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Ecological effects of highways on coastal wetlands, Atlantic coast region

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ECOLOGICAL EFFECTS OF HIGHWAYS
ON COASTAL WETLANDS
-ATLANTIC COAST REGION-

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Abstract:

A literature reviews past and on-going research and activities of the principal investigators is the basis for evaluating environmental effects of highways in wetlands. Values of wetlands are discussed briefly. Physical, biological and chemical impacts are associated with highway construction, operation and maintenance. Environmental impacts are scaled in terms of magnitude and duration and mitigating measures are identified. The foregoing are summarized in matrices. The report further identifies further research which is needed to design highway projects with environmental aspects in mind.

PREFACE

This report is based on a literature search and review, on previous and on-going research of the Virginia Institute of Marine Science, on the daily experience of the Institute's Section of Environmental Impact Assessment and on an on-going case study. The Section of Environmental Impact Assessment reacts daily to applications involving proposed works in navigable waters including the shoreline and wetlands thereof. In this regard, the Section evaluates approximately thirty applications per year from the Virginia Department of Highways and Transportation and from private developers that involve highways or roads crossing tidal rivers or streams in Virginia.

The experience gained in more than five years of evaluating projects prior to construction and informally evaluating post-construction results is now being amplified in a specific case study funded by the Federal Highway Administration. The full results of the case study are being documented in another report, however there is some transfer of information into this report.

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ABBREVIATIONS AND SYMBOLS

MHW - Mean High Water

MLW - Mean Low Water

MSL - Mean Sea Level

MTL - Mean Tide Level

ENVIRONMENTAL EFFECTS

OF HIGHWAYS ON WETLANDS

INTRODUCTION

The coastal wetlands of the Atlantic Coast Region differ vastly in eir physical, biological and chemical properties as one moves from Maine Florida. There are rocky tide pools, sandy beaches, mud flats and getated areas which extend in elevation from just below mean tide level TL) to heights of a foot or more above mean high water (Marcellus, 72; Boon, et al., 1976). The latter areas vary in vegetation and include ch species as saltmarsh cordgrass (<u>Spartina</u> <u>alterniflora</u>) in the more line areas and at lower elevations, mangroves (<u>Rhizophera</u> <u>mangle</u>, icennia <u>nitida</u>) also at low elevations, saltmeadows (<u>Spartina</u> <u>patens</u> d <u>Distichlis</u> <u>spicata</u>) in salt and brackish areas at higher elevations, row arum (<u>Peltandra</u> <u>virginica</u>) and pickerel weed (<u>Pontederia</u> <u>cordata</u>) und in the tidal freshwater regime, and many other species, sometimes many as fifty in one acre (Silberhorn, 1976). These areas are commonly own as coastal marshes.

Despite the wide variety in environmental characteristics, coastal etlands have many properties in common in that they are the ecotone etween the aquatic and the land environment. It is here that we find a gh order of biological productivity involving aquatic, terrestrial, and vian life (Shaw & Fredine, 1956). In the case of the coastal marshes in hesapeake Bay, for instance, it has been reported that 90% of the fish nded in Virginia are dependent, at one time or another in their lives, the vegetated wetlands (Wass and Wright, 1969). Silberhorn, et al., 1974, tribute five basic values to coastal marshes and have typed and classified irginia's marshes based on these values: 1) contribution to the aquatic od web, 2) value to wildfowl and fur bearing animals, 3) contribution to e maintenance of water quality, 4) a resistance to shoreline erosion, and) buffering of coastal flooding.

The ecotone containing coastal wetlands is dynamic. The shoreline rodes and accretes, marshes expand or regress as salinity, tidal immersion ates and other factors change. Astronomic or predicted tides are unctuated by storm tides far exceeding the normal tides. The creatures d plants living in this environment are hardy and are specially adapted the rigors of their environment. Despite this, coastal wetlands and its nhabitants are peculiarly fragile and, most particularly, susceptible to amage or destruction by man's activities. Yet it is the coastal area at attracts man and leads to pressures exemplified by the megalopolis extending from Massachusetts to Virginia and, further south, along the Florida coast.

It is debatable as to whether highways follow man or vice versa. In any event, a generalization can be made that any highway across a wetlands will have an environmental impact, most often adverse. Yet there will always be pressures of economics and transportation to utilize wetlands as sites for highways. It is the purpose of this investigation to summarize existing literature and experience relative to environmental impacts, favorable or adverse, of highway construction, operation and maintenance in wetlands of the Atlantic Coast Region. A further aim is to summarize means of avoiding or mitigating adverse impacts that can occur and to assess what further research may be necessary to accommodate the location of highways in coastal wetlands without also generating an unacceptable environmental loss.

II. Highway Construction Activities

Highway construction in coastal wetlands involves a number of activites which can be categorized as follows:(VIMS Permit Application Files)

A. Pile driving as permanent supports for a causeway or bridge, or supports for a temporary platform for construction equipment.

B. Dredging to obtain fill, to clean out poor soil for a better foundation, for tunneling under waterways, for construction equipment access, or for temporary cofferdams to allow construction of culverts or bridge and causeway supports.

C. Filling for a solid causeway, to replace poor soil, to dispose of dredged material, to obtain equipment access, or to refill temporary cofferdams.

D. Culvert construction and design, either pre-cast or in-place, in order to provide for tidal and drainage flow.

E. Channel realignment, either temporary or permanent, to permit construction "in-the dry" or to meet other engineering considerations such as highway alignment or better soil conditions for culverts.

F. Channel stabilization to prevent shoreline erosion which could endanger structures.

G. Land erosion control measures, both temporary during construction and permanent for the post-construction period.

H. Paving or other measures for the final highway surface.

I. Air pollution, while not considered as activites per se, air and noise pollution will also be discussed in this section.

A. PILE DRIVING

There is nothing in the literature that indicates any significant short or long term adverse impacts are associated with pile driving, or open-pile structures per se, though there may be other problems engendered by needs for equipment access.

VIMS scientists have observed both the construction and post-construction effects of open-pile structures over streams, rivers and wetlands in Virginia. They have also noted apparent conditions in and around long established open-pile structures. In some cases, construction was accompanied by dredging or filling for equipment access, a topic to be addressed subsequently. In those cases where construction progressed from one pile supported bent to another, with equipment operating from completed sections, there appeared to be no adverse impact either during construction or after construction. There was probably minor destruction of benthic life at the immediate point of contact of the piles and the bottom. In the case of brackish and saline waters, any such loss was probably more than offset by the attachment of barnacles and other molluscs, oysters in some cases, to the pilings. Except in very silty soil, turbidity was imperceptible to the eye. Even when turbidity did result, it was minor and quickly dispersed. There has been no discernable change in the hydraulic regime in any of the open-pile systems observed thus far.

While not a highway there is one instance in which a low plank road on pilings has been in existence for several years over a brackish water marsh. There have been no adverse effects observed even upon the marsh plants directly under the road. Because marsh plants are a product, in part, of photosynthesis it is probable that the impact of a low, open pile crossing of a marsh may be primarily a function of the height of the road over the marsh as compared to the width of a road. As long as sufficient sunlight can penetrate under the structure, there should be no significant adverse impact. We have found no literature to support this hypothesis, however, nor anything that would indicate highway heights vs. widths that would be appropriate.

It is concluded that open pile structures and pile driving activities cause little of any environmental impact. Indeed, the Commonwealth of Virginia encourages such structures for crossing of rivers, streams and wetlands (Virginia Marine Resources Commission).

B. DREDGING[1]

There is considerable literature on various facets of dredging and more research is ongoing. Unless one is dredging for the express purpose of obtaining suitable soil, sand or gravel, the major problem is disposal of spoil, although massive dredging may significantly alter a hydraulic regime. For purposes of this paper, spoil disposal will be discussed under the heading of "filling". Other problems associated with dredging include:

Disturbance of Benthic Fauna. Except in sandy areas or areas where there is very dynamic erosion and/or accretion, coastal wetlands usually contain many organisms living in or on the bottom. These organisms serve many environmental functions such as being a basic element in the aquatic food web, providing food for humans in the form of clams and oysters, enhancing water quality through reduction of nutrients in the water column and bottom sediments and the aeration of bottom soils. The nature, quantity and diversity of benthic animals depends on several variables such as nutrient availability, salinity, turbidity, type of bottom and depth of water. A dredging operation usually destroys benthic organisms in the direct path of the dredging apparatus, but also suspends sediment which

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1 As used herein, dredging means any excavating in coastal wetlands by hydraulic means, dragline, bucket or other similar techniques.

may settle as overburden smothering nearby benthos and, most importantly, changes the depth of water and sometimes the soil and water chemical properties (Darnell 1967).

There is also sometimes a temporary lowering of dissolved oxygen levels (Brown & Clark, 1968). It is known that benthos will recolonize an area after it has been dredged (Boesch, 1974). It is not known how soon an area can be expected to respond after a dredging. Varying estimates range from several months to two or more years. There is also an apparent lack of predictive capability concerning the types and diversity of species which will take part in recolonization. Because more is known about commercially valuable species than others - and perhaps because commercial species supply a direct human use - more attention has been given to effects on clams and oysters than on other animals, the effect on other animals being termed "temporary" (Virginia Marine Resources Commission). Nevertheless, many of these noncommercial species are useful as indicators of the level of stress being placed on the entire benthic community at any given time. We therefore favor further research which examines the total response of the benthic community to dredging activity.

Submerged Aquatic Plants and Coral. Submerged aquatic plants include such plants as eel grass (*Zostera marina*), widgeon grass (*Ruppia maritima*) and others. In Florida, there is found coral (*Corallium* spp.). Though of differing nature coral and submerged aquatic plants serve the same purpose of providing habitat and shelter for numerous forms of aquatic life. A recent decline in the Chesapeake Bay crab fisheries has been attributed in part to a dramatic loss of eel grass due to storms and other natural processes in the bay (Van Engle, personal communication).

Coral and submerged plants in the path of the dredging apparatus will be destroyed. Because submerged plants are dependent upon photosynthesis their recolonization will be dependent upon residual water depths and turbidity levels. Eel grass has been known to recolonize in two years in one area of Virginia where dredging to two feet below the ambient bottom was performed (Orth, personal communication). However, the entire area was shallow and the water was relatively clear. Coral, if it recolonizes at all, will take infinitely longer because of the nature of its growth, i.e., a build up of calcareous skeletons of marine coelenterate polyps.

Emergent Vegetation. Marsh vegetation grows in such a small range of elevation that dredging therein almost always results in an irretrievable loss of marsh wetlands. Aside from the direct destruction of marsh in the dredger's path, dredging may, depending upon the circumstances, either inhibit or increase the rate of flooding in the remaining marsh. The maximum effect usually occurs in higher elevation marshes, such as the saltmeadows, but other types may also show a response. If the effect is to drain the residual marsh, upland vegetation will eventually supplant marsh vegetation (Bourn & Cottam, 1950). If the effect is to enhance tidal flushing, more productive species such as saltmarsh cordgrass may supplant the saltmeadow.

Tidal Hydraulics. Even if significant benthos, submerged or emergent vegetation are not in the path of the dredge, a dredging operation can change hydraulics to the point where there can be impacts, positive or negative, on adjacent wetlands. If the result is an increase of tidal action, high marshes may be transformed into low marshes. Depending upon the nature of the area, this may in effect supplant a productive wildfowl area with an amenity more favorable to the aquatic environment. It may also drown a marsh or, on the other hand, create conditions for the establishment of marsh from uplands. An enhanced tidal action may also lead to shoreline erosion problems, a subsequent topic.

Sedimentation. Virtually all dredging leads to some sediment escaping to the water column, the amount of sedimentation depending upon the dredging method, the skill of the dredge operator, soil types, currents and tides. There are mitigative measures which can sometimes be implemented. If not and if heavy sedimentation occurs, there can be damage or destruction of benthos (Loosanoff, 1961; Davis and Hidv, 1969) and submerged and emergent plants considerably remote from the dredging area (Darnell, 1976). Physical problems may also occur in nearby navigational channels.

Pollutants. There are differences of opinion regarding effects of dredging polluted sediments (Wetzel *et al*. 1976). There appears to be a concensus that heavy metals in disturbed sediments will tend to remain attached to sediment particles rather than dissolve into solution. There also appears to be a concensus that bacterial pollutants (coliforms) will dissolve into solution and consequently be carried much further than heavy metals. The effect of dredging sediments containing toxic substances, such as kepone, is not well known. Further research is needed in this area, much of which is underway sponsored by the U. S. Army Corps of Engineers (Dredged Material Research Program, Vicksburg).

C. FILLING

Any filling in wetlands will inevitably constitute an irretrievable loss of wetlands value. This is not to say that filling cannot be done with an eye toward substituting amenities of various values. Nevertheless, the change is usually irreversible as in the case of filling a shallow water area to create a marsh - the loss of shallow water benthos is permanent. There are no known studies relating the biological productivity of shallow water areas to the productivity of marshes therefore generalizations cannot be made other than that a substitution of an amenity is better than nothing. Considering the great diversity of environmental factors found in wetlands, it is probable that site specific studies would be required to quantify exchanges of values in any particular project. Other than the foregoing, there are more specific concerns in the filling of wetlands. These are:

Tidal Wetlands Hydraulics. Any sizeable modification of the seaward entrance to wetlands can be expected to produce significant changes in the interior hydraulic regime as this disturbs the primary zone of control for the admittance of the tide wave (Keuliegan, G. H., 1967). Moreover, it is well known from studies of the hydraulic geometry of natural streams that an equilibrium relationship exists between the volume discharge conveyed by a channel and the width, depth, and flow velocity that will be found in that channel (Myrick and Leopold, 1967). Hence we may be certain that adjustments in response to the new equilibrium conditions will be forthcoming, including a change in the tidal prism accompanied by erosional or depositional change, unless the modifications have been carefully planned.

Modification of the hydraulic regime can have at least three types of impact on the wetlands through:

1.) changes in the elevation of the tidal datum planes (mean high water, mean low water),

2.) change in channel stability,

3.) change in the tidal prism or volume of water entering and leaving the marsh during a tidal cycle.

In the first case, the response of a marsh could be either a minor change in species distribution or possibly a complete transition in marsh community type and/or a dislocation of the marsh-uplands boundary. This change would reflect the dependence of floral community distributions upon prevailing immersion frequency levels, a relationship which has been generally established but requires further refinements through field research (Boon, et al., 1976). In the second case, channel instability would be destructive of the marsh and could impact on highway structures such as culverts and pilings. In the third case, a change in the tidal prism means a change will occur in the flushing characteristics of the marsh and the transport of nutrients and particulate matter in suspension (Axel[illegible]l, 1974).

Impoundments. In some instances, fills for causeways have been deliberately designed to impound upstream waters in order to form non-tidal lakes. Again, this is an irretrievable loss of coastal wetlands in exchange for a different environmental amenity. It would be difficult to quantify values in such an exchange, but considering the limited amount of wetlands, their overall value, and a reported loss of more than a third of the nation's wetlands (Darnell, 1967), the practice is dubious.

In addition to the outright destruction of wetlands, there is some undocumented evidence that impoundments can affect downstream marshes that are otherwise unaffected by the initial construction project. The impoundment acts as a sediment trap thus altering the sediment budget. It is suspected by the authors in one instance that the diminution of sediment supply combined with a rise in sea level has resulted in a big cordgrass marsh (*Spartina cynosuroides*) being gradually converted to an arrow arum marsh (*Peltandra virginica*) over the years. In this particular instance, the owner of the marsh is discomfited by the loss of muskrat habitat and consequent loss of his commercial trapping enterprise.

Marsh Alteration. A fill on a marsh can range from complete obliteration to changes in vegetative species. According to the techniques utilized, damage to residual wetlands can occur through the severance of tidal waters. In other instances, a more varied habitat can result. Studies in Louisiana have shown that some dredge spoil sites become attractive to various species of wildfowl.

Mud Waves. In silty and silty-clay soils, a fill in coastal wetlands more often than not results in a mud wave. The authors have recorded one mud wave that extended 300 feet from the base of fill for a causeway - impoundment. What was formerly a viable big cordgrass (*Spartina cynosuroides*) marsh had been elevated and rifts in peat one metre deep were measured. A second causeway project, through shallow water and an arrow arum (*Peltandra virginica*) marsh, is currently being observed. Engineers had calculated a mud wave extending to 45 feet from the fill. In four months the wave had extended to an average distance of 62 feet and was still growing.

Erosion Control. A fill operation inherently generates sedimentation which, as previously discussed, is a potential source of damage or destruction to both benthic fauna and to plant life. The primary problem time is obviously during the construction phase when loose soil is dumped into the aquatic environment. Construction plans usually provide for ultimate stabilization for engineering if for no other purposes. However field observations indicate that heaviest sedimentation occurs during construction and that sediment control during construction is important.

D. CULVERT CONSTRUCTION AND DESIGN

Culvert construction involves the three items previously discussed - dredging, filling, and tidal hydraulics. Dredging and filling at the culvert site itself usually has a minor influence on wetlands whether or not the culverts are pre-cast or built in place. The third item, tidal hydraulics, can be quite significant in terms of the dynamic behavior of the wetlands drainage system and may be considerably affected by the design characteristics of the culvert.

Traditionally, dimensional criteria for culverts have been established that provide adequate conveyance for upstream runoff resulting from a specific storm event such as a fifty-year flood. However, the reversing flows of a tidal stream attain maximum velocities which recur much more frequently and may be critical in terms of stream bank erosion depending upon flow routing and the degree of local constriction of flow near the culvert.

In particular, studies are needed that will determine the flow impedance of various types of culverts which in turn determines what fraction of the potential tidal prism they will admit to the upstream wetlands drainage network. These aspects have been addressed on a larger scale in coastal inlet systems by Keulegan (1967), and others. In addition, the work of Myrick and Leopold (1963) and Boon (1973) on the hydraulic geometry of small tidal estuaries should be considered for improved design criteria in wetlands projects. The latter work relates tidal discharge to stream velocity, width, and depth values in open - channel systems under equilibrium conditions.

E. CHANNEL REALIGNMENT

Channel realignment may be temporary for construction purposes. If so, it can be likened to dredging and filling operations. In other cases, the realignment is permanent. The key problem here is again one involving tidal hydraulics and equilibrium flow conditions.

Natural stream channels in coastal wetlands, particularly marshes, tend to migrate slowly and shift their location with time. This is done gradually therefore fauna and flora can adapt to the changing conditions. An artificial realignment is an abrupt change and it can be expected that the new channel will lack the normal distribution of colonizing vegetation and bottom-dwelling organisms until it has stabilized. There is no literature that indicated how long this may take.

F. CHANNEL STABILIZATION METHODS

It has been indicated that certain construction activities may lead to erosion requiring some purposely designed form of channel stabilization. There may be also be natural erosion which threatens highway structures and is generally undesirable. There are many methods of stabilization ranging from armored banks to the use of vegetation. Some mechanical methods are bulkheading the banks with vertical bulkheads, stepped gabions or rock riprap. The decision on which method to employ is usually based on physical requirements, probably laced with cost considerations. Whatever method is adopted, it must be compatible with the projected energy which will cause either shoreline erosion or an undesirable shifting of the channel. If one takes a biological approach to stabilization, the further removed from a natural channel the more undesirable the solution.

There is some literature to support the use of tidal marsh vegetation, for stabilization, particularly in the salt and brackish water areas (Silberhorn, *et al*., 1974). One of the authors has participated in several successful efforts to stabilize shorelines with saltmarsh cordgrass (*Spartina alterniflora*). If the energy to be countered is projected to be more than vegetation can withstand, rock riprap is an acceptable biological alternate as it will also provide habitat of some value. Rough faced gabion structures follow in order of desirability for the same reason - provision of some habitat. Vertical structures, hardening banks with concrete or, indeed, an entire section of channel pretty much prevents the establishment of a productive biological system.

G. LAND EROSION CONTROL

Fastlands erosion leads to sedimentation with the accompanying detrimental effects discussed previously in regard to dredging and filling. The highway approaches to wetlands are typically located in the watershed of the wetlands concerned. Any erosion engendered in the watershed by highway cutting, filling and grading will tend to contribute sediment to the wetlands system. Since the effects of sediment have been previously discussed, they will not be reiterated at this point, except to emphasize the need for erosion control during construction as well as post-construction more permanent controls.

H. PAVING

Thus far we have no information in the literature relative to impacts of paving. On the presumption that paving will be placed over otherwise compacted and stabilized areas, there would appear to be little impact on the marine environment from the paving operation itself. There are some documented long-term effects, such as run-off from asphalt roads carrying hydrocarbons, but there appears to be documentation of the immediate impacts during contruction.

I. AIR POLLUTION

There are a number of titles pertaining to the effects of lead from automobile exhausts upon roadside vegetation and small animals. These effects are a result of long-term operational factors, however, rather than effects of construction.

In the investigators' experience, the primary air pollutant from highway construction is fugitive dust. Ill effects of fugitive dust on wetlands animals and plants, if any at all, are probably very short term. It is improbable that there would be any effect on aquatic life.

J. NOISE POLLUTION

There has been nothing found concerning the impact of noise pollution on coastal wetlands. The impact of noise during the construction phase is probably of a very local and temporary nature if, indeed, there is any impact at all.

III. Highway Operations

A. General

For purposes of this paper, highway operations is defined as the regular use of highways by motorists and truckers and de-icing operations in areas of ice and snow. The maintenance of highways will be discussed in the succeeding section.

B. Effects on Biota

There is considerable literature on the effects of automotive emissions on roadside vegetation and animals. Brooks and Reeves (1974) and Word and Reeves (1975) have discussed the effects of lead from motor-vehicle exhausts on roadside vegetation in New Zealand. Darnell (1976) reports that the California Department of Highways has been having difficulty in maintaining vegetation in highway median strips. Evans (1972) and Mieran (1975) have discussed lead levels in small mammals residing or captured adjacent to highways. None of these reports refer specifically to tidal wetlands or wetlands biota.

It must be assumed that if there is an impact on biota in non-wetlands areas from automobile exhaust emissions, there must be some impact on biota in wetlands areas. However, the referenced reports concern fairly site-specific research. In their own experience, the investigators find viable marsh, nesting wildfowl, muskrat dens, marine snails and crabs immediately adjacent to the shoulders of busy highways. Deer have been seen browsing in marsh meadows and in some instances constitute a hazard to motorists as they cross highways in search of food. The most discernable impact is the killing of animals by vehicles as animals cross the road. This effect has not been quantified but otherwise the din and emissions of passing traffic appears to be of little concern to wetlands wildlife. –

C. Chemical Pollution

Drippings of oil, greases and gasoline from motor vehicles will find their way, in part, to adjacent wetlands. There may be hydrocarbons in runoff from asphalt roads. What proportion might reach the wetlands or the scale of dosage is not known. It is probable that weathering reduces the toxicity of these pollutants as they are normally transmitted during rains. Traces of oil have been observed in marshes and streams adjacent to highways but there could have been sources other than the highway. In any event, there were no apparent lethal effects. The effects of chronic sub-lethal dosages of oil is now under investigation (Hersher, 1977), and may lead to a refinement in assessing vehicle droppings, through the basic research involved chronic dosages probable in excess of what occurs from road runoff.

Massive spills, such as would occur in an accident involving a tank truck, can have varying degrees of lethality depending upon the product carried and other considerations. Actions to be taken in such circumstances are probably site specific due to the multitude of chemicals transported and the varieties of wetlands. One specific action should be taken - notify the U. S. Coast Guard.

E. De-Icing Operations

There is literature on the effects of de-icing using compounds or salt. None has been found regarding possible impacts of clean sand. All reports pertaining to salts involved non-tidal areas where salts had an opportunity to accumulate in an environmental area.

Salt from highways probably has little impact in salt and brackish water areas where the biota is salt-tolerant and where there is constant flushing of waters and consequent dilution of high concentrations. One would expect only local and temporary increases in salinity. There is a greater possibility of damage in tidal freshwater wetlands. But bearing in mind winter conditions when salt is used, the possibility of major or lasting damage is small. Freshwater marsh vegetation is not emergent at this time of the year and tidal action should quickly dilute the salt as it enters the system.

The amount of sedimentation resulting from the use of sand is not known. As a matter of opinion, it is probable that it is a small proportion of total sedimentation in any given wetlands. It might be well, however, to investigate in those areas where sand is heavily utilized.

F. Roadside Litter

Roadside litter is an aesthetic insult. It also provides breeding areas for noisome insects such as flies and mosquitos. Impact on wetlands biota appears to be negligible.

IV. Highway Maintenance

A. General

Highway maintenance activities extend from patching the surface to resurfacing to rebuilding segments of the highway. The investigators can see little differences between construction and maintenance activities. A resurfacing, for example, should be little different in environmental impacts than the original paving process. If maintenance is major in scope, then subjects previously addressed (dredging, filling, erosion control) should be considered.

B. Cost Effectiveness

The purpose of this report is to discuss environmental aspects of highways in wetlands. When considering highway maintenance, however, we would be remiss in not discussing at least one situation resulting from constructing a solid fill causeway through a big cordgrass (*Spartina cynosuroides*) marsh. This particular causeway has been traversed often over a period of 30 years by one author. It is a rarity when the causeway is not being resurfaced, has just been resurfaced or needs resurfacing. The section is permanently marked as a bumpy road. The cause may have been initially poor construction. Nevertheless it points up a basic problem in building highways over soft surfaces. It also suggests the possibility of investigating initial and long term costs of alternate structures such as open-pile causeways. Darnell (1976) states that open-pile structures are less expensive but does not elaborate therefore the basis for this judgement is not known. The Virginia Department of Highways and Transportation (Thomas, 1974) stated in two instances that initial construction costs for open-pile structures were higher than costs of filled causeways, however no data was not available on comparative long-range maintenance costs. Colley (1950) and Dryburg and McKillop(1954) discuss construction and maintenance techniques in peat and muck areas but, again, relative construction/maintenance cost figures are not highlighted.

V. Mitigating Techniques

A. General

As can be seen by the foregoing, the most damaging and long lasting effects of highway construction in coastal wetlands are those physical operations that result in permanent loss of wetlands or in changes in the hydraulic routine which, over a period of time, can cause considerable change in the nature of wetlands. In essence, this is a loss of habitat which Darnell (1976) cites as being the most important impact of construction activity. Sometimes these long term changes can result in the creation of environmental assets but we lack a predictive capability at this time, a particularly vexing problem.

Sedimentation, either as a result of fills in the aquatic environment or lack of erosion control in the fastlands, is in the next lower order of damaging effects. There are techniques which can somewhat control sedimentation and these are referred to in this chapter in generalized terms on the premise that highway engineers are well experienced in specific techniques.

B. Choice of Structures

From purely the environmental viewpoint, it is obvious that the open pile causeway or bridge is far preferable to the solid-fill causeway. In the case of the open-pile structure, there are minimal and practically undetectable impacts. The solid fill causeway causes irretrievable environmental losses and, depending on specific cases, may extend irretrievable losses far beyond the bounds of the actual construction site.

Cost of construction of the two alternatives will have a considerable effect in the decision process. It is hoped that those charged with the decision process will consider costs of long term maintenance as well as initial construction costs. However, if solid fill is selected, one should consult Bergstrom (1971) and Bergstrom et al.,(1971) relative to wetlands enhancement opportunities.

C. Tidal Hydraulics

The foregoing references pertain primarily to non-tidal wetlands and to enhancement for wildlife purposes, not aquatic resources. The role of tidal hydraulics in coastal wetlands must receive a major share of attention in the decision process and, once a solid-fill causeway has been decided upon, in the design process. A design based simply on accommodating fastland drainage during certain storm conditions is not adequate. As pointed out previously, constrictions of tidal creeks can have impacts upon tidal amplitudes, stream courses, erosion and other physical factors which in turn will affect biological properties of wetlands. If there were a predictive model in existence, such changes might be used to advantage, i.e., to develop vegetated wetlands in lieu of a shallow water environment. An easily used predictive model does not now exist and further research is necessary to build upon prior research (Boon, Keulegan, Leopold, Myrick) to develop such a model. In the meantime, culverts or other openings in solid fill causeways should be designed with a specific objective of not inhibiting normal tidal flows. In a current study Dawes (1977), it was found that a doubling of capacity of a culvert, over that required to handle fastland drainage from a 50 year storm, resulted in a decrease of tidal amplitude of approximately a tenth of a foot. Had the orginially designed culvert benn installed, the decrease in tidal amplitude would have been greater with accompanying greater possibilities of environmental changes upstream.

C. Substitution of Environmental Amenities.

Careful, specific site studies may indicate opportunities for substituting one environmental amenity for another. Marshes can be created in a shallow water environment, for example (Johnson and McGunnies, 1975). However it should be borne in mind in this example that shallow water environemnts are highly valuable and that there is no present method of measuring trade-off values without intensive site study. The historical loss of wetlands, tends to argue against the substitution of coastal wetlands with fastland or non-tidal amenities such as lakes.

D. Dredging.

In addition to possible problems, with tidal hydraulics, a major impact of dredging is the dispersal of sediments in the water column where they can affect marine organisms in areas remote from the actual dredging operation. While there are techniques for limiting sedimentation, subsequently discussed, the impact upon biota can be further reduced by selecting times of dredging. In saline and brackish waters where shellfish are a consideration, dredging should be timed to avoid spawning, spat and setting times as well as the coldest months of the year when shellfish cannot free themselves from any sediment over-burden due to lowered metabolism. In tidal freshwaters, timing should be designed to avoid spawning and nursery activities of finfish.

The amount of sediment introduced into the water column by dredging is the result of a number of factors such as sediment type, depth of water, type of equipment utilized, condition of the equipment, and training and supervision of equipment operators. The latter two factors are most important when dredging hydraulically. One leaking joint in a hydraulic dredge pipeline was observed by one of the authors to have covered about a half acre of marsh up to 18 inches deep. Hydraulic pipelines should be scrupulously monitored and the dredge shut down when leaks appear.

Most hydraulic dredging uses a rotating cutter head to stir up sediment and a section pipe to draw the sediment into pipelines. If the operator rotates the cutter head too slowly, he is inefficient as he is pumping too much water in relationship to sediment. He is much more efficient if he operates the cutter head at a fast rate; but, if it is too fast he reaches the point where the suction pipe can no longer accommodate all of the sediment. The result is the release of sediment into the water column, an event that is usually detectable visually. Supervision is again the key to this problem.

Bucket or dragline dredging is a more simple operation. Yet this type of dredging inherently causes some sedimentation as sediment is picked up off the bottom and lifted through the water column to be deposited in a spoil area. If oversize "bites" are taken into the bottom, chunks of spoil will fall out of the bucket or dragline as the spoil is lifted out. Another supervisory function appears.

Silty and silty-clay soils constitute a greater problem than sand or more granular soils which tend to settle out quickly in a local area. There is evidence, moreover, that silty soils will retain more pollutants than sandy soils (Wetzel et al., 1976) hence the dredging of silty soils in polluted areas requires stringent sediment controls.

Distance of the spoil area from the dredging area is an important factor in selecting dredging equipment. A hydraulic dredge can more remotely dispose of spoil than can a bucket or dragline unless trucking of spoil is utilized. Equipment access is another consideration. If the dredging site is deep within a marsh, utilization of existing waterways by a hydraulic dredge or barge mounted crane equipment should be considered even if minor dredging is necessary to accommodate the vessels. Tractor-crawler type crane equipment can be operated in many marshes, with only temporary effect, if pads are utilized. If deep within a marsh, and trucking of spoil is required in order to prevent spoiling on the marsh, a temporary road may be constructed and subsequently removed provided the marsh is a high marsh.

In view of the fact that crane equipment must lift spoil through the water column, the deeper the water the more desirable it is to use the hydraulic method. The investigators have not ascertained a "break even" point but suggest that in silty areas that dredging deeper than six-eight feet of water would better be done hydraulically if possible.

The use of silt curtains or screens has been investigated in an open water environment (Boon and Byrne, 1975). They were found to be largely ineffective under these circumstances even though the sediments were mostly sand. The depth of water, about 20 feet, as well as wind and tide may have contributed to the curtains' inefficiency. Silt curtains have had some success in quieter, shallower waters and their use should be considered.

F. Filling

Filling can be divided into two basic categories; filling to dispose of unwanted spoil, and filling for a causeway. One may be for convenience and the other a judged necessity. In either case there is an irretrievable loss of wetlands. If one has accepted the necessity of filling in wetlands, the major mitigating effort must be directed at preventing the spread of damage by sedimentation, mud waves and interruption of tidal flow to the residual marsh.

There are no structural engineering considerations in simply disposing of spoil. There are, however, at least four methods of doing so which have differing biolgoical values. A fifth value, a physical value, would be to utilize good sandy soil as beach replenishment material.

In recent years, marshes have been created in tidal waters, utilizing dredge spoil, in all three broad salinity regimes, (Dredged Material Research Program; personal experience). Such marsh creation projects are trade-offs that have not been measured, i.e., the value of a shallow water bottom versus the value of a marsh. Another factor to consider would be the effect on tidal hydraulics, particularly in sub-estuarines where a marsh creation may significantly alter the land - water volume relationship. Nevertheless, the creation of marsh from spoil has positive aspects as compared to filling on marshes and should be a definite consideration.

In some instances spoil may be thinly scattered over the surface of a marsh with relatively minor impact. Considering that inches in elevation can change the characteristics of a marsh, care should be taken not to change the value of the marsh. Too much change in elevation could change a saltmarsh cordgrass (Spartina alterniflora) marsh into a somewhat lower value meadow marsh. A high meadow marsh could be inadvertantly converted to fastlands.

A third method is to dispose of spoil in selective piles using lower value portions of the marsh and avoiding interference with tidal flushing of the remainder of the marsh. While generally undesirable, this method will create a more varied habitat that will attract wildfowl and animals.

Both of the previously mentioned methods - scattering soil or selectively piling it - will lead to some sedimentation. The method normally used to prevent sedimentation is to retain spoil within an area by dikes or bulkheads. Dikes can be earthen, in which case they should be constructed of fastland material and the outer face sloped and vegetated. Riprap or vertical bulkheads can be used, the latter being considerably less desirable than riprap or earthen berms. A bermed containment area should be located and shaped with care. If possible, lower value marsh areas should be used. Every effort should be made to avoid severing remaining marsh from tidal action. Though this method is considered less desirable, research performed for the U. S. Army Corps of Engineers indicates that these spoil areas often provide habitat for various wildfowl.

Selection of the method of disposal also involves consideration of dredging equipment to be used. A thin scattering of soil generally is applicable to only small projects using draglines or buckets, and some manual labor will be necessary. It is best to selectively pile spoil by using buckets in that attempts to pile hydraulically would be largely uncontrolled. Any kind of equipment can be used to fill a contained disposal area. In any event, a contained disposal area should be treated and vegetated as soon as possible. In the case of hydraulically filled contained areas, it is necessary to plan an effective means of conveying runoff, to a safe receiving area.

Should it be unavoidable to sever residual marsh from tidal action, consideration should be given to creating new channels to the affected area using special marsh ditchers similar to those used in mosquito control operations in New Jersey.

G. Stabilization Techniques

Banks of newly constructed channels, abutments and causeways must be stabilized as soon as possible. In the wetlands zone the stabilization can be artificial - physical means - or more naturally by seeding or transplanting marsh vegetation. The basic choice will depend upon projected forces or energy which will work upon the bank. Unless considerable energy is predicted, environmental considerations dictate considering marsh vegetation as a stabilizing device. If marsh vegetation is to be used, it is best to carefully grade the toe of the banks so as to get a progression from lower elevation plants through higher elevation plants to upland species. An example in salt or brackish waters would be a succession of saltmarsh cordgrass, saltmeadow, saltbush to upland vegetation. Such a progression not only mimics nature but provides a defense in depth against shoreline erosion. If there is other marsh in the near vicinity, nature will probably help in this process and it may be found to be quite cost effective.

If artificial techniques are employed, consideration should first be given to the use of riprap. Riprap avoids some physical problems associated with vertical structures in that it tends to absorb energy rather than transfer it (Silberhorn, et al., 1974). It also provides nooks and crannies suitable as habitat for various aquatic species. In some cases, riprap traps sediment which is subsequently colonized by marsh vegetation.

Rock filled gabions are an environmentally intermediate structure between riprap and vertical bulkheads. Oftentimes, however, gabions are filled with a relatively smooth face for aesthetic reason. It would be environmentally preferable to fill them haphazardly in order to maintain the nook and cranny aspect of riprap.

If vertical structures are used, or if slopes are hardened with concrete, designers should consider the possibility of scour which could endanger the toe of the structure. If a threat of scour is present, utilization of riprap along the toe of the structure may be pertinent.

H. Mud Waves

There may be instances where a calculated mud wave can be useful in developing the toe of a causeway and subsequently planting it with marsh vegetation. As a generality, however, mud waves should be avoided or minimized. To do so may require the dredging out of soft mud until a firm substrate is encountered. There should be a site specific analysis which should weigh the advantages and disadvantages of dredging against the predicted effects of a mud wave.

I. Fastland Erosion Control.

A case study documenting effects of a file causeway across wetlands (Dawes, 1977) indicates that aside from the fill itself and a resulting mudwave, the major impact may have been erosion from construction in the fastlands leading down to a creek. At an extremely low tide following a rain, all uncovered creek bottom was covered with a red silty-clay instead of displaying its normal black mud color. Fastland erosion control techniques are well known and will not be documented in this paper. Nevertheless, it is an important subject as effective erosion control in abutting fastlands is a major factor in mitigating construction impacts in the aquatic environment.

VI. RESEARCH NEEDS

A. General

The previous sections have indicated from time to time the need for additional research in order to avoid or reduce environmental losses when highways are constructed in wetlands. This section, therefore, is a summarization of needs with some amplification of the direction the research should take.

There appears to be adequate research already conducted or being conducted on the impacts of dredging and filling in wetlands. A substantial and on-going program has been underway for three years which is sponsored by the U. S. Army Corps of Engineers (Dredged Material Research Program). An additional report has been prepared for the U. S. Environmental Protection Agency, (Wetzel et al., 1976). There is current research pertaining to nutrient flux in a marsh with a constricted entrance caused by a highway culvert (Wetzel, in process).

While the above research is not directed specifically at highways in wetlands, the results are directly transferable insofar as dredging and filling is concerned. The Corps of Engineers publishes periodic reports pertaining to research results, progress and future projects. (Dredged Material Research, U. S. Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, Mississippi 39180). It is strongly recommended that federal and state highway researchers and designers subscribe to this free report.

B. Tidal Hydraulics

Additional research is needed which will establish a measure of predictive capability of marsh hydraulic behavior. This capability is especially needed in the case of re-entrant marsh systems whose drainage basins typically connect to larger tidal waterways through a trunk channel of fourth of fifth stream order at their mouths. The high order channels are often chosen as crossing points for highway access routes in coastal regions, resulting in the construction of bridge piling or roadfill and culvert structures within the tidal system. The latter features are often designed so that they adequately convey surface runoff during unusual storms (criteria directed toward protection of roads and structures) but not necessarily so as to minimize change in the tidal flow regime (criteria directed toward protection of the marsh).

A keulegan-type model incoporating both inertial effects and changing area effects should be investigated for possible application in marsh drainage basins. Such a model would require careful verification using field data collected in typical systems, including those with and those without culverts. Objectives of the modeling effort should include prediction of the following tidal response characteristics after culvert construction:

1. Change in the interior relevation of tidal datums including mean high water, mean low water and mean tide level within the marsh basin.

2. Change in the tidal prism or volume of water entering and leaving the marsh during a given tidal cycle.

3. Change in the mean arrival times of high and low water in the basin.

4. Change in the time-varying tidal dishcarge resulting in the trunk channel.

5. Change in peak discharge and peak current velocities for flood and ebb in the trunk channel.

Items 1. and 2. are important in terms of possible effects on the distribution of marsh vegetative zones which are closely attuned to frequency fo tidal inundation (Johnson and York, 1915; Hinde, 1954; Adams, 1963; Marcellus, 1972; Boon, Boule, and Silberhorn, 1976). Item 2. is also related to the natural flushing ability of the marsh basin as is itme 3. Items 4. and 5. are important to channel stability and erosional-depositional patterns.

Finally, it should be noted that tidal characteristics, particularly the tidal datums, require a thorough understanding of definitions and procedures to avoid inconsistencies in obtaining field results. For example, it should be recognized that a primary determination of mean high water requires averaging all of the high water elevations in a specific 19-year tidal epoch (Marmer, 1951; NOS, 1975). Tidal datums of lesser precision but fully equivalent to the 19-year definition may be determined over shorter periods using the method of simultaneous comparisons (Swanson, 1974). Special techniques have also been utilized for the extrapolation of tidal datums or for obtaining equivalent datums in shallow creeks that are fully exposed during low water stages (Guth, 1974; 1975). Tidal measurements, however, are few in number for small tidal waterways entering marshes, pointing to the need for more systematic study in this area.

C. Marsh-Shallow Water Values

Methods of quantifying the values of marshes have not been developed for all of the values attributable to marshes. Some work is on-going. In the meantime, however, vegetative productivity can be measured and there is sufficient data available to place at least subjective values on marshes. This has been done in one state (Silberhorn, et al., 1974). In order to make value judgements when considering filling in shallow waters, it would be desirable to be able to place similar type values on submerged aquatic vegetation and on benthic fauna. It is possible that a research program could be centered around different types of bottom ion, water depths, salinity regimes, and most important, on the ationship of marshes with adjacent shallow water bottoms.

Recolonization of Bottoms

re is insufficient data available to determine the rate of re- tion of submerged aquatics and benthos when disturbed by a operation. Data is also lacking concerning the types of on and fauna which will recolonize in the new depths and, perhaps, sulting from a dredging operation. A research program could be monitoring of dredging projects in various portions of the Coastal Region.

APPENDIX A

MATRIX

The following attempts to summarize the information previously explored. In employing the matrix, the following symbols and definitions are employed:

S = Severe impact. An irretrievable loss or a continuing degradation of an environmental asset to the ultimate point where it has little or no wetlands value.

M = Moderate Impact. A temporary loss, but one of long duration; or a degradation of an asset but not to a scale which completely negates its value.

I = Insignificant impact. A short term loss or degradation after which the asset can be expected to fully or nearly completely recover.

ACTIVITIES	DISTURBANCES			CORRECTIVE OR MITIGATING MEASURES	RESEARCH NEEDS
	Physical	Biological	Chemical		
1. <u>Construction</u>					
a. open-pile structure	I	I	I	None necessary	None (1)
b. dredging	M-S	M-S	I-M	Sediment control, time of year tidal hydraulics compatability	Tidal hydraulics, bottom recolonizati
c. filling	S	S	I	Sediment control, marsh creation, selective piling, thin scattering assure tidal flooding of remaining marsh, tidal hydraulics compatability	Tidal hydraulics, m shallow water botto values
d. culverts	M-S	I-S	I	Size compatible with tidal hydraulics, avoid discharging on marsh, bank stabilization	Tidal hydraulics
e. channel realignment	I-S	I-S	I	Size and direction compatible with tidal hydraulics, channel stability	Tidal hydraulics
f. channel stabilization	I-M	I-S	I	Vegetate banks, riprap or rough face gabions	None
g. land erosion	I-S	I-S	I	Strict upland erosion control measures	None
h. paving	I	I	I	Debris and litter control	None
i. air pollution	I	I	I	Fugitive Dust control	None
j. noise pollution	I	I	I	None	None
2. <u>Operations</u>					
a. traffic	I	I	I	None	None
b. air pollution	I	I	I	None	Possible
c. chemical pollution	I	I	I	Assessment does not include single large spills resulting from tanker accidents	None
d. de-icing operations	I	I	I-M	Limit to minimum necessary	None
e. roadside litter	I	I	I	Enforce litter laws	None
3. <u>Maintenance</u>					
a. resurfacing	I	I	I		None
b. painting	I	I	I		None
c. spraying	I	I	I		None

(1) Based on observation of VIMS Environmental Assessment Section personnel in the field.
(2) Based on lack of information in the literature.
(3) Based on availability of literature and VIMS field observations.
(4) A more specific literature review may be useful.

APPENDIX B

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