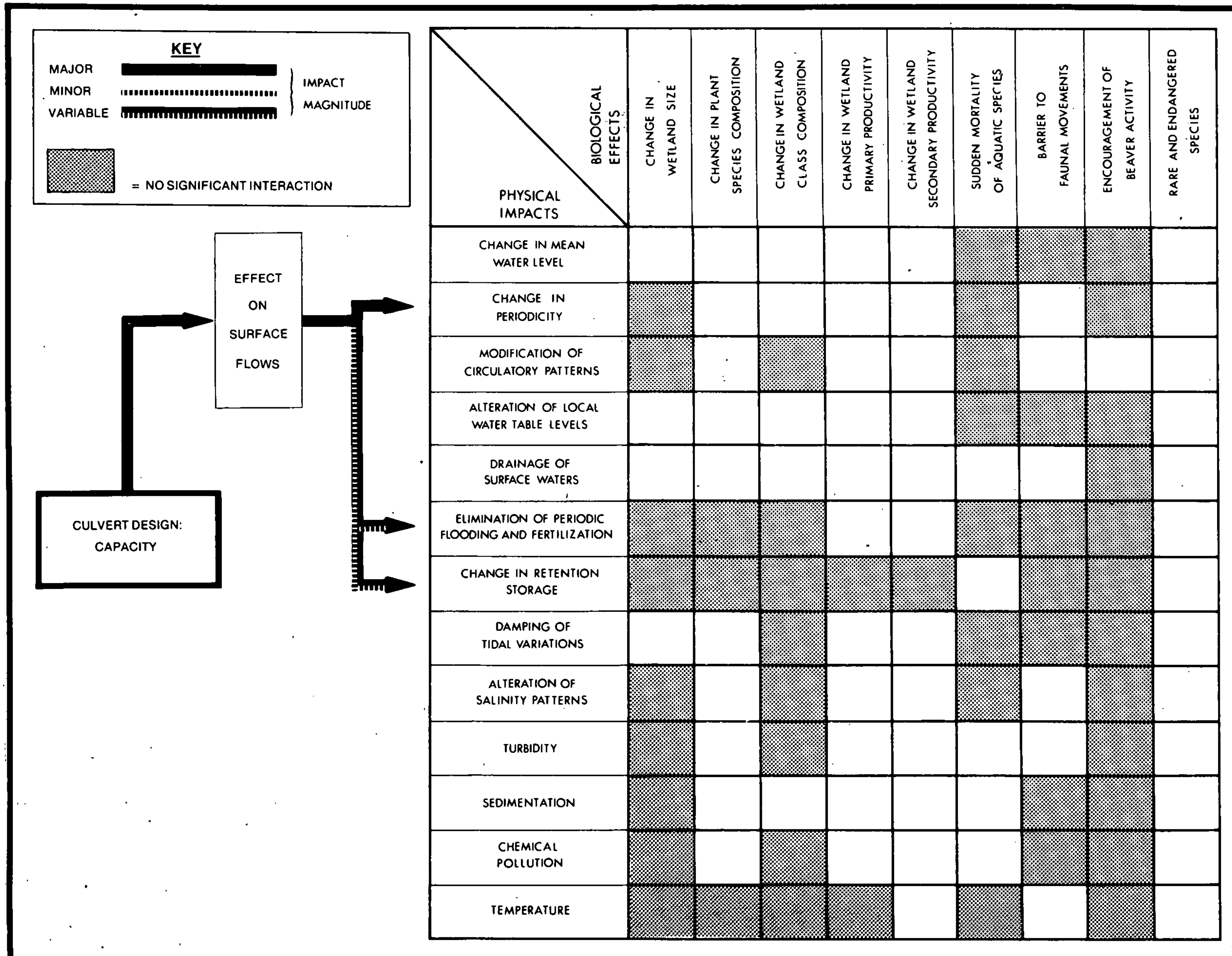



*Figure B-6. Physical impacts flow chart and biological effects matrix form.*

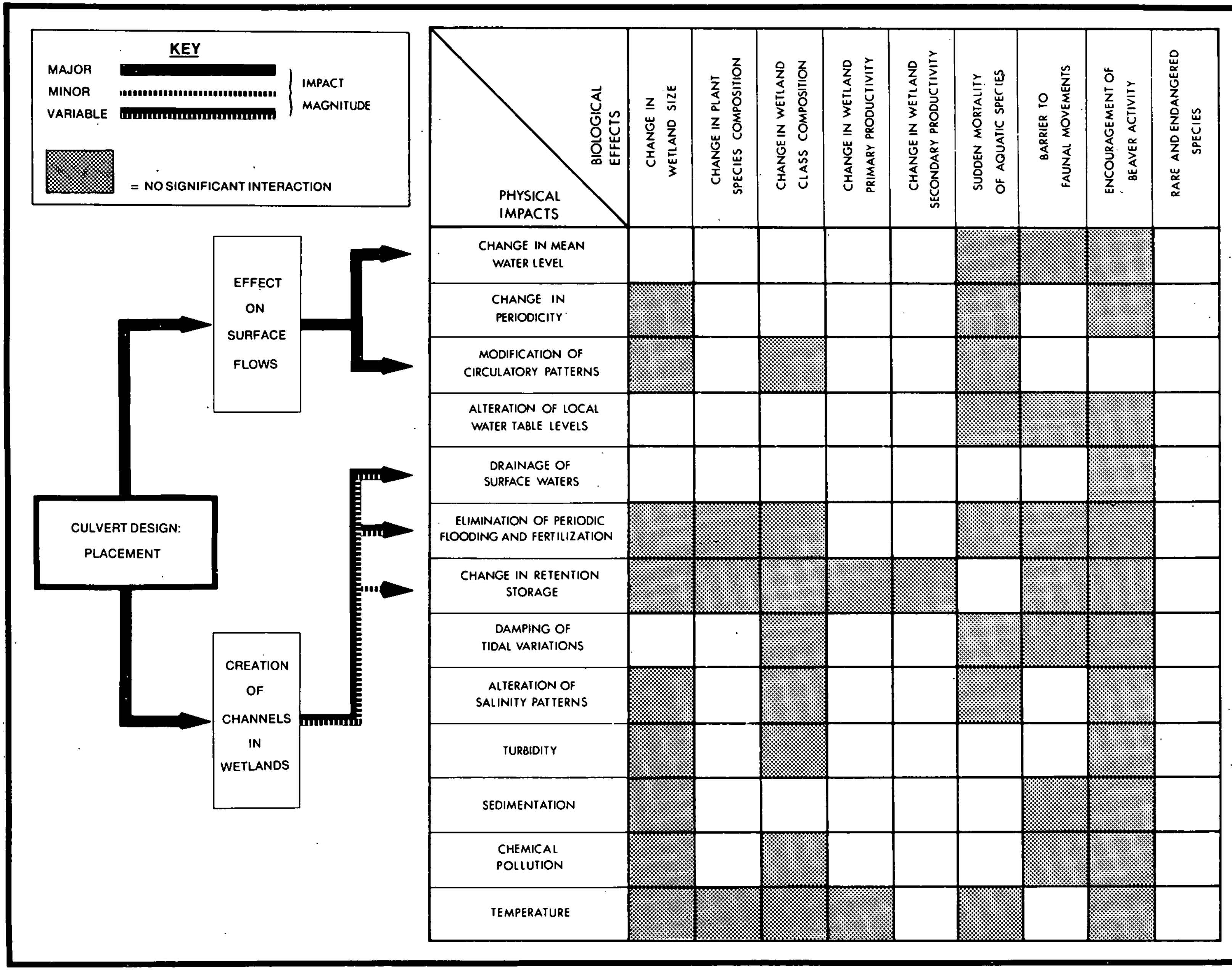
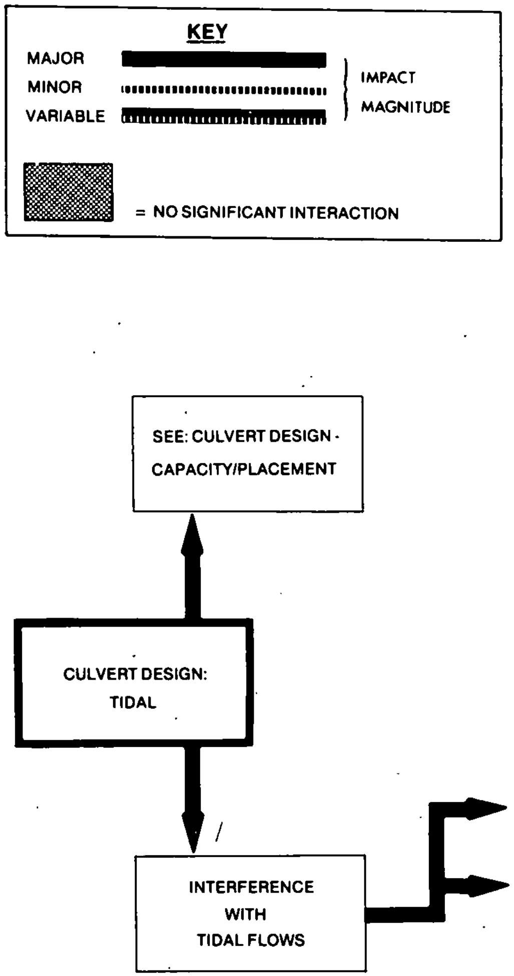



*Figure B-7. Physical impacts flow chart and biological effects matrix form.*




| PHYSICAL IMPACTS \ BIOLOGICAL EFFECTS | CHANGE IN WETLAND SIZE | CHANGE IN PLANT SPECIES COMPOSITION | CHANGE IN WETLAND CLASS COMPOSITION | CHANGE IN WETLAND PRIMARY PRODUCTIVITY | CHANGE IN WETLAND SECONDARY PRODUCTIVITY | SUDDEN MORTALITY OF AQUATIC SPECIES | BARRIER TO FAUNAL MOVEMENTS | ENCOURAGEMENT OF BEAVER ACTIVITY | RARE AND ENDANGERED SPECIES |
|---|---|---|---|---|---|---|---|---|---|
| CHANGE IN MEAN WATER LEVEL | | | | | | ▒ | ▒ | ▒ | |
| CHANGE IN PERIODICITY | ▒ | | | | | ▒ | | ▒ | |
| MODIFICATION OF CIRCULATORY PATTERNS | ▒ | | ▒ | | | ▒ | | | |
| ALTERATION OF LOCAL WATER TABLE LEVELS | | | | | | ▒ | ▒ | ▒ | |
| DRAINAGE OF SURFACE WATERS | | | | | | | | ▒ | |
| ELIMINATION OF PERIODIC FLOODING AND FERTILIZATION | ▒ | ▒ | ▒ | | | ▒ | ▒ | ▒ | |
| CHANGE IN RETENTION STORAGE | ▒ | ▒ | ▒ | ▒ | ▒ | | ▒ | ▒ | |
| DAMPING OF TIDAL VARIATIONS | | | ▒ | | | ▒ | ▒ | ▒ | |
| ALTERATION OF SALINITY PATTERNS | ▒ | | ▒ | | | ▒ | | ▒ | |
| TURBIDITY | ▒ | | ▒ | | | | | ▒ | |
| SEDIMENTATION | ▒ | | | | | | ▒ | ▒ | |
| CHEMICAL POLLUTION | ▒ | | ▒ | | | | ▒ | ▒ | |
| TEMPERATURE | ▒ | ▒ | ▒ | ▒ | | ▒ | | ▒ | |

*Figure B-8. Physical impacts flow chart and biological effects matrix form.*

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