218A

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

ECOLOGICAL EFFECTS OF HIGHWAY FILLS ON WETLANDS

RESEARCH REPORT

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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ECOLOGICAL EFFECTS OF HIGHWAY FILLS ON WETLANDS
RESEARCH REPORT

P. W. SHULDINER, D. F. COPE, AND R. B. NEWTON
University of Massachusetts
Amherst, Massachusetts

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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.

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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.

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FOREWORD

By Staff
Transportation Research Board

This report, *NCHRP Report 218A*, and a companion report, *NCHRP Report 218B*, "Ecological Effects of Highway Fills on Wetlands—User's Manual," will be of special interest and value to people responsible for the environmental assessment of proposed transportation facilities in the area of wetlands. 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 this research report. The companion report contains 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.

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 an 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—User's Manual." This document (*Report 218A*) contains summaries of the literature review and the case studies. It serves as background material for the manual (*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.

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ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 20-15 by the University of Massachusetts, Amherst, Mass., with Dr. Paul W. Shuldiner, 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

RESEARCH REPORT

SUMMARY

The placing of highway fills on wetlands can have significant physical, chemical, and biological effects on the ecology of the affected area. The prediction of such effects, and their avoidance or mitigation where feasible, is required of highway agencies by a variety of federal and state laws. Sufficient knowledge of ecological processes does exist for reasonable predictions of probable impacts to be made in most instances. It is also possible in many cases to avoid, or keep to a minimum, highway-induced impacts through the careful application of existing knowledge and procedures.

Wetlands occur because there is water present on or in the surface soils on a permanent or reliably recurring basis, and it is the characteristics of this water that exert the greatest single influence on wetland ecology. Based on case studies, highway fills, by altering the hydrologic regime or by adversely affecting water quality, can trigger effects on the adjacent wetland and on related areas removed from the immediate site of construction.

A thorough review of the literature pertaining to wetland ecology and to the environmental impacts of highways and analogous structures reveals the central role played by hydrologic features in determining the severity and extent of the ecological effects that may result from the placement of highway fills on wetlands and associated flood plains. A series of case studies conducted as part of this research underscores this point. In all but one of these studies, highway-induced alterations in surface and/or subsurface drainage resulted in significant changes in the ecology of the affected wetlands.

The literature also provided evidence of the potential for ecological damage from sediments resulting from fill construction and erosion; salinity regime changes; disturbance of tidal exchanges; and the degradation of water quality resulting from the inadvertent introduction to surface and ground waters of heavy metals, nutrients, and road salts.

It is possible to summarize and structure the major physical, chemical, and biological effects that various highway practices might induce in wetlands in which highway fills are placed. A user's manual, the major product of this research, was prepared to provide in a concise format guidelines and information needed for the determination of such effects and to suggest procedures by which deleterious impacts can be minimized or avoided. The planning, assessment, and mitigation guidelines presented in the manual provide tools that will help the highway engineer determine the ecological effects of placing highway fills in wetlands and make decisions regarding routes, materials, design and construction alternatives, and maintenance and operation activities.

The users' manual (*NCHRP Report 218B*) 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 potential

ecological effects of project construction in 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 graphically. Analytical methods necessary to delineate the possible severity or extent of the effects, expertise needed to analyze the resulting data, and practices that can be used to minimize the adverse effects or enhance the positive benefits of construction 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 responses to these changes which can occur in wetland systems, a series of flow charts and a matrix was prepared. Each flow chart displays a set of physical impacts that might result from a particular construction method or culvert design or placement. 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 matrix becomes evident. The matrix then not only describes the environmental relationships, but also gives the user a clear and graphic picture of the biological consequences of each alternative, thus allowing the highway planner to consider environmental impacts in conjunction with economic and other concerns.

The user's manual and other reports of this research are based on knowledge that is in a state of active evolution. Considerable progress has been made in recent years in understanding how wetlands function and of 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.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

The increased use of bridges and pile-supported structures rather than earth fills across wetlands to be traversed by highways is being advocated by many people. Earth fills produce various ecological effects, frequently reported to be detrimental, on wetlands. Reported effects include (1) inhibition of storm water and tidal distribution, (2) increased water turbidity, (3) alteration of water circulation patterns, (4) removal of natural filtration systems, (5) introduction of exotics, (6) inhibition of movement of animals, (7) alteration of biological productivity, and (g) alteration of nutrient flux.

Determination of the impact of an earth fill or other structure on the ecology of a specific wetland is a very complex problem. Nevertheless, transportation agencies are required by a variety of federal and state laws to make environmental assessments for proposed wetlands facilities. Consequently, a need exists for a better understanding of the ecological effects of highways on wetlands as well as for guidance in making highway location and design decisions when wetlands and associated flood plains are involved.

In recognition of this need, the objectives of this project were to determine the 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 and construction alternative.

The accomplishment of these objectives involved performing the following tasks:

1. Review, examine, synthesize, and evaluate all available information relevant to the over-all objectives and prepare a state-of-the-art report covering (a) the ecological effects of highway fills and bridges on wetlands and (b) techniques, procedures, and methodology for assessing the ecological effects. The state-of-the-art report was published in August 1978 and distributed to the state highway and transportation agencies.
2. Conduct wetlands case studies for which ecological data were available—either at the same or comparable sites—prior to, during, and following construction of a highway or similar fills and structures. These case study data were evaluated and compared to determine the nature and extent of ecological impacts. Types of wetlands that were studied include fresh water marshes, salt water marshes, and prairie pothole areas. A synthesis of case study data was prepared and presented at the Fifty-Eighth Annual Meeting of the Transportation Research Board.
3. Identify, adapt, or develop systematic guidelines to be presented in the form of a user's manual, for ecological assessment of wetlands and for guidance in selecting from among such design alternatives as fills, bridges, and related elements in wetlands and associated flood plains. Existing and potential engineering remedies for adverse impacts and any observed beneficial ecological effects related to the location of highway fills and bridges were also to be reported on. The user's manual was prepared and is provided in *NCHRP Report 218B*.

The core of the user's manual consists of a series of physical/chemical effects flow charts and a matrix which arrays physical/chemical effects on one axis and biological impacts on the other. Sample wetland/highway crossing alternatives were analyzed using the flow charts and matrix (see Chap. 3 of this report).

CHAPTER TWO

FINDINGS

STATE-OF-THE-ART REPORT SUMMARY

Introduction

The first task of NCHRP Project 20-15 was to conduct a wide-ranging literature search and review in order to determine the state of the art of assessing the ecological effects of placing highway fills on wetlands.

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 conditions of the issuance of such permits. These needs

have yet to be met by research specific to the task. Plans for the mitigation of unavoidable impacts are also required.

Within the past decade the study of wetland dynamics—the interaction of wetland species and biotic communities over time—and associated changes in wetland productivity have been greatly aided by improved scientific theory and extensive use of computer simulations. Emerging from these relatively recent advances in ecosystem modeling is a growing understanding of how wetlands interact with other ecosystems and of the relationship between wetlands and local and regional hydrology.

In contrast to the vast volume of research specific to highway practice or wetlands *per se,* relatively little research has been directed to the highway–wetland interface. This is particularly evident with respect to studies involving the joint efforts of engineers and ecologists.

In most cases, the impact literature did not deal specifically with the effects of highway activities on wetlands. Much of what is reported on has been inferred from experience with analogous engineered works such as pipelines, dikes, and dredging operations. And, even in these cases, information about the responses of wetland ecosystems to various kinds of stress was available only in the most general terms; specific wetland classes are often poorly represented in published reports. Gross models of wetland ecosystems have been developed, but experimental and empirical studies of total system relationships, from which predictions of highway-related impacts could be made, are rarely presented.

Recent advances in the understanding of wetland ecosystems have led to a new approach to classifying wetlands that combines structural and functional points of view. Research is in progress to detail these general models, especially with regard to the stochastic behavior of the various wetland classes and subclasses. Included within this research are studies of the controlling influence exerted by the hydrologic regime on the biotic structure and ecological productivity of existing and developing wetlands, and of the impacts that human intervention in the hydrologic regime has upon affected wetlands. Highway planners and engineers have traditionally given strong consideration to the effects of projects on the physical environment, but the emphasis has rested primarily on the engineering constraints imposed by natural features of the land. In recent years this focus has been broadened to include not only analysis of the physical environmental base but also the natural life systems depending on the base.

Hydrological Effects of Highway Fills on Wetlands

Highways impact upon wetlands in a variety of ways. In addition to direct physical alterations resulting from construction activities, there are often physical, chemical, and biological effects that extend well 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 which receive, detain, retain, and discharge both surface and ground-water flows. As such, each wetland reflects even the smallest changes in the waters that feed it, transmitting these changes in turn to wetlands downstream.

The critical physical process occurring in a wetland, then, is the water cycle, and the hydrologic regime is the controlling environmental factor in the wetland ecosystem. The presence of water is also a major consideration in highway design, construction, and maintenance. The highway engineer must relate various engineering alternatives to wetland construction site limitations and to the expected ecological response of the wetland. Unfortunately, the state of the art is weak regarding ecological responses of wetlands to changes in their water regime, and considerable research is needed if more reliable models are to become available for use in impact prediction.

Highways and analogous structures impound the flow of surface and ground water to a greater or lesser degree, tending to raise water levels on the upflow side of the structure and lower levels on the downflow side. Conversely, directing water around and at specific places through the structure may concentrate the flow from the affected watershed to specific aquifers, channels, and wetland areas, thus raising water levels in those areas (*1*). Any alteration of water regime by the placing of a highway facility can have effects that may extend well beyond the immediate locale, depending on the size of the wetland, the magnitude of the facility, and the ground- and surface-water hydrology. However, water level changes can produce positive as well as negative effects on wetlands. It was found that wetland managers often use regulated drawdown and flooding as a means of inducing shifts in plant species composition and enlarging waterfowl use areas.

Over-all, the literature is sparse on the subject of direct effects of highway activities on seasonal flow patterns in wetlands. Most ecological assessment is derived from studies of streams and the local effects on discharge or flow rate changes from stream relocation and associated channelization. Such information may, by implication, be related to other local changes in riverine or seasonally inundated flood plain wetlands that might be caused by alteration of stream channels by highway construction.

Erosion and Sedimentation Effects of Highway Fills on Wetlands

Highway construction has frequently been documented as a major source of sediment loads in the nation's waterways (*2, 3*). Sediment yields from highway construction during an average storm can be as much as 10 times greater than that of cultivated land and 200 times greater than that of grassed and forested lands (*4*). These ecological impacts may be as severe as those resulting from water regime alterations because the plant and animal communities that exist in various wetlands are adapted to, and dependent on, limited ranges of substrate conditions and water quality.

Excess suspended solids and sediments stem from two aspects of the highway construction process. First, disturbance of the existing submerged substrate can create heavy loads of suspended organic and inorganic matter in the surrounding water. Dredging, excavation, piling construction, and equipment operation are usually associated

with this type of sediment problem. Second, sediment runoff from cleared land and constructed fills, or sediment loads from gravel washing and dredged material disposal, can place enormous quantities of predominately inorganic matter into the aquatic system. This occurs during construction and may continue until stabilization follows completion. It is likely that particulate matter will be transported by currents and diffusion away from the construction site before settling out and may burden large areas of the wetland beyond the highway right-of-way.

Sedimentation follows, at varied time intervals, the events which place solids in suspension. An abundance of technical literature exists on the subject of the biological effects of sedimentation on aquatic organisms. Accumulated knowledge documents the adverse impacts of sedimentation on aquatic biological systems (*4, 5*). When sediments accumulate sufficiently to clog water channels and alter the flow regime, substantial changes in the wetland hydrology occur and the ecology of most aquatic systems has been found to be adversely affected by accelerated erosion and sedimentation (*4*). However, in certain coastal marshes, such as those in Louisiana, the sediment input through river overflow and build-up of organic matter is necessary to counteract the natural tendency of the deep river deposits to subside gradually. Highway construction involving draining and channelling of these wetlands may adversely affect these systems by depriving them of their annual sediment load.

Chemical Effects of Highway Fills in Wetlands

Salinity

Adverse ecological effects may result from highway construction in wetlands through the alteration of the salinity regime. Fresh-water wetlands are especially vulnerable to elevated salt concentrations resulting from deicing chemicals, and extensive literature exists which deals with the effects of those chemicals. Coastal saline wetlands are less affected by salt inputs, but are more directly affected by any disturbance of the normal fresh water/salt water mixing patterns in the estuary. A review of the literature reveals that both situations do occur and should be considered during environmental impact analysis.

Gunter et al. (*6*) discuss a variety of cases where engineering works have influenced coastal salinity regimes. In demonstrating the potential for ecological impact, they also provide a thorough review of salinity requirements of all estuarine fauna, establishing a useful state-of-the-art assessment for this consideration in planning highways across coastal wetlands.

Heavy Metals

Highways under construction may present sources of heavy metals that can affect the wetland ecosystem. The sources of these materials during construction include emissions from construction machinery, spillage of toxic materials, leachate from asphalt or concrete, and herbicide application prior to laying of the road surface. There is no direct evidence attesting to the significance of heavy metal contamination of wetlands by highway construction, use, and/or maintenance. However, an abundance of literature documents that heavy metal levels are significantly higher along roads than in adjacent habitats (*7*). The effect on the biota is poorly documented, but possible food chain magnification, as occurs with some pesticides, could threaten the survival and/or reproduction of higher organisms.

Dissolved Oxygen

Oxygen is required for respiration by most aquatic organisms and, in fact, the dissolved oxygen concentration (D.O.) of natural waters is an indicator of water quality (*8*).

The construction of a highway can cause reductions in dissolved oxygen levels which are variable in duration. Activities that induce heavy consumption of oxygen already in solution may cause only temporary impacts through oxygen depletion. However, permanent alterations of the aquatic system, which reduce the potential oxygen availability, are also possible and may have long-term effects on the biota of a wetland. The duration of the impact is primarily dependent on the duration of change in the suspended solid load, flow regime, and/or temperature.

Depletion of dissolved oxygen in wetlands may be directly or indirectly deleterious to the survival, reproduction, growth, and movement of populations of aquatic organisms. Most of the information on the effects of reduced oxygen is based on research involving fresh water fishes, particularly game species.

Nutrient Effects

The construction of a highway often necessitates land clearing and/or construction of an artificial landfill. In these situations, the passage of a period of time before denuded areas and fills are revegetated is inevitable. The impact of nutrient loading resulting from sediment inputs, fertilization to speed slope stabilization (revegetation), and runoff from drained wetlands is a distinct problem of highway construction. Postconstruction refertilization to establish vegetative cover is capable of creating locally heavy nutrient runoff depending on the rate of application, soil stability, and substrate affinity for the particular nutrient. Additionally, suspended soil particles and deicing salts often contain absorbed plant nutrient compounds which, if made available for biological uptake and use, can lead to accelerated eutrophication. Even unfertilized sites may introduce nutrients into runoff waters by erosion of nutrient rich soils.

The primary effect of nutrient enrichment is stimulation of plant growth, and this may take the form of phytoplankton, attached algae, rooted vegetation, or floating plants. The effect of increased nutrients may be an increase in the populations of certain species already present in the environment, and a decrease of species that are not tolerant of such nutrients. If the composition of the increased nutrients is intolerable to most forms of aquatic life, or if the ratio (nitrogen:phosphorous) is not correct, excessive blooms of undesirable species may develop.

Water Quality Effects

Prediction and assessment of water quality effects involve description of the types and quantities of pollutants that are likely to be generated during the construction and operation of each alternative being considered. The major water quality impact during construction is from sediment that is eroded from the construction site, transported by surface runoff, and deposited in adjacent bodies of water. The mechanics of this process are well understood, and procedures are available for predicting the extent of erosion and deposition to be expected under various soil and slope conditions.

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 collecting 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 FHWA *Water Quality Manual,* Vol. 1. (Section III, "Water Quality Survey") (see also (*9*)).

Faunal Movement Effects

Wetland crossings may sometimes act as barriers to the migration and free movement necessary for the survival of aquatic biota. Similarly, alterations of natural tidal movement of water carrying fresh water plankton and invertebrates can have adverse ecological effects (*6*). Wetlands are rich wildlife habitats and frequently are used as corridors of travel. Highways may physically block these routes of travel and thus contribute to wetland wildlife mortality (*6*). Critical areas of heavy wildlife use, such as winter concentration cover, and travel routes to and from these areas should be identified and avoided. Where sizable or unusual populations are known or expected to inhabit a wetland, a determination of the year-round habitat selection and movements should be incorporated in the impact assessment.

Mitigating Ecological Effects of Highway Fills on Wetlands

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 placement or 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.

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. In addition, the options available to the highway agency are often restricted by institutional constraints. 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. Increasingly, however, highway agencies have come to recognize the importance of early, comprehensive assessment of alternative locations and have begun to set up interdisciplinary teams within their planning sections for this purpose.

Erosion and Sedimentation Control

Erosion and sediment control measures are instituted both during and after construction not only to protect affected wetlands from this type of pollution, but also to ensure the continuing integrity of the highway structure and the unimpeded operation of drainage appurtenances. Both 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. North Carolina, for example, requires developers to submit acceptable erosion-control plans to county or state agencies prior to construction.

Varieties of devices and construction procedures—including berms, sediment basins and traps, mulching, and revegetation—are employed by highway agencies to limit the extent of erosion and to mitigate its impact on erosion-control features on the one hand and sensitivity of the potentially impacted environment on the other.

Mitigation of 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* (*10*). 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

"green-tree reservoirs" (wooded swamps with regulated flooding periods). Habitat improvement in streams and lakes includes development of impoundments, manipulation of water levels, treatment of stream channels and streamsides, regulating stream flow, and maintaining and improving water quality.

Creation of New Habitat

The use of highway construction to create new wetland habitat is becoming increasingly common, as highway agencies gain experience with the advantages that can accrue from such practices to both highway users and the public at large. Early and continuing coordination between highway agencies and state natural resource or wildlife departments is essential if the full benefits from the creation of new wetland habitat are to be realized. Of the many highway features and construction activities that can be employed in this capacity, three (use of ditches and culverts, construction of borrow pits, and dredge material disposal) appear to offer the most extensive opportunities for habitat creation.

Conclusions

Both coastal and inland wetlands have been well studied by biologists over many decades. The resulting literature provides a comprehensive, but essentially static, picture of wetland biota in terms of individual species and biotic communities and their distribution by geographic area and wetland type. There is a growing body of literature which can guide the engineer or planner in understanding the often subtle interactions that occur between the physical and biological elements of an aquatic system. This impact assessment material needs to be continually expanded, however, in order to enable the prediction and assessment of the effects of highway construction on the functioning of natural systems.

SYNTHESIS OF CASE STUDY DATA

Introduction

In an effort to establish a more comprehensive base of empirical evidence regarding highway–wetland interactions, a set of case studies (see App. A) was conducted at highway sites in wetlands throughout the country. The choice of field sites and the conduct of the studies were strongly influenced by the resources available to the investigators and by the lack of documented information on which instructive case studies could be based. There are very few instances where the physical and biological characteristics of a wetland have been documented prior to, during, and after construction of a highway facility. Since the resources available did not permit the acquisition and analysis of primary data, the research team depended almost wholly on secondary information, supplemented by after-the-fact observations on-site. Further contributing to the problem was the fact that relatively few highways are built in pristine wetlands, unaltered by the prior construction of railroad embankments, water control and drainage structures, and other works of man. Thus, the effects of the highway are often confounded, if not totally obscured, by the impacts of prior (or subsequent) alterations.

For these reasons, what is reported here is a forced compromise between what would have been preferred ideally and what, in reality, was possible to obtain. As can be seen on the accompanying map of the lower 48 states (Fig. 1), a reasonable approximation to geographic comprehensiveness was achieved. The eight case study sites range from Oregon to Massachusetts and from Minnesota and North Dakota to Florida. A wide range of wetland classes is represented, including examples of both tidal and inland situations. The studies include a variety of highway types ranging from gravel roads 50 years old or more to Interstate Highways. Nevertheless, vast areas of the country,

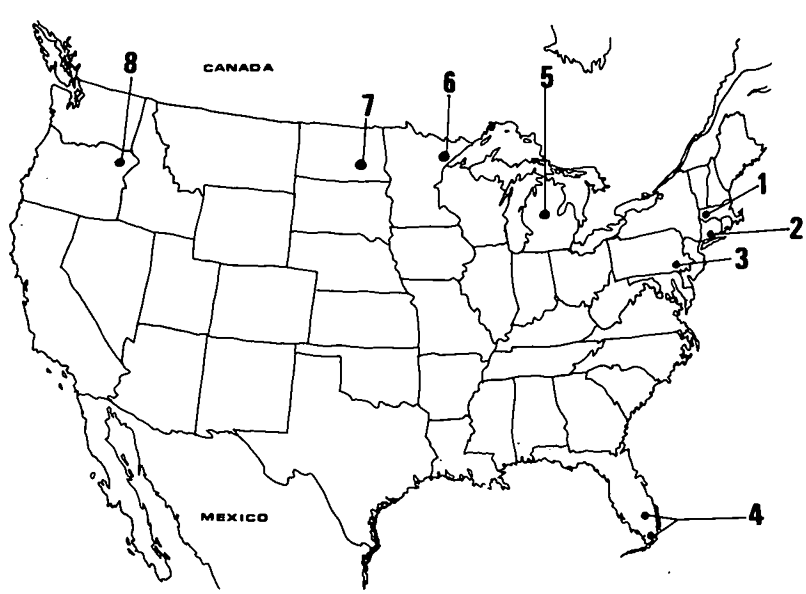


Figure 1. Case study sites.

particularly the West Coast and South Central and Southwestern regions, are not represented. However, the nature of the effects that are reported on is such that, in many instances, experience in one area can be transferred to another. The various study locations are listed as follows, along with the wetland class and primary effect(s) caused by the highway in question.

WETLAND LOCATION	WETLAND CLASS AND EFFECT
Whatley, Mass.	Borrow pit ponds adjacent to I-91; habitat creation
Fairfield, Conn.	Estuarine salt marsh; interrupted tidal exchange
Philadelphia, Penn.	Fresh water marsh; obliteration by fill
South Florida	Fresh water marsh and wooded swamp; altered drainage
Roscommon, Mich.	Wooded swamp over organic soils; altered drainage
Northeast Minn.	Wooded swamp over organic soils; altered drainage
Jamestown, N.D.	Prairie potholes; altered drainage; obliteration
La Grande, Ore.	Cattail–bullrush marsh; altered drainage

The information derived from each case study is organized according to type of ecological effect. Emphasis here is on those effects that tended to predominate in several studies or that are most graphically illustrated at one or more study sites. Because all the case studies involved a retrospective analysis of a wetland in which highway-induced changes had already taken place, the effects that were obeřved or deduced were limited, by-and-large, to major, long-standing changes resulting from the continuing physical presence of the highway facility. There was no opportunity, given the nature of these studies, to observe such significant, but relatively transitory, effects as erosion and sedimentation resulting directly from on-going construction activities. The absence of such effects from these case studies should, therefore, not be taken as reflecting their lack of importance but, rather, as due simply to the practical limitations of the case studies themselves.

Of the many effects of highways on wetlands that were identified in the various case studies, four classes of effects appear to predominate. Most common by far is *altered drainage;* indeed, to a greater or lesser extent, all the case studies (with the exception of the Whately borrow pits) provide evidence of this class of impact. In total area, the effects of altered drainage are manifested as *interrupted tidal exchange,* and this class of effect is placed in a separate category. The *physical obliteration* of wetlands resulting from the placement of highway fill or dredged material disposal was also a commonly identified impact of highway construction. The fourth class of impact is *habitat creation.* This last class is included not because of its general occurrence but, rather, as an example of what can be done in many instances.

Altered Drainage

Wetlands are defined in various ways; in each case, however, it is the presence of water in and on the soil that is critical to the definition, and the existence, of wetlands. Thus, for example, the U.S. Fish and Wildlife Service (*11*) defines a wetland as:

> Land where water is the dominant factor determining the nature of soil development and types of plant and animal communities living at the soil surface.

The U.S. Army Corps of Engineers (*12*) 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.

The hydrologic regime is the controlling feature in wetland ecology, and alterations in this regime will have profound impacts on the affected environment. Wetland plant communities are dependent not only on the presence of water but also on the frequency and amount of inundation. Changes in community structure may be expected when any of these characteristics are altered. The exact nature of the change will depend on the new water regime, the species composition of the former community, the available seed sources, and other factors. In most parts of the nation, the occurrence of water in wetlands is the result of seasonal patterns of precipitation, freezing, thawing, and the rate of water use by plants (transpiration). The duration and timing of these influences are stochastic phenomena particular to a given geoclimate area. Thus, the concept of "normal flow pattern" in wetlands is understood as a pattern of flow probability in volume, time, location, and duration of occurrence.

Highways and analogous structures impound the flow of surface and ground water to a greater or lesser degree. As such, they tend to raise water levels on the upflow side of the structure and lower levels on the downflow side. Conversely, directing water around and at specific places through the structure may concentrate the flow from the affected watershed to specific aquifers, channels, and wetland areas, thus raising water levels in those areas. In most instances these effects are most apparent in those situations where sheet flow is intersected by the highway embankment. Attempts to accommodate the interrupted flow by means of culverts is generally successful only insofar as protection of the highway structure is concerned. The change from diffused to concentrated flow results in a significant disruption of the hydrologic regime, which is reflected in alterations in the associated ecological system. Two types of sheet flow should be distinguished—surface and subsurface.

Subsurface Flow

Subsurface sheet flow is essentially ubiquitous, representing as it does the manner in which ground water typically moves through the earth. However, it is in organic soils, which underlie many classes of wetlands, that the interruption of subsurface flows often presents a problem. The

Roscommon, Mich., and Northeast Minnesota sites exemplify this situation. In both cases, the highway embankment interrupted the movement of subsurface flows, leading to the elevation of the water table on the upstream side of the highway. Culverts, where they were installed, were generally placed too high and too far apart to affect significantly the upstream build-up of water.

Large areas of the several states and Canadian provinces bordering the Great Lakes are overlain to a greater or lesser depth with peat and other poorly drained soils. Typically, these areas are dominated by various species of wetland conifers, the harvesting of which is a major economic activity. Extensive damage to timber has been observed on the upstream side of highways and other embankments crossing peat wetlands. It has been estimated by staff of the U.S. Forest Service that more than 30,000 areas of swamp conifers have been so affected in northern Minnesota alone.

The nature of the problem is illustrated in Figures 2 and 3, drawn from the Minnesota study. Figure 2 is a planimetric view of a typical wetland crossing and the area in which flooding occurs. The road is shown running parallel to the contours of the land and positioned so as to cross the wetland at its narrowest point, a typical situation. The cross-hatched area upland from the highway represents the location of inundation caused by blockage of drainage. The extent of this zone of inundation is usually considerably larger than the area immediately adjacent to the road because of the geometry of the basin.

Figure 3 is a profile view of the area shown planimetrically in Figure 2. In part A of the figure, the level and direction of flow of the water table are shown by the broken line, BB. In undisturbed peat wetlands the water table tends to be located from 10 to 50 cm below the surface during much of the growing season, and it is in this zone that most of the horizontal movement of water through the soil takes place. Below 50 cm or so the soil is consolidated because of the weight of the overlaying soil, and little, if any, movement of water occurs in this near-impermeable medium.

Part B of Figure 3 shows the effect that the construction of the road has on the level of the water table. In the first instance, the road fill acts as a dam, blocking the movement of water along and below line BB. The peat immediately below the fill is consolidated by the weight of the overburden, reducing its hydraulic conductivity effectively to zero. Because only the upper 50 cm of the peat are hydraulically active, almost any combination of fill, displacement, and consolidation will impede the movement of water across the line of fill regardless of the depth of the peat layer. The water that is impounded by the fill will rise at the embankment to the level of the culvert; the level of the water table will assume a position along line B'B', intersecting the undisturbed water table, BB, some distance uphill from the road.

The invert elevation of the culvert relative to the undisturbed water is the most important design feature affecting the state of inundation caused by construction of the road. Typically, the culvert is located at or above the point of intersection of the embankment with line AA, so as to intercept surface flow in a more or less defined channel. Although this practice may suffice to prevent overtopping of the roadway by storm runoff, it does not provide adequately for subsurface flow, which is the primary means of drainage in peat wetlands during much of the year. Flooding and damage to timber in the area above the road are almost inevitable consequences. (Highway-induced flooding, however, may also have a beneficial effect on wildlife by providing open water, standing dead trees, and other favorable habitat. In consideration of these

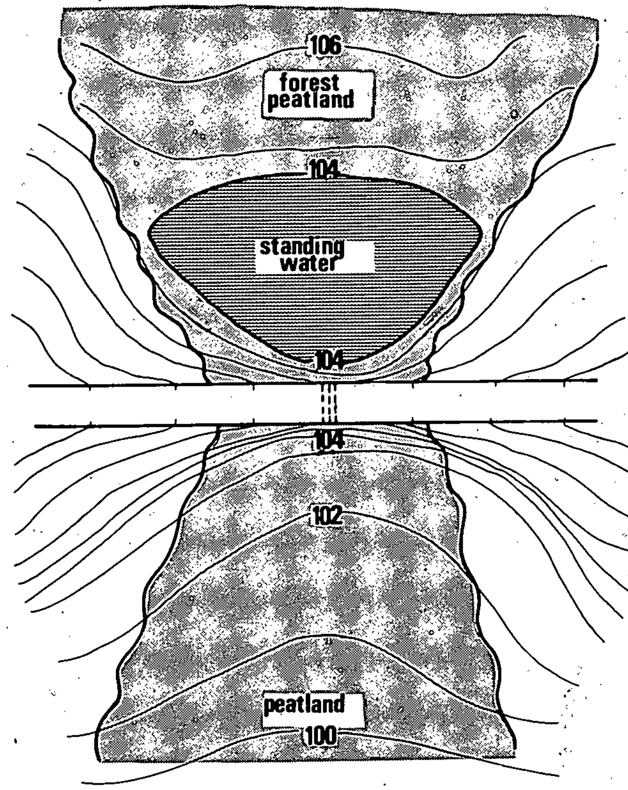


Figure 2. Planimetric view of tyical peat wetland crossing area in which flooding occurs (13).

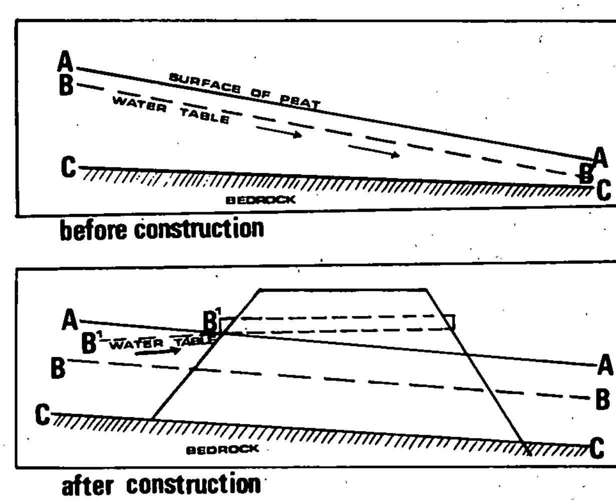


Figure 3. Hydrologic problem and water table relations in roads crossing peatlands approximately parallel to the contour (13).

and other wildlife benefits, fish and wildlife agencies periodically request the creation of highway impoundments.)

The extent of damage resulting from highway-induced flooding, and the road design and location features most frequently associated with such damage, was investigated in 1965 by the North Central Forest Experiment Station of the U.S. Forest Service (*13*). A systematic random sample of 70 forest wetland crossings in 7 contiguous counties in northeastern Minnesota was studied in order to ascertain the extent of tree damage caused by the damming effect of roads. The roads studied had all been in place for a considerable period of time, many for 50 years or more; all could be classified as low standard in terms of design features such as width, surface type, foundation, and drainage. Eighty percent of the crossings were on peat; the rest on mineral soil. The forest types involved were mainly black spruce and tamarack. Northern white-cedar, black ash, red maple, and associated species were also present.

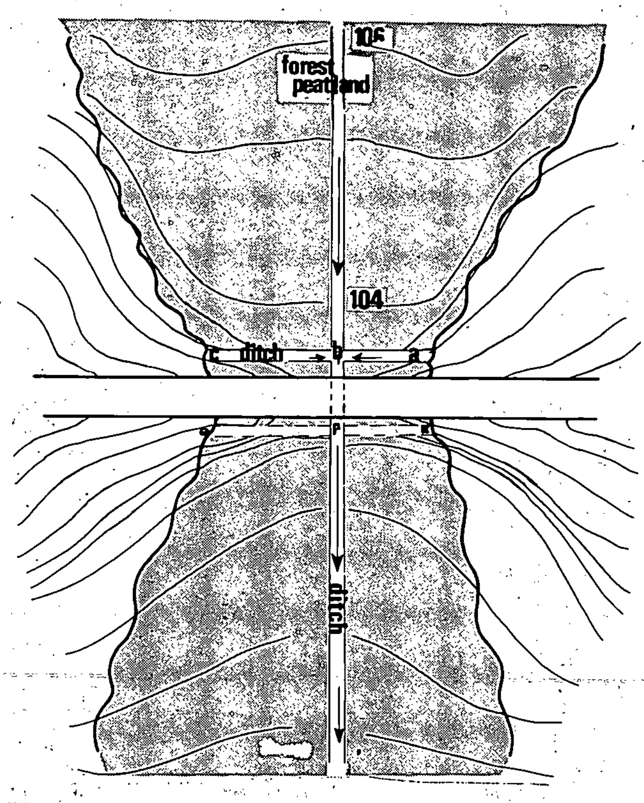


Figure 4. Location in plan of various ditches to ensure proper drainage of peatland road crossing (13).

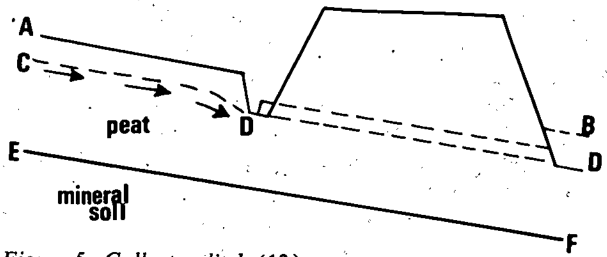


Figure 5. Collector ditch (13).

Tree damage was classified into three categories: none, trees killed or weakened within 15 m of the road, and trees killed beyond 15 m. Of the 70 sites included in the sample, 55 percent evidenced some degree of damage. All of the 39 crossings that showed damage were oriented within 45 degrees of being parallel to the contours along which they ran; that is to say, they tended to run across, rather than along, the drainage flow. The apparent rise in water table in the zone of most serious tree damage averaged about 28 cm over the 39 crossings, with a maximum rise of 76 cm.

A comparison of U.S. practice with European practice in the design of road drainage features in organic soils suggests several steps that can be taken to prevent the damming action of roads crossing peat wetlands. European practice calls for the excavation of a collector ditch along the upstream side of the road. Culverts are placed so that their inverts are at or near the bottom of the collector ditch, several feet below the original level of the swamp. A discharge ditch, perpendicular to the roadway, to carry water beyond the influence of the road is also recommended. A perpendicular entrance ditch on the upstream side of the road and an additional discharge ditch running parallel to the downstream side may also be used. Figure 4 shows the location of the various ditches (*13*).

The location of these drainage features in profile and their effect on the water table are shown in Figure 5. The dimensions and location of the various drainage features will, of course, vary with conditions at the site.

The converse of the blocked drainage problem observed in the Michigan and Minnesota cases is represented at Ladd Marsh, in La Grande, Ore. In this instance, the water table has been lowered as a result of highway construction activities. The manner in which both the surface and subsurface water regimes have been altered by highway activities at this site is shown in Figure 6. The Foothill–Ladd Canyon Road was constructed with borrow. Drainage for the road is provided by a ditch along the uphill (west and south) side of the road. In the absence of lateral culverts through the road embankment, surface sheet flow that formerly fed the marsh is now diverted around it. A secondary source of sheet flow from the north is intercepted by a preexisting drainage ditch at the end of the marsh. The deprivation of water for the marsh is compounded by the borrow ditch along the west side of Interstate 80-N, which has lowered the subsurface water table in the marsh by reducing the base grade at which ground water discharges.

The combined effect of these hydrologic changes has been to lower the water table in the marsh during all seasons, thus changing the vegetation from wetland to upland, and slowly eliminating areas of open water important to water fowl and other marsh animals. Despite attempts by the Oregon Game Commission to divert runoff back into the marsh, over the past 29 years, wetland acreage has been reduced by 15 percent.

Diffused Surface Flow

The effects of highway construction on wetlands that are dependent on diffused surface drainage are most dramati-

cally illustrated in the Everglades and Big Cypress complexes of South Florida. The marsh and swamp systems of these two vast wetlands receive the bulk of their water from surface runoff and sheet flow over shallow aquifers. The natural flow is generally from the latitude of Lake Okeechobee on the north, south through the Everglades and Big Cypress, exiting through the mangrove forests bordering Florida Bay and the Gulf of Mexico (see Fig. 7). Although highways occupy a minute fraction of this environment and generally do not block critical flow points, their construction has contributed to significant changes in portions of this vast region.

These changes stem principally from two aspects of the highway construction process. In the first instance, the presence of roadway embankments across the axis of primary flow has the potential of blocking sheet drainage, much as in the case of the peat wetlands discussed in the Minnesota and Michigan examples. However, unlike these latter cases, the bulk of the flow is above the aquifer and can often be effectively accommodated by proper culverting. Where this has been done (as in the case of State Route 27 between the Everglades Park entrance and Flamingo), the drainage-related impact of the highway embankment is negligible. Where provisions for surface drainage are not adequate (as along the western portion of Alligator Alley), backwater conditions develop on the upstream side of the highway, which are reflected in the drawdown of the water table on the downstream side; vegetative changes are the inevitable consequence of these hydrologic alterations.

The effect of highways in the Everglades–Big Cypress environment is very much a function of the presence or absence of drainage canals associated with the construction of the roadway embankment. Unlike Route 27, which was constructed with borrow from sites well removed from the right-of-way, the other roads that were the subject of this study were constructed on fill obtained from borrow canal spoil excavated along the right-of-way. Although these canals are used as flood control structures at critical periods during the year, they also serve to collect sheet drainage on the upstream side of the highway and, where they exist, to facilitate the reestablishment of sheet flow on the downstream side. In those instances where the combination of parallel canals and adequate culverts at all natural drainage channels is sufficient to reestablish natural drainage immediately downstream from the highway (as along Tamiami Trail and the eastern portions of Alligator Alley), little, if any, ecological effect is observed.

It is important that a balance be struck between too little and too much drainage. For example, connection of the borrow canal along Alligator Alley to the south-running Barron River and Turner River canals has accelerated flows south of the Alley and directed water away from the historic pattern. Similarly, the borrow canals along State Routes 29 and 840A—which run parallel to the north–south drainage axis between Alligator Alley and the Tamiami Trail—intercept substantial amounts of surface water and divert it directly to the estuaries of Florida Bay. There is evidence that the reduction in fresh water head resulting from this diversion has led to inland migration of salt water.

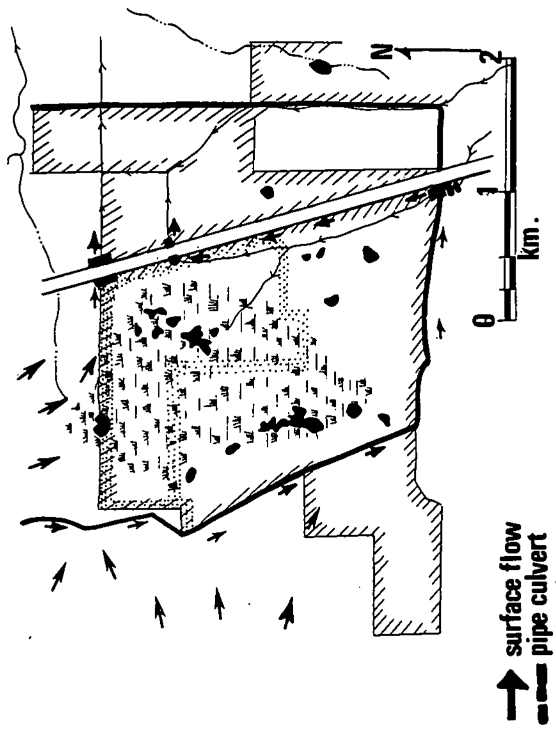


Figure 6. Ladd Marsh, Ore.

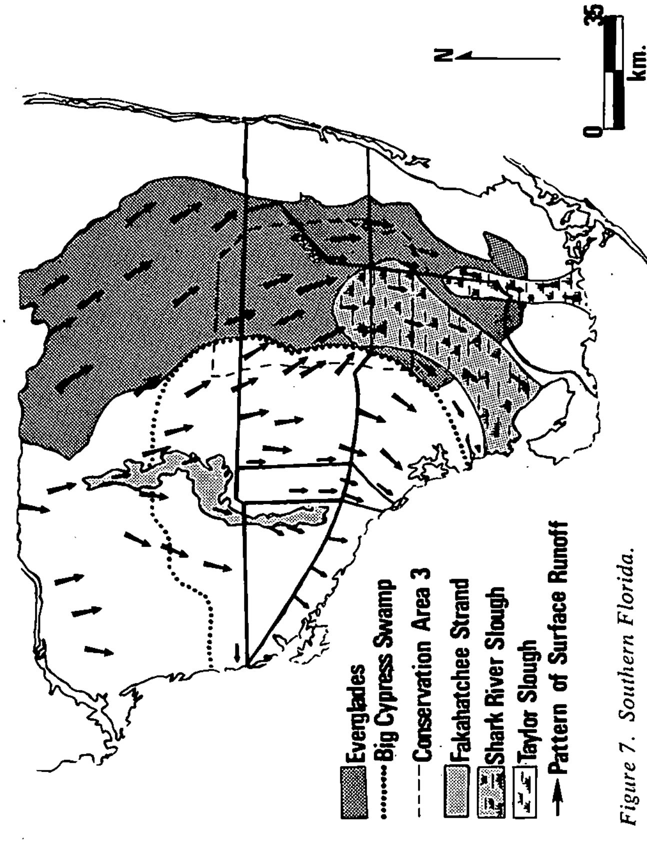


Figure 7. Southern Florida.

The Flamingo Road demonstrates that, if highways must be constructed across sheetflow wetlands, extensive use of culverts without borrow canals can have minimal effects. The original construction of the Tamiami Trail suggests that borrow canals in combination with culverts need not have adverse effects but that they lay the foundation for subsequent disruption of the wetland ecosystem. Alligator Alley illustrates that even with attention to the impact on hydrology, modern road and borrow canal construction techniques are in need of further refinement in order to obtain uniform desirable results. State Routes 29 and 840A are examples of a straightforward effort to use a combination of canals and no culverts in conjunction with a spoilbank base to drain a wetland—with questionable economic and adverse ecological effects.

Appropriate drainage features are obviously necessary for avoiding ecological damage in the Everglades–Big Cypress environment; but, given the destructive effects of many of the activities associated with roads such as the Tamiami Trail, it is clear that proper drainage, alone, will not suffice. Rigid control of access is also essential in preventing adverse impacts and a radiation of inappropriate uses of these vast wetlands. Reconstruction of Alligator Alley to Interstate standards will provide an opportunity to develop a major demonstration of compatible road construction and wetland protection.

Interrupted Tidal Exchange

The interruption by embankments and other structures of the tidal exchange in coastal and estuarine marshes is an important special case of altered drainage. The twice-daily ebb and flow of tidal waters is essential in maintaining the level and salinity of these salt and brackish marshes and in carrying detritus from marsh areas to the marine environments that rely on this source of nutrient. Highway drainage structures typically are designed to accommodate stormflow from upland sources. The capacity of the culvert, its invert elevation, and erosion protection measures associated with it are characteristically based on the need to convey storm waters flowing down from upland locations. Insufficient attention is often directed to the passage of tidal waters, which, during part of their cycle, move through these structures in a direction opposite to the design flow. Often the result of such "unidirectional design" is the alteration of the tidal regime within the marsh.

The ecological effects of restricted tidal exchange are illustrated by the Fairfield, Conn., study. Pine Creek Marsh is a 24-acre estuarine salt marsh on Long Island Sound in the Town of Fairfield, Conn. A storm and flood control dike was constructed in 1970. The location of this dike and changes in the dike and culvert system that have been proposed in an effort to mitigate effects of tidal interruption on the marsh are shown in Figure 8.

The interruption of tidal flows by the dike has resulted in an average reduction of 23 cm in tidal elevations within the marsh, and a reduction of as much as 46 cm has resulted during spring tides. Ground water levels have receded well below that required to support two common species of marsh grasses. The reduction in tide height has reduced the total marsh area exposed to salt water, and, in combination with lowered ground water levels, has resulted in a shift of vegetation from salt marsh to fresh; at the landward margins of the marsh, upland species have begun to replace the wetland biota. Where upland or fresh water species have become established, the peat soils of the original salt marsh have become compacted and less permeable. As a consequence, even if current efforts to restore the historic tidal hydrology are successful, the capacity of the marsh to support salt marsh species would be reduced.

The restriction of salt water intrusion into an estuarine system by a highway acting as a barrier to, or restrainer of, tidal inundation will greatly affect a wetland. Where salt water intrusion is prevented by a highway barrier, plant populations will show slow but significant changes. Many estuarine plants actually grow well in fresh water, but cannot compete successfully with fresh water species in that environment because of slow growth and lack of viable seeds. Some estuarine plants require salt for growth and will die in fresh conditions. The estuarine species of macroscopic algae and microscopic diatoms will be replaced by fresh water species.

Physical Obliteration

The physical obliteration of wetland habitat by the highway embankment itself is an unavoidable consequence of that form of construction. In those instances where such loss of habitat is unacceptable—for example, where a unique wetland may be lost, or rare or endangered species may be threatened—rerouting of the highway or open pile construction may be the only alternative. However, there are many occasions where habitat loss or alteration through physical obliteration extends well beyond the highway fill. The construction of I-95 through Tinicum Marsh in Pennsylvania is a case in point.

Tinicum Marsh occupies the lowlands along Darby Creek in Delaware and Philadelphia Counties in southeastern Pennsylvania. The marsh, before construction of I-95, covered about 500 acres between Pennsylvania Rt. 291 and the Tinicum Wildlife Preserve of the City of Philadelphia (see Fig. 9). Though the marsh area was historically greatly disturbed and considerably reduced in size over the past 300 years, it was, and still is, an important tidally inundated fresh water environment. No rare or endangered species consistently live or breed in Tinicum Marsh, but the habitat itself is rare, being the last remaining tidal wetland in the State of Pennsylvania.

In the initial planning phase for I-95, a compromise between the Pennsylvania Department of Highways and local conservation groups in 1963 provided for the routing of the highway along the southern edge of the marsh, where it would have interfered least with tidal flows and would have obliterated the least amount of marsh habitat. This compromise, however, was not included as a restriction when construction bids were advertised in 1968. The project contractor, unencumbered by the earlier compromise, negotiated contracts with the private owners of the marshland to obtain sand and gravel lying under the marsh for roadbed fill. These contracts also obligated the contractor to fill other parts of the marsh to a level above the highest tide so that light industrial facilities, high rise apartments,

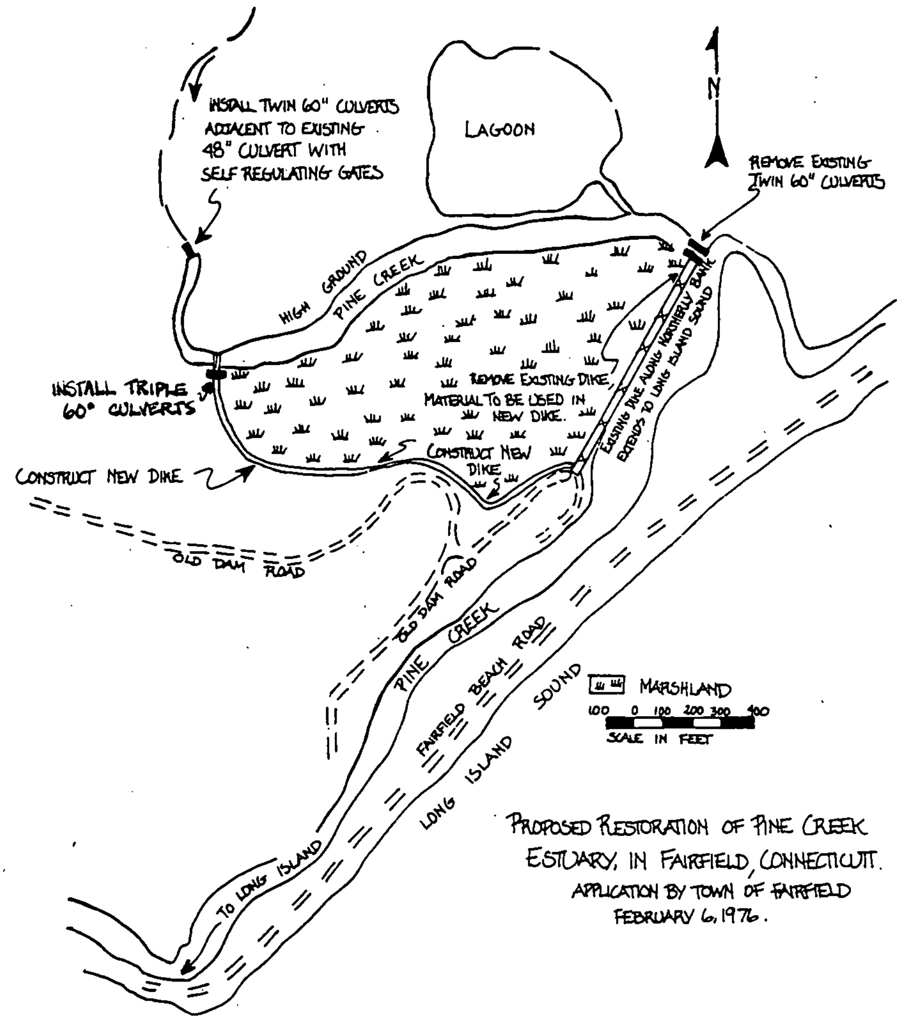


Figure 8. Proposed restoration of Pine Creek estuary, Fairfield, Conn.

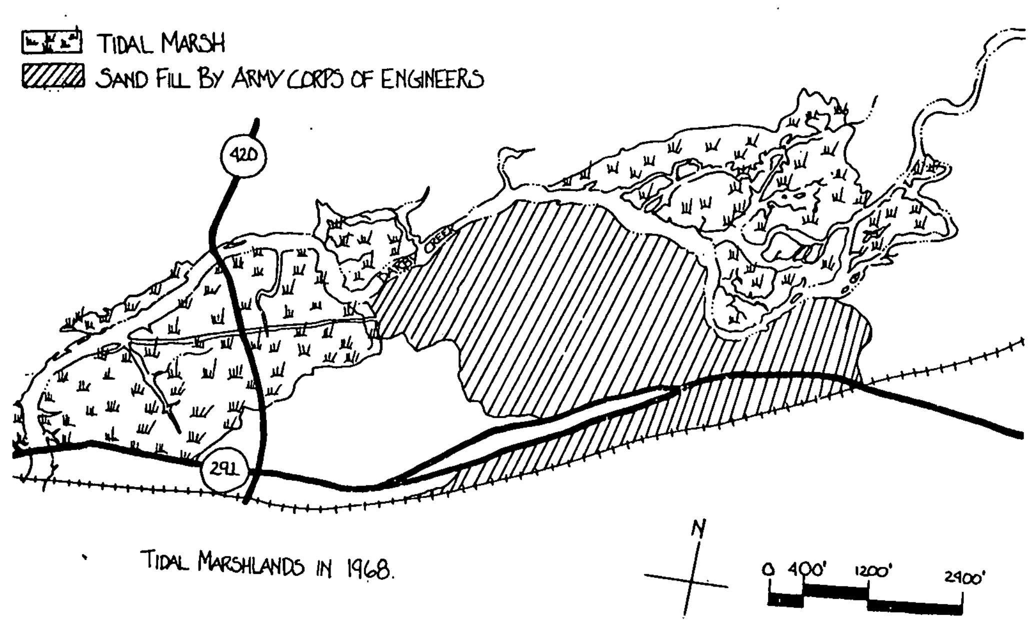


Figure 9. Tinicum tidal marshlands in 1968.

or shopping centers could be erected. Even though this filling was not a direct result of roadbed construction, the entangling contracts tied it intimately with highway construction. The location and extent of the marsh areas destroyed or altered by this set of related activities are shown on Figure 10.

Creation of New Habitat

Highway construction may result in the creation, as well as the destruction, of wetland habitat. Often such habitat creation is the unplanned result of borrow pit excavation or the inadvertent blockage of surface or subsurface drainage by a highway embankment. Increasingly, however, provisions for the creation of new habitat are being incorporated explicitly in highway location and design plans as highway agencies gain experience with the advantages that can accrue from such practices to both highway users and the public at large. Early and continuing coordination between highway agencies and state natural resource or wildlife departments is essential if the full benefits from the creation of new wetland habitats are to be realized. Of the many highway features and construction activities that can be employed in this capacity, three—use of ditches and culverts, construction of borrow pits, and dredge material disposal—appear to offer the most extensive opportunities for habitat creation. The material dredged from a wetland or removed from an upland site can be used to create new wetlands or extend existing ones.

The ecological uncertainties attending the accidental creation of wetland habitat are exemplified by a series of borrow pits excavated in 1959 and 1960 along I-91 in Whately, Mass. Figure 11 shows the location of the larger of these pits and identifies four that are the subject of the present case study. In this instance, location of the various borrow areas and the excavated configuration of each pit were dictated by the availability of appropriate borrow ma-

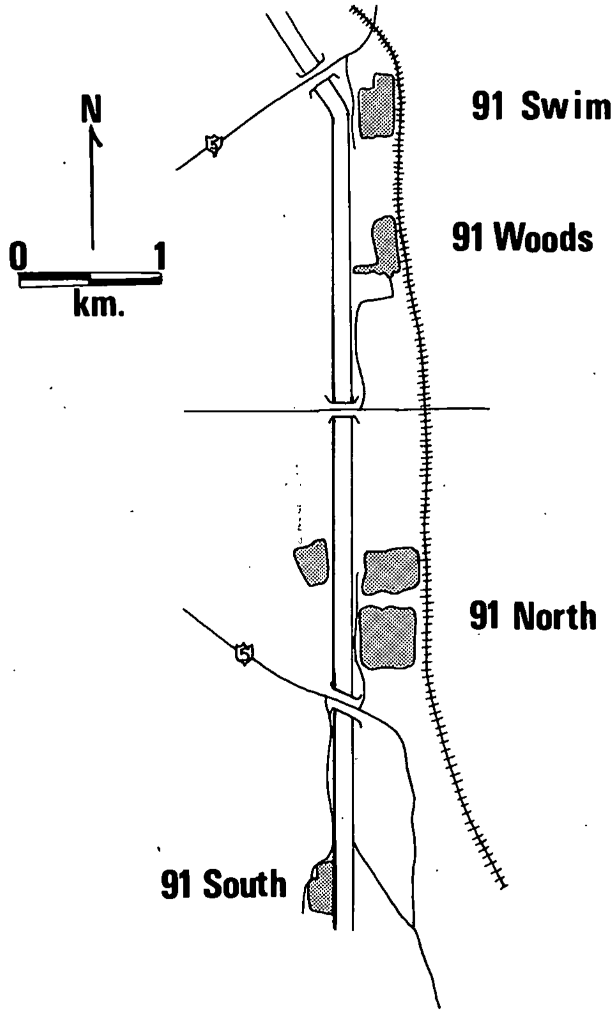


Figure 11. Interstate Route 91 Borrow Pit Ponds (15).

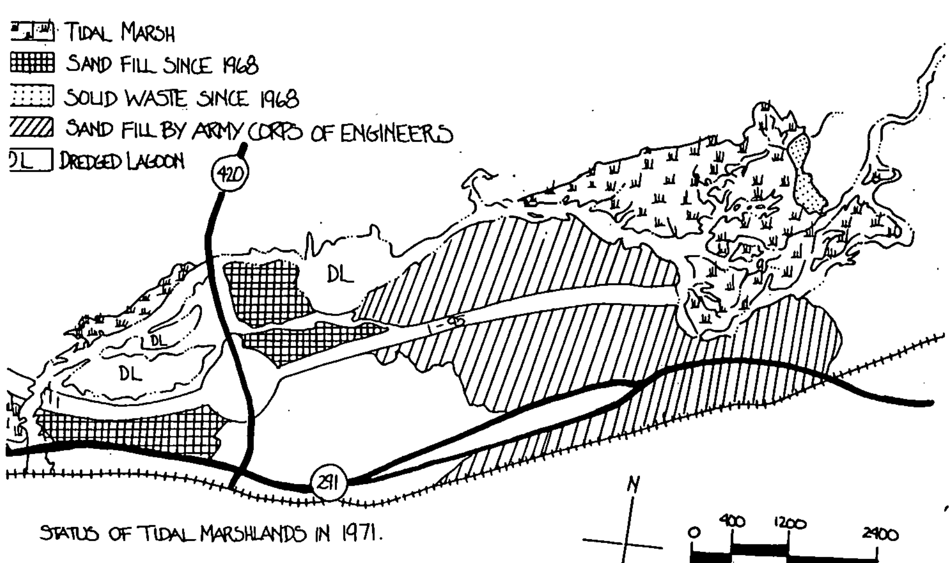


Figure 10. Status of tidal marshlands in 1971 (16).

terial and ease of excavation and haul to the construction site. Consideration was not given to the ecological potential of one location or excavation procedure relative to another.

The four borrow pit ponds are very similar in most respects. All four ponds have predominantly granular bottoms (as would be expected, given the purpose for which they were excavated), and all four are fed mainly by ground water supplemented to a degree by surface drainage from I-91 and the surrounding fields. The principal differences between the ponds lie in their basin configuration (91 SWIM and 91 WOODS have greater average depths and considerably less shallow margin than do 91 NORTH and 91 SOUTH), in the composition of the surface flows into them, and, directly related to these two factors, in their biological productivity.

Borrow pit productivity is strongly related to nutrient availability, substrate composition, runoff characteristics, and basin morphology. Because of the nature of borrow pits, the bottom sediments are primarily sand and gravel, contributing little to wetland fertility. Upland seepage and runoff are characteristically slow, and, although they do exert a major control over water chemistry, they usually do not encourage rapid eutrophication. Growth of aquatic vascular plants is dependent on the extent of shallow areas in the basin. Borrow pit morphology often results in either extensive shallows or none at all.

Of the four sites discussed, 91 SOUTH and 91 NORTH exhibited the highest productivity. 91 SOUTH exhibited extensive growths of algae and a dense population of cattail (Typha spp.). Both shallow water and agricultural drainage contributed to this condition. Shallow water was also a contributing factor in the higher productivity of 91 NORTH, but the absence of agricultural drainage leads to most of the pond's energy being cycled through the benthic flora rather than through an extensive plankton population. 91 SWIM lacked both shallow areas and nutrient-rich upland drainage. As a result, this impoundment was more deficient in plant nutrients (oligotrophic) than the previous two wetlands. In addition, because of its use as a swimming area, turbidity was high throughout the growing season, inhibiting light penetration in the water column. Drainage entering 91 WOODS was primarily from a pine-mixed hardwoods swamp with a resultant pH range of 4.9 to 3.7. This pond had very little emergent vegetation, a very small plankton population, and no fish population. It emphasizes the importance of site in relation to subsequent wetland characteristics.

In marked contrast to the strict highway-function orientation that characterized construction practices of a decade ago, increasing numbers of highway agencies are making explicit provision for creating or replacing wetland habitat in the course of highway construction. The practices of the North Dakota State Highway Department and those of Minnesota are instructive in this regard. A number of artificial wetlands has been created, for example, by the North Dakota Highway Department, as an integral part of the construction of I-29. Borrow areas are designed specifically to create marsh habitat, and include flat slopes and shallow areas necessary for the establishment of marsh vegetation. Figure 12 shows the type of plan and basin configuration employed. It is reported that within one year after construction marsh vegetation appeared along the periphery of the borrow area, and waterfowl were observed.

In addition to making good use of the opportunities for wetland creation provided by borrow excavation, the North Dakota Highway Department has employed a substantial number of highway embankments as dams for the purposeful impoundment of surface drainage. The management of the lakes and other wetlands so created is coordinated with the North Dakota State Water Commission and the State Game and Fish Department to provide the fullest possible ecological and recreational benefits from these areas.

North Dakota's policies with regard to the replacement of wetland habitat lost through highway construction are also worthy of note. A Memorandum of Understanding has been entered into between the Highway Department and the U.S. Fish and Wildlife Service establishing a basis of exchange for the replacement of wetlands beyond the highway right-of-way covered by fish and wildlife easement agreements with private owners. Wetland acreage filled or drained as a result of highway construction is replaced by alternative land as agreed to by both agencies. Exchange options are reviewed at the location and predesign phase. The range of options is narrowed during the preliminary design phase, with the final choice being made in conjunction with the final design of the project. Twelve wetland types for which replacement may be required under the Highway Department/FWS agreement are specified, along with six replacement options. The ratio of replacement area to impacted area varies, depending on the type of wetland that is to be lost, the type of area with which it is to be replaced, and the biotic region in which the replacement land is located. Replacement ratios range from 0.25, where the replacement wetland is considered to be of a higher type than that to be replaced, to 8.0, where tame grassland is to replace prime wetland in another biotic region. Minnesota DOT has also entered into such a Memorandum of Understanding with the Fish and Wildlife Service and uses borrow pits and control structures to create new habitat.

Conclusions and Recommendations

The impacts that highway fills have on the wetlands in

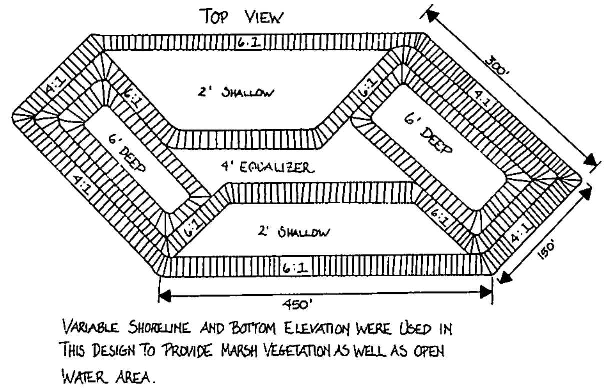


Figure 12. Basin configuration (17).

which they are constructed depend primarily on the extent to which the surface and subsurface hydrology of the affected wetland is disturbed. Standard design and construction practices do not appear to provide adequately for the unimpeded flow of ground water through the fill, with the result that the water table on the upstream side of the embankment is raised, leading to the destruction of timber and to other ecological changes. In coastal wetlands, drainage facilities designed to accommodate surface flow from upland sources often do not adequately handle tidal ebb and flow; the level and salinity of the waters within these tidal marshes are reduced, with consequent change in marsh biota. Restriction of tidal exchange also reduces the amount of nutrients that can be exported from the marsh to other, dependent, environments.

The extent of physical obliteration of wetlands resulting from embankment construction and dredge spoil disposal can be limited by careful location and construction practices. With the assistance of ecologists and other environmental specialists highway construction can also be designed to create new wetlands. The extent of damage or enhancement resulting from highway construction is, in the final analysis, determined not so much by the nature of wetlands or by the construction process itself, but rather by the perceptions and objectives of those responsible for location and design decisions.

USER'S MANUAL SUMMARY

The major product of this research is a manual that presents, in detail, the potential physical, chemical, and biological impacts of highway fills in wetlands and their interrelationships.

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 was drafted. Each flow chart displays a set of physical impacts that might result from a particular construction methodology 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 are 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 under each impact heading 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.

CHAPTER THREE

INTERPRETATION AND APPLICATIONS

The physical and biological impacts that may result from the construction of highway fills in wetlands are detailed in the user's manual (*NCHRP Report 218B*). In keeping with the general findings of the study that highway-induced impacts derive principally from changes in surface and subsurface hydrology, the discussion of physical impacts is organized primarily around hydrological modifications that may result from the placement of highway fills. Biological impacts are then discussed within the context of the hydrological and water quality changes that lead to their manifestation.

FLOW CHARTS AND MATRICES

The core of the user's manual seeks to make explicit the chain of causes and effects by means of a set of simplified flow charts and related impact matrices. Each flow chart traces the major hydrological and water quality ef-

fects that may be caused by each of four typical methods of highway fill construction (consolidation, displacement, excavation and replacement with borrow material, and use of lightweight fill), and by construction of pile-supported roadways or bridges. Because culvert design may affect both surface and subsurface flows, regardless of the type of fill used, separate charts are also provided for the analysis of culvert capacity and placement effects.

The effects of each construction type and culvert feature are shown initially in terms of their primary impacts on surface and subsurface flows and water quality. These effects are then detailed further in terms of changes in mean water level, modification of circulatory patterns, turbidity, sedimentation, and other hydrologic and water quality characteristics. These detailed water quality and hydrologic effects provide the link between highway design and construction practices and biological impacts on wetlands. A biological effects matrix relates each physical and chemical effect to one or more of nine potential biological impacts.

Figures 13 through 20 show the flow charts and matrices on which the format of the user's manual is based. (Full-sized representations of these charts are provided in App. B of *NCHRP Report 218* 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, which deal with physical impacts and biological effects.

AN EXAMPLE USE OF THE PROCEDURES

The use of the flow charts and the biological effects matrix 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. Based on these assumptions, the impacts of each construction procedure are traced through the appropriate flow chart and recorded on the biological effects 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 surface 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 the physical impacts and the biological effects 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.

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

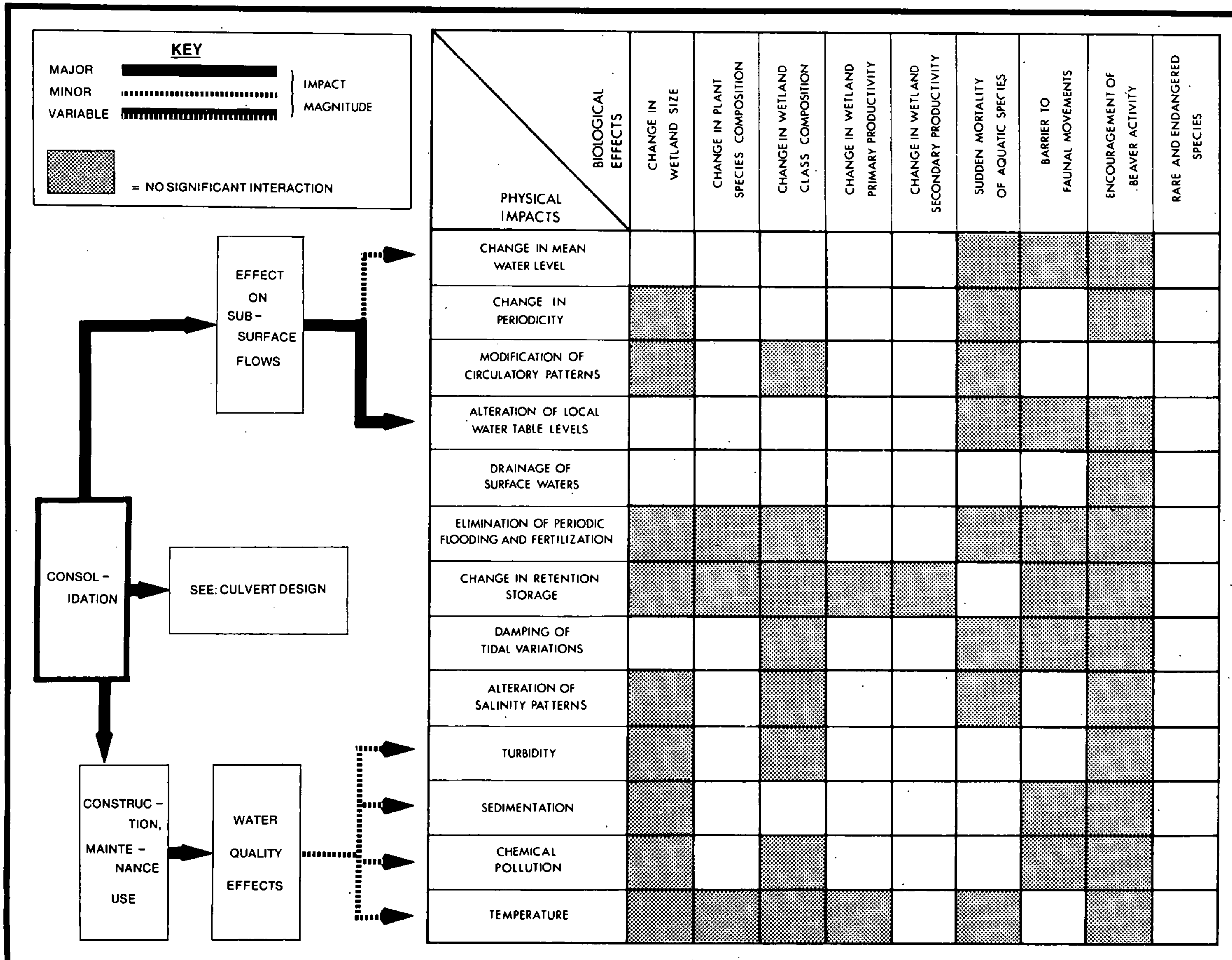


Figure 13. Physical impacts flow chart and biological effects matrix.

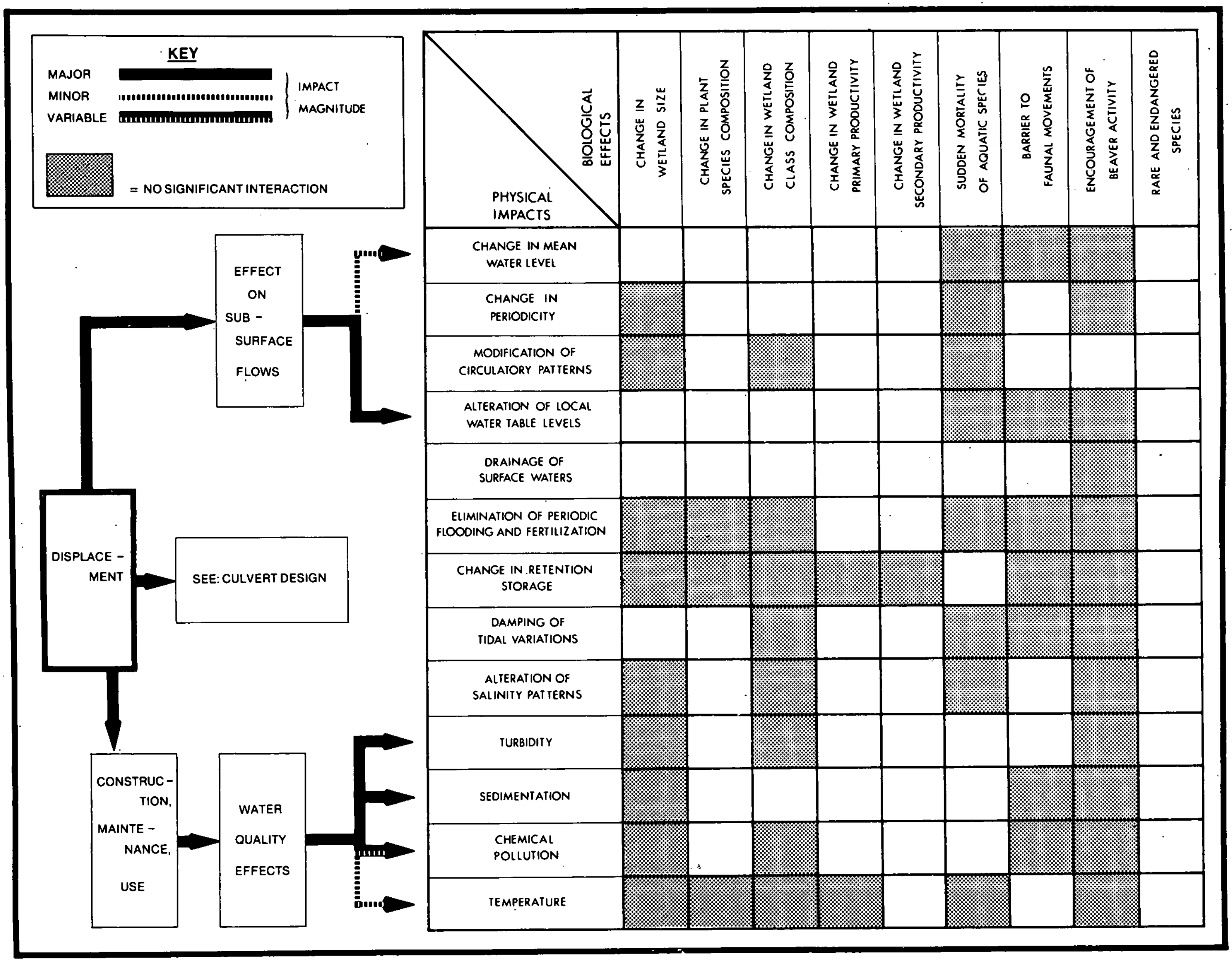


Figure 14. Physical impacts flow chart and biological effects matrix.

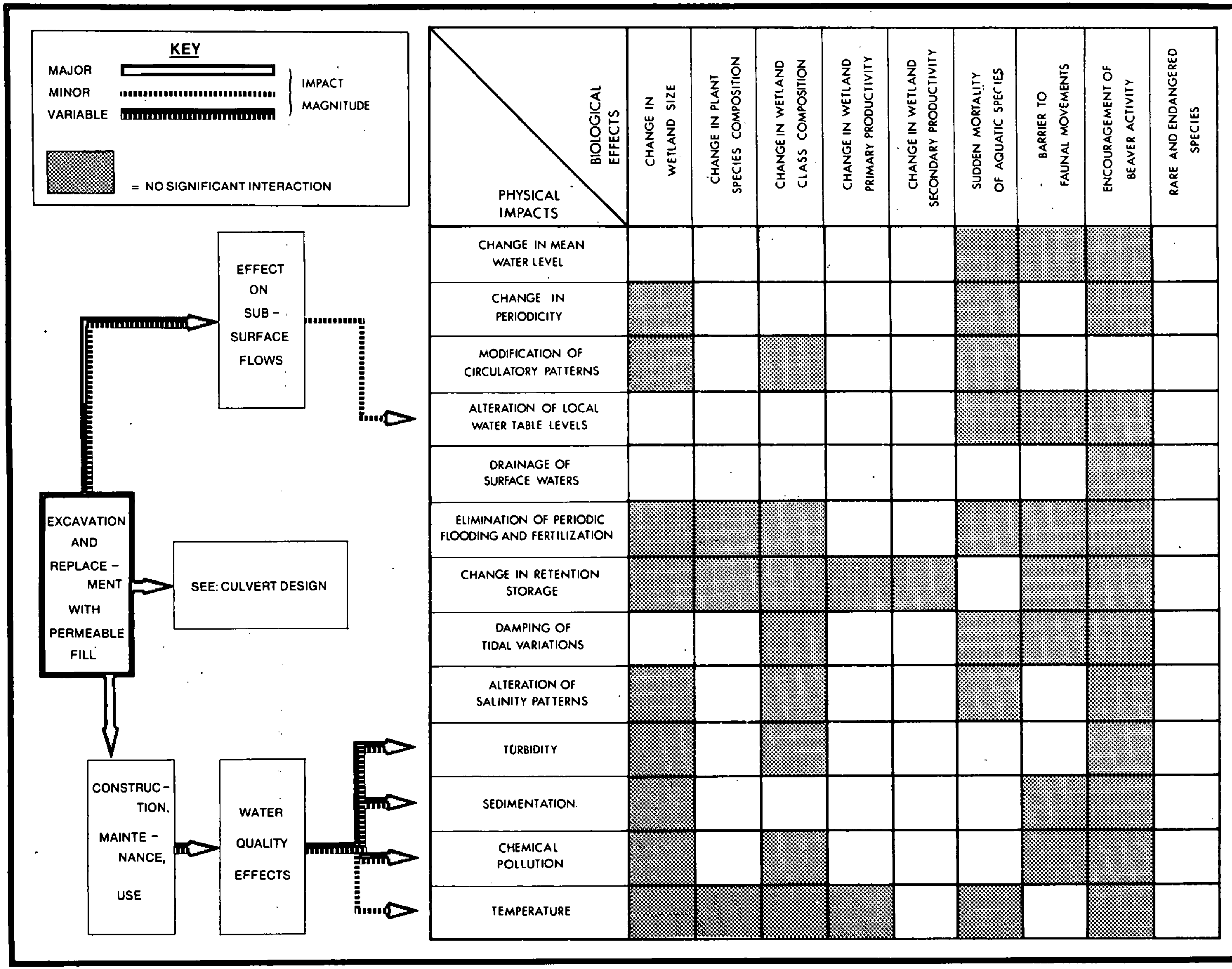


Figure 15. Physical impacts flow chart and biological effects matrix.

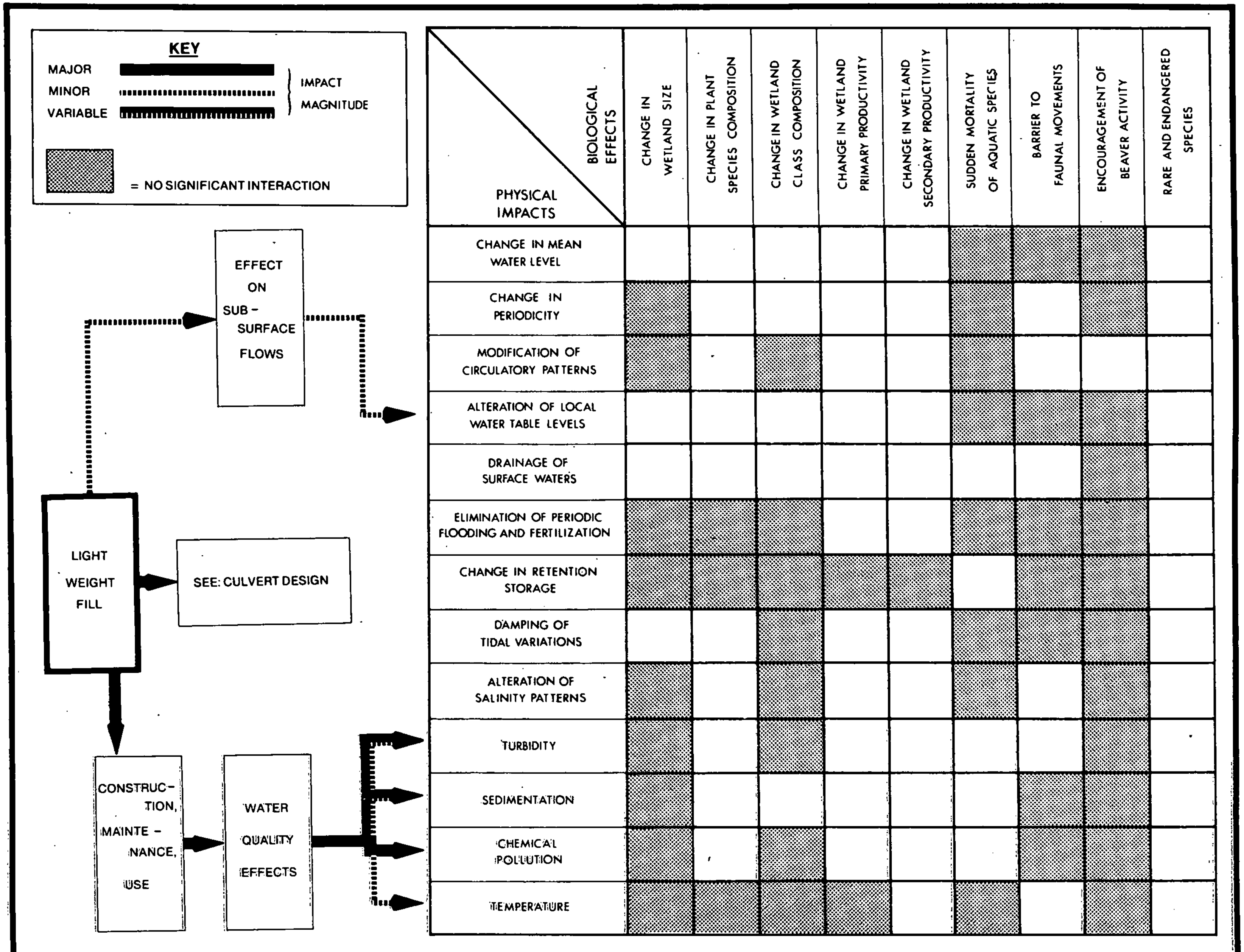


Figure 16. Physical impacts flow chart and biological effects matrix.

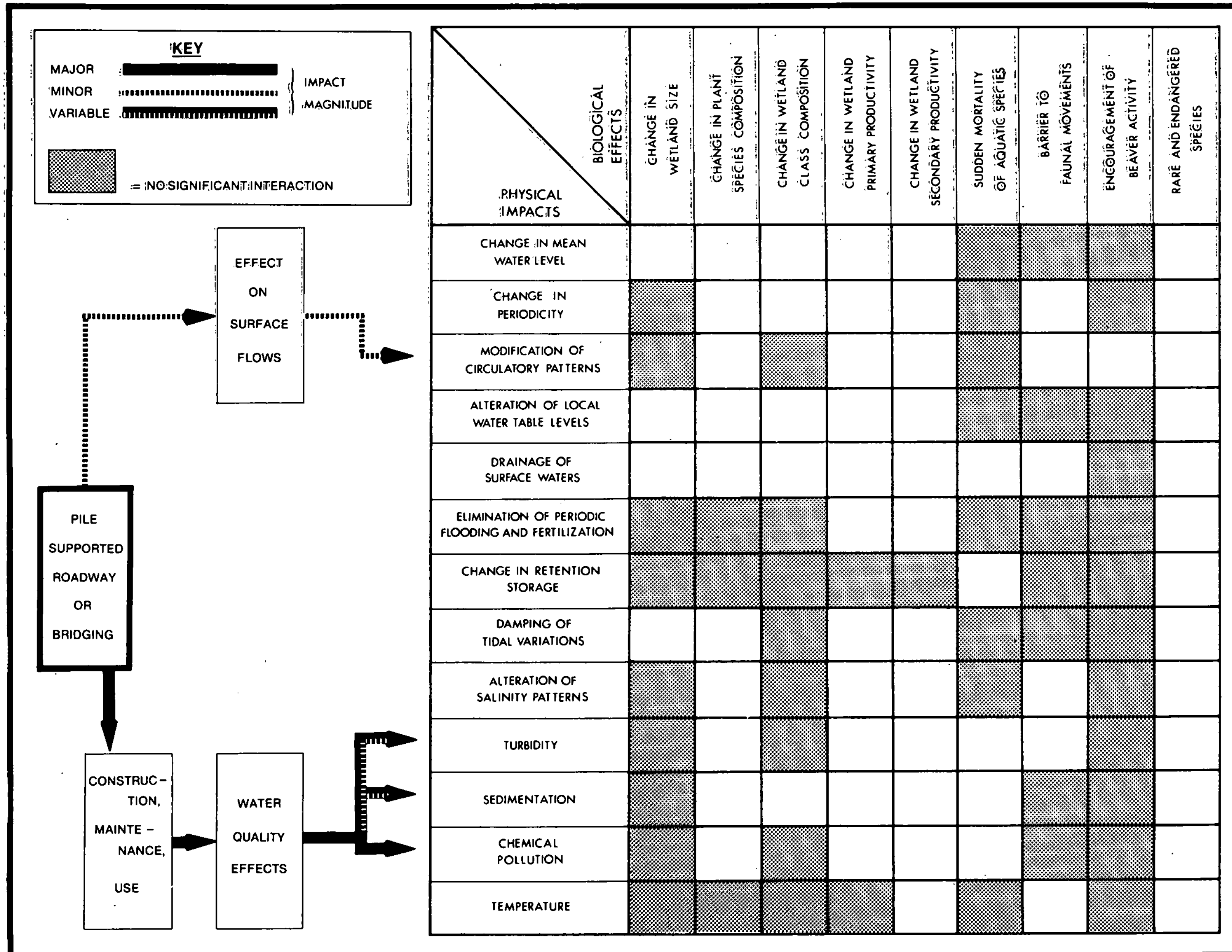


Figure 17. Physical impacts flow chart and biological effects matrix.

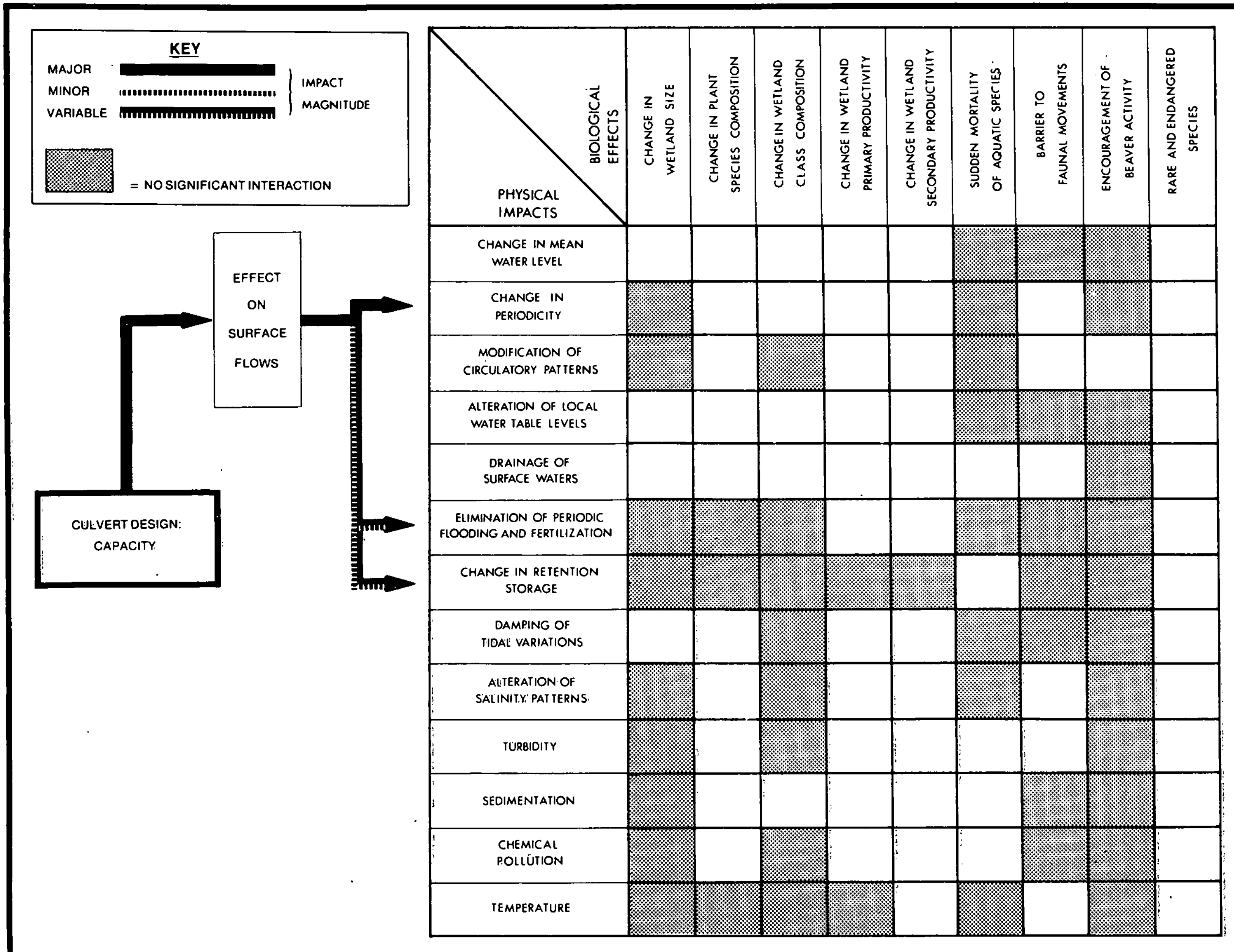


Figure 18. Physical impacts flow chart and biological effects matrix.

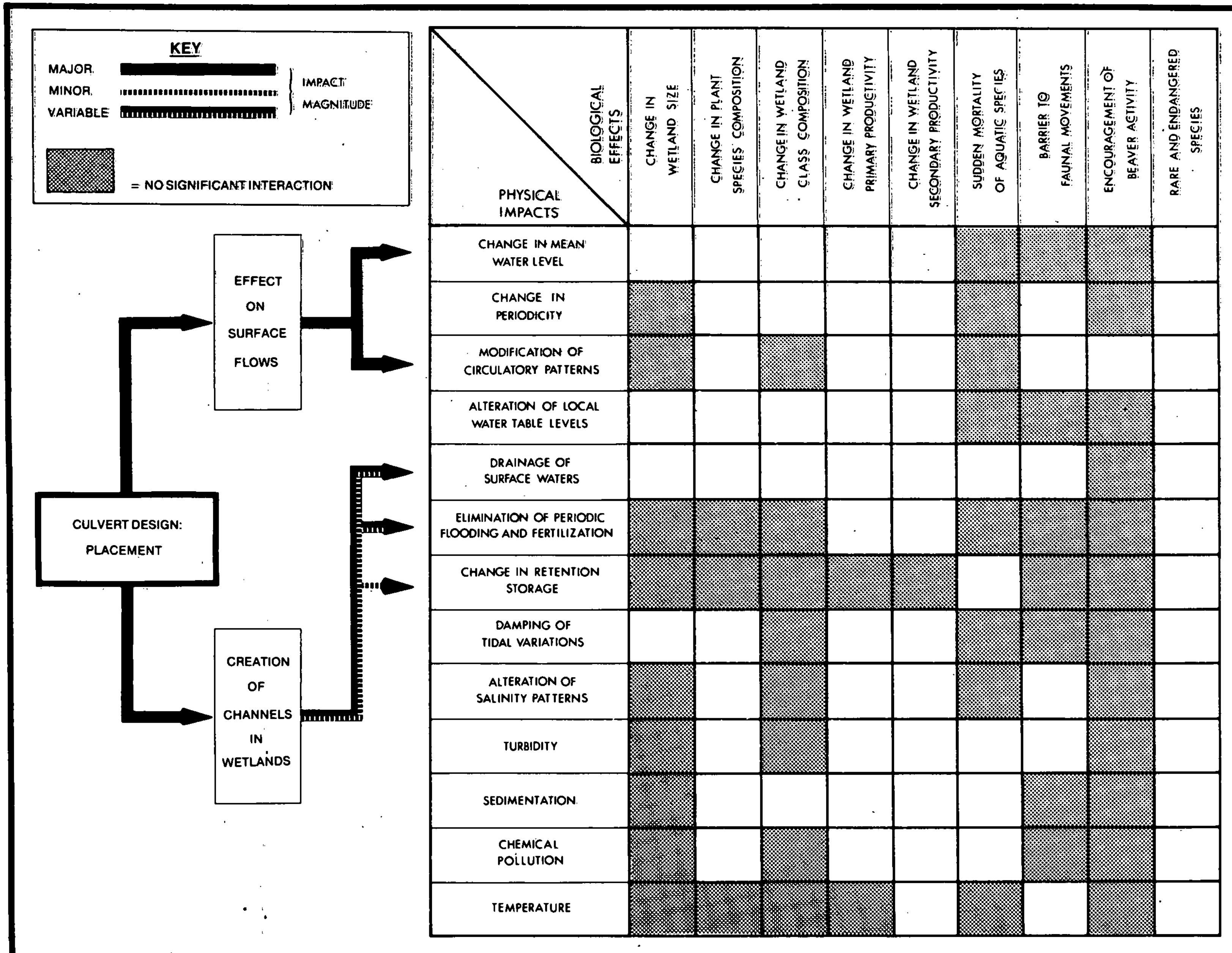
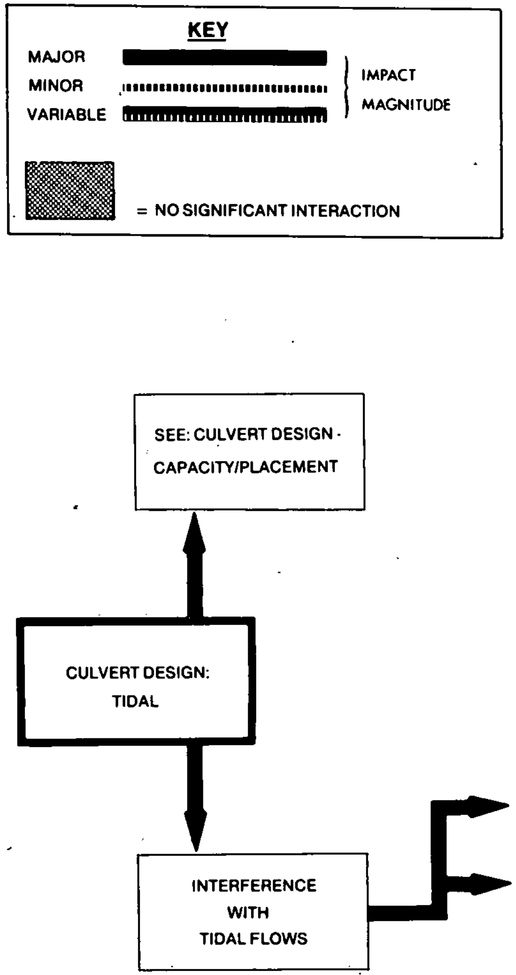


Figure 19. Physical impacts flow chart and biological effects matrix.



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						(shaded)	(shaded)	(shaded)	
CHANGE IN PERIODICITY	(shaded)					(shaded)		(shaded)	
MODIFICATION OF CIRCULATORY PATTERNS	(shaded)		(shaded)			(shaded)			
ALTERATION OF LOCAL WATER TABLE LEVELS						(shaded)	(shaded)	(shaded)	
DRAINAGE OF SURFACE WATERS								(shaded)	
ELIMINATION OF PERIODIC FLOODING AND FERTILIZATION	(shaded)	(shaded)	(shaded)			(shaded)	(shaded)	(shaded)	
CHANGE IN RETENTION STORAGE	(shaded)	(shaded)	(shaded)	(shaded)	(shaded)		(shaded)	(shaded)	
DAMPING OF TIDAL VARIATIONS			(shaded)			(shaded)	(shaded)	(shaded)	
ALTERATION OF SALINITY PATTERNS	(shaded)		(shaded)			(shaded)		(shaded)	
TURBIDITY	(shaded)		(shaded)					(shaded)	
SEDIMENTATION	(shaded)						(shaded)	(shaded)	
CHEMICAL POLLUTION	(shaded)		(shaded)				(shaded)	(shaded)	
TEMPERATURE	(shaded)	(shaded)	(shaded)	(shaded)		(shaded)		(shaded)	

Figure 20. Physical impacts flow chart and biological effects matrix.

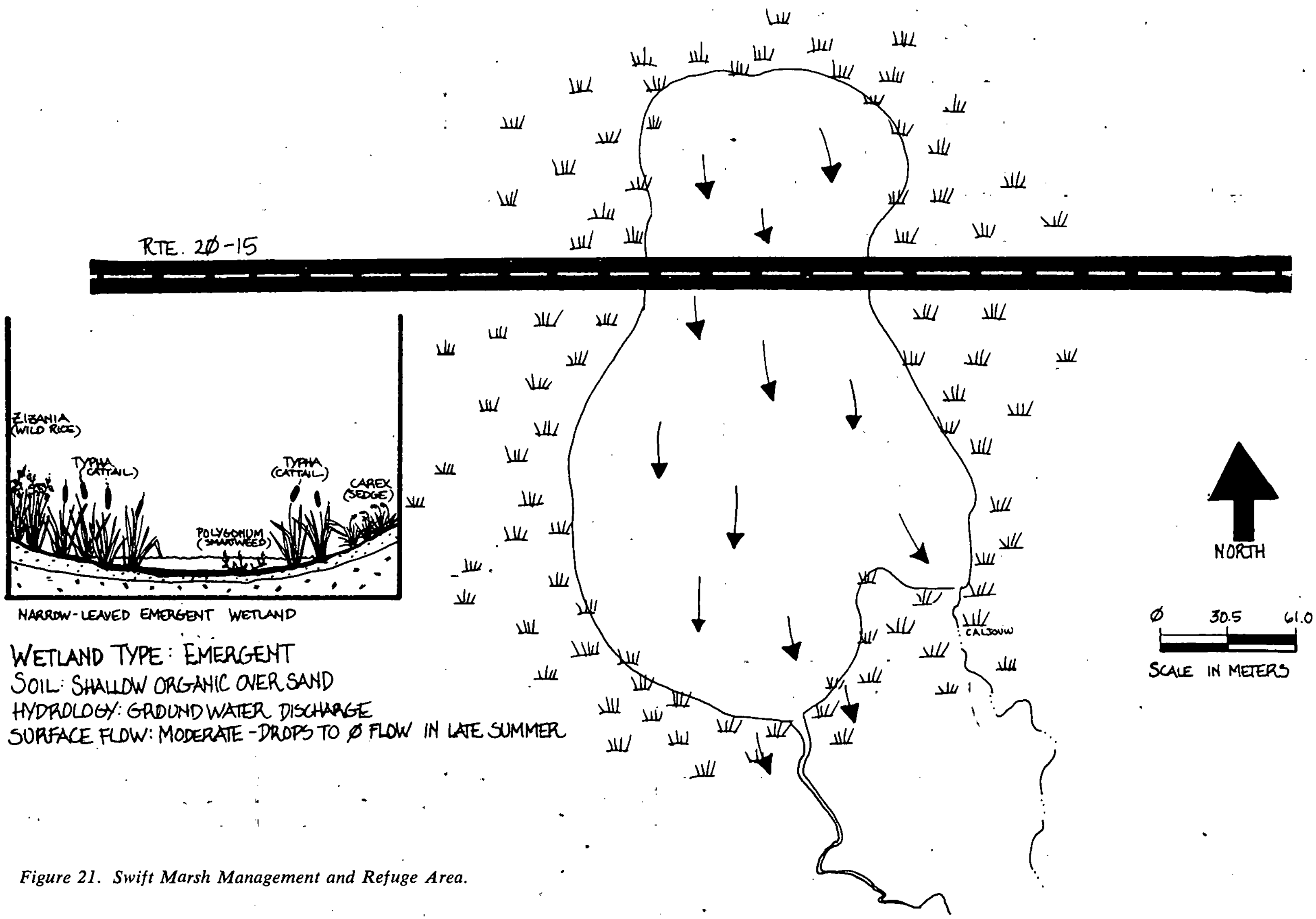
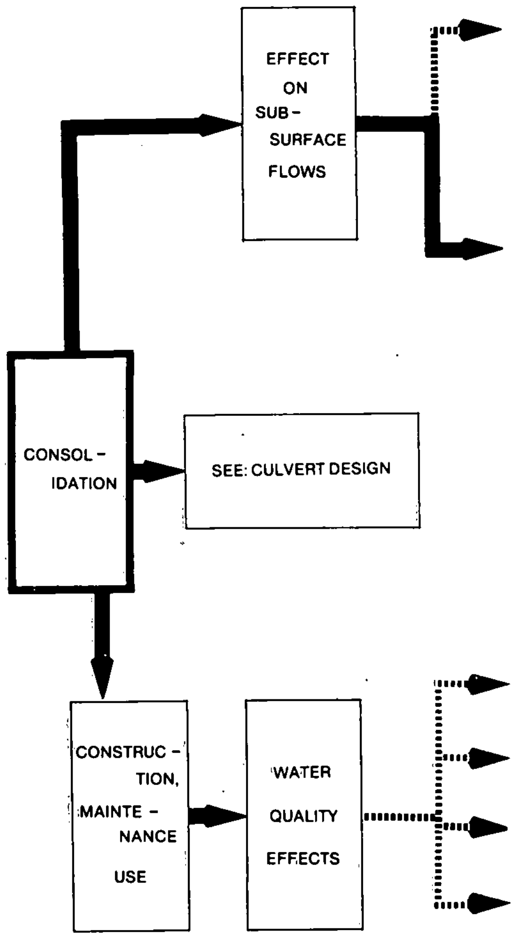


Figure 21. Swift Marsh Management and Refuge Area.

KEY

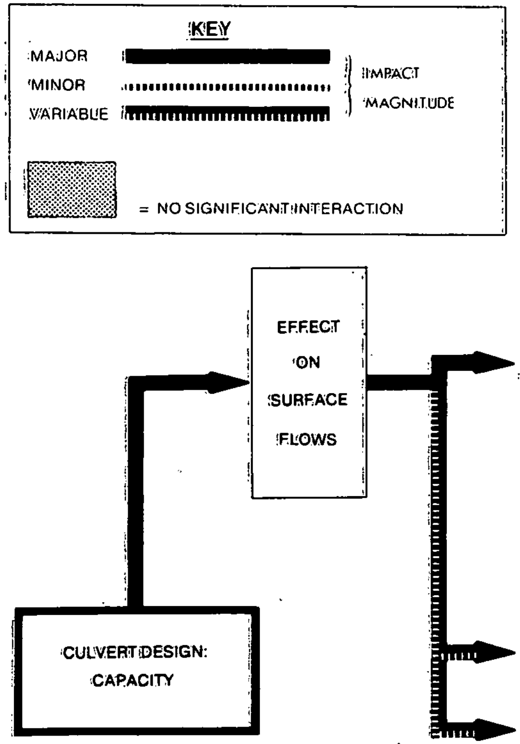
MAJOR / MINOR / VARIABLE — IMPACT MAGNITUDE

= 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	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.

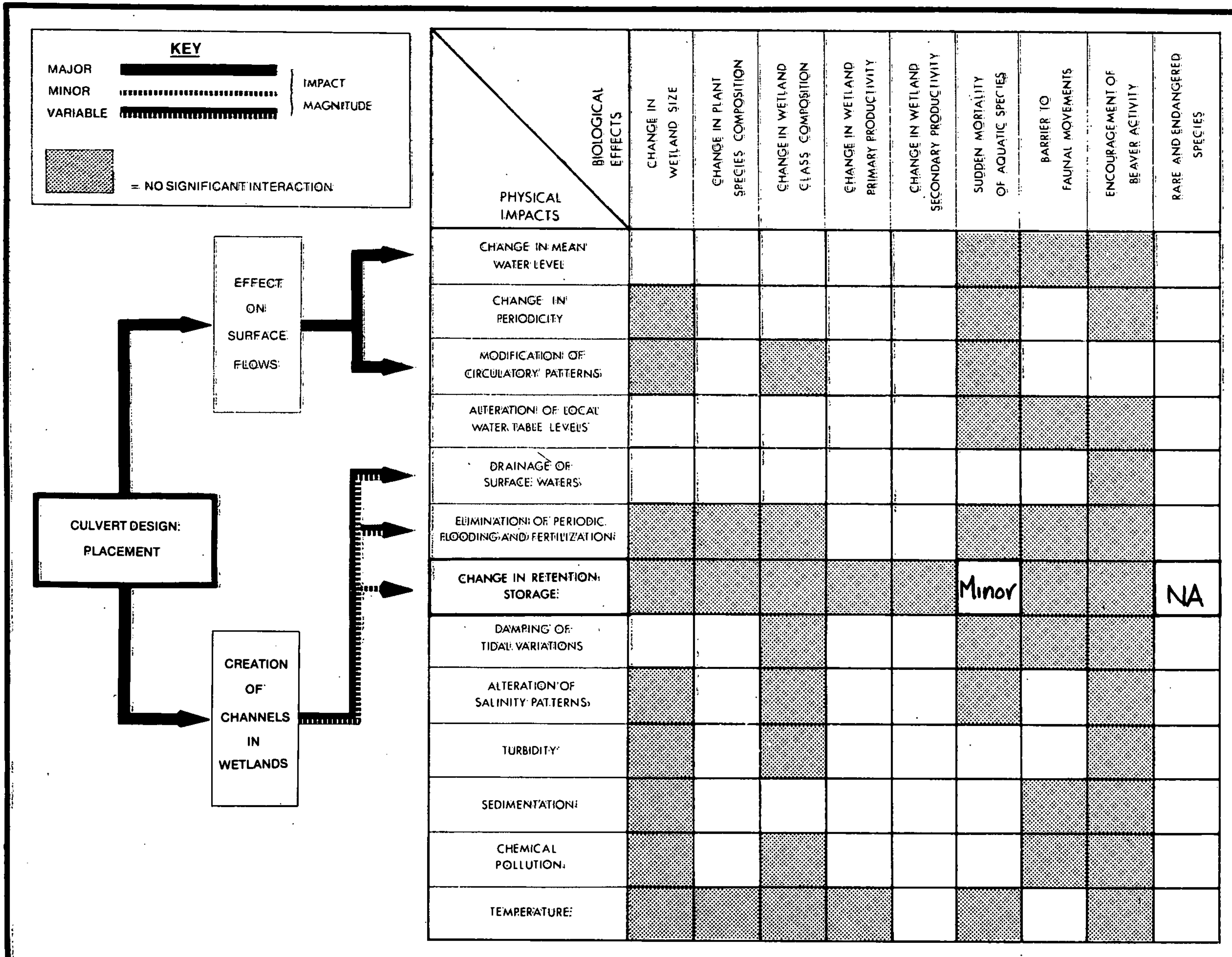


Figure 24. Construction alternative 1—culvert design placement.

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				
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 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	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 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		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 4

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									

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

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.

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 the combined biological matrix (Fig. 25), the biological effects of these two physical impacts are assumed to be less severe than in the case of displacement.

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. The combined biological matrix 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.

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

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.

NCHRP Project 20-15 has helped to promote just such a merger through the publication of a user's manual for highway engineers. This manual (*NCHRP Report 218B*) provides, through the mechanism of flow charts and matrices, an efficient means for engineers to evaluate the biological effects of the more familiar physical impacts of highway-related activities.

RECOMMENDED RESEARCH

Alteration of the Hydrologic Regime

The controlling environmental factor in wetlands is the hydrologic regime. Even apparently minor changes in rate of flow, periodicity of the rise and fall in level, and other aspects of both surface and ground water regimes can have profound effects on the biologic structure and function of wetlands. One's understanding of the effects of various highway construction activities and design features on the hydrologic regime is incomplete, especially insofar as induced changes in the movement of ground water at the local and regional scale are concerned. Present knowledge of how the ecology of specific wetland types will respond to a given change in the hydrologic regime is also badly deficient. Therefore, it is recommended that the following steps be taken to increase knowledge of the effects of highway construction on local and regional hydrology and of the responses of various wetland ecosystems to changes in the hydrologic regime:

1. Research should be undertaken to further knowledge of the geophysical factors that govern the movement of surface and subsurface waters at both the local and re-

gional scale. Particular emphasis should be given to studies of ground water movements at the regional scale.

2. Studies of local and regional hydrology, including both surface and subsurface flows, should be incorporated into the preliminary engineering studies that precede highway location and design decisions.

3. Research should be undertaken to increase understanding of the responses of various wetland ecosystems to given changes in the hydrologic regime associated with each wetland class.

Alteration of Water Quality

Changes in water quality can significantly influence the biotic composition and viability of a wetland. Road salts and herbicides can affect aquatic plants and other organisms far from the site of their application. Eroded soil can materially increase the turbidity of streams and ponds, diminishing photosynthetic activity, and, when deposited on the bottom, can destroy the organisms that dwell there. The response of various aquatic plants and animals to specific changes in water quality is reasonably well understood, as is the nature and amount of foreign material that a given highway activity is likely to introduce into the wetland environment. What is often lacking, however, is the effective application of this knowledge in the design, construction, and maintenance of highway facilities so that harmful impacts on wetlands from highway-induced changes in water quality may be avoided or kept to a minimum. Therefore, it is recommended that the following steps be taken:

1. The current efforts of highway agencies to reduce the amount of soil eroded from highway construction sites and transported beyond the highway right-of-way should be expanded, and new or improved methods to achieve these ends should be continually explored and developed.

2. The quantity and composition of suspended solids and sediments that the construction of a highway will introduce into a wetland system should be carefully estimated prior to a decision regarding the location, design, and construction of that highway; and such decisions should be made with due regard to keeping to a minimum the quantities of eroded materials that may be expected to be introduced.

3. Current efforts to minimize the quantities of road salt and herbicides that highway maintenance activities introduce into wetlands should be expanded, and research should be continued to develop more environmentally neutral alternatives to chemicals and practices in use.

Minimizing Impacts

The severity of the effects of highway fills and other structures in wetlands depends in large measure on the location of the facility and the details of its design and construction. By and large, engineering practice in this regard has focused on cost-effective ways to ensure the integrity of the highway structure in the presence of water and saturated subgrades. However, the knowledge and experience of the engineer, if applied in concert with that of ecologists and other environmental specialists, can result in the construction of highways that are not only structurally sound but also are environmentally benign. Indeed, it is likely that increased knowledge of wetland hydrology, soils, and other natural features that such collaboration can bring to the engineering profession will lead to the construction of highways that are better by any measure. Therefore, it is recommended that the following steps be taken:

1. Highway agencies should initiate, with the assistance of environmental specialists, a careful review of specifications and practices used in the placement of highways in wetlands. The objectives of such a review would be to identify ways in which the natural processes of wetlands could be accommodated more adequately in the location, design, and construction of highway facilities.

2. A continuing program of research should be undertaken by highway agencies dealing with design and construction of highway fills in wetlands. The focus of such research should be on procedures for accommodating the movement of ground water through highway fills and on ways of dealing with compressible subgrades that will avoid ecological degradation of the affected wetland.

Systematization of Mitigation Procedures

Regardless of the care with which highways are constructed in wetlands, some degree of environmental impact generally results. In recognition of this fact, federal and state laws require that every reasonable effort be made by highway agencies to mitigate those impacts that cannot be avoided. Fortunately, a considerable body of knowledge exists regarding steps that can be taken at each stage in the highway development process to minimize the ecological effects of those actions. This knowledge is not well organized, however, and fails to take into account the high degree of the interrelatedness that exists in both the highway development process and in the physical-chemical-biological system that governs the ecology of a wetland. Therefore, it is recommended that highway agencies develop a formal set of location, design, and construction specifications for the mitigation of impacts resulting from the placement of highway fills and other structures in wetlands. These specifications should be internally consistent—for example, design specifications intended to minimize ecological impacts should not lead to construction practices that would have the opposite effect—and should relate clearly to existing standards and practices governing the location, design, and construction of highways.

Wetland Classification

Wetland classification and associated definitions provide a basis for the delineation of wetlands in keeping with legislative requirements. Wetlands classification is also a basis of communication and common understanding among environmental specialists. National and state inventories of wetlands are to be organized in accordance with the classification scheme being developed under the auspices of the U.S. Fish and Wildlife Service. In order that the wealth of information contained in these inventories be available for use by highway agencies, it is recommended that the wetland classification system now under development by the

U.S. Fish and Wildlife Service be adopted by highway agencies as the basis for wetlands identification and analysis. Regional modifications should be incorporated as appropriate.

Monetary Valuation of Wetlands

The preservation or enhancement of wetlands by highway agencies often involves the expenditure of highway funds. Justification for such expenditures is based in part on the economic value to society that wetland functions provide. Unlike many of the other functions associated with highway investments, however, the preservation of wetlands lacks a firm economic base from which to derive monetary benefits against which cost may be set. What information is available is scattered and incomplete. It is, therefore, recommended that a program of research be initiated leading to a better understanding of the economic value of various wetland functions and a more widespread acceptance of the monetary worth of such functions.

Assessment of Highway Impacts

The major impacts of highway activities derive initially from alterations in water regime and water quality; biological changes follow, leading generally to the ecological degradation of the affected wetland. The assessment of the potential ecological effects of a proposed highway activity, therefore, requires a determination first of the physical changes in the water regime that may be induced by that activity and, second, the likely biological consequences of those changes. The skills of both engineers and biologists or other environmental specialists are needed if this linked set of events is to be assessed adequately. It is, therefore, recommended that the assessment of the potential ecological effects of highway activities in wetlands be conducted jointly by teams of engineers and environmental specialists, each contributing to the process those special skills that are the hallmark of their respective disciplines.

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APPENDIX A

CASE STUDIES

A summary of the case studies is included in Chapter Two of this report. The complete case studies are available for loan upon request to the NCHRP Program Director.

APPENDIX B

ANNOTATED BIBLIOGRAPHY

Appendix B is not published herewith but is available for loan upon request to the NCHRP Program Director.

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