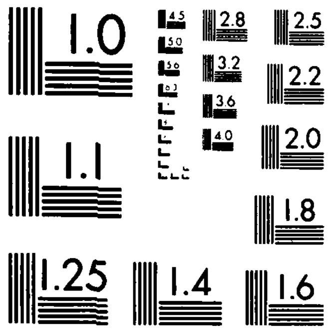
AD-A149 377 ANALYSIS OF SELECTED FUNCTIONAL CHARACTERISTICS OF WETLANDS(U) SCS ENGINEERS RESTON VA J ATCHESON ET AL. FEB 79 DACW72-78-R-0017 1/2

UNCLASSIFIED F/G 8/8 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A149 377

Ⓒ

FINAL REPORT

ANALYSIS OF SELECTED FUNCTIONAL CHARACTERISTICS OF WETLANDS

RFP NO. DACW 72-78-R-0017

PREPARED FOR
U.S. ARMY COASTAL ENGINEERING RESEARCH CENTER
KINGMAN BUILDING
TELEGRAPH AND LEAF ROADS
FORT BELVOIR, VIRGINIA 22060

PREPARED BY

JOHN ATCHESON
E. T. CONRAD
STEPHEN FOURNIER
WILLIAM BAILEY
MARK HUGHES, JR.

SCS ENGINEERS
11800 SUNRISE VALLEY DRIVE
RESTON, VIRGINIA 22091
(703) ~~620-3077~~ 471-6150

FEBRUARY 1979

CONTENTS

TABLES

FIGURES

INTRODUCTION

BACKGROUND

The U.S. Army Corps of Engineers has been given regulatory authority over construction activities in the wetlands of the United States. Enabling legislation is both longstanding and extensive.

Section 10 of the River and Harbor Act of 1899 requires the Corps to administer a permit program over a broad range of construction activities in or affecting navigable waters of the United States. More recently, Section 404 of the Clean Water Act of 1977 (formerly known as the Federal Water Pollution Control Act) gave the Corps the authority to regulate the disposal of dredge and fill activities within the navigable waters of the United States. With regard to wetlands, Corps regulations provide that: "Unless the public interest requires otherwise, no permit shall be granted for work in wetlands identified as important unless the District Engineer concludes that the benefits of the proposed alteration outweigh the damage to the wetlands resource and the proposed alteration is necessary to realize those benefits".

Executive Order 11990 also pertains to the protection of wetlands and provides the following brief definition of wetlands.

> The term "wetlands" means those areas that are inundated by surface or groundwater with a frequency sufficient to support and under normal circumstances does or would support a prevalence of vegetative or aquatic life that requires saturated or seasonally saturated soil conditions for growth and reproduction. Wetlands generally include swamps, marshes, bogs, and similar areas such as sloughs, potholes, wet meadows, river overflows, mud flats, and natural ponds.

As a result of these acts and mandates, Corps personnel in all Districts must review permit applications that are submitted by public and private entities, and then decide to grant or reject a permit for the alteration of wetlands. An important part of the decision process rests on the ecological and environmental impacts of construction to the wetland. Accordingly, it is necessary that wetland functions and the values of these functions be understood so that Corps personnel can intelligently assess the value of various wetlands in performing various functions.

The task is complicated by societal and scientific views concerning wetlands. Initially, wetlands were considered useless areas whose natural fate was reclamation. Subsequently, ecologists and scientists identified a number of important functions that wetlands perform in our ecosystem. It was discovered that, in many cases, wetland destruction not only was ecologically disastrous, but in many circumstances could prove economically disastrous. But some of the claims made for wetlands have not been substantiated. Indeed, Boelter and Verry, relating to popular conceptions concerning wetlands, refer to a "wetland folklore".

PURPOSE

The purpose of this study was to investigate four functions attributed to wetlands, including:

- Water Quality Improvement;
- Groundwater Recharge;
- Storm and Flood Water Storage; and
- Shoreline Protection.

The investigation focused on identifying determinant factors and criteria that could be used to develop procedures and methodologies to assist Corps personnel in assessing the value of general wetland types and of specific wetlands in performing the functions indicated.

As a result of the investigation, a detailed research program was developed for the functional areas. These programs are designed to provide data required to develop accurate predictive models that can be used in permitting activity by the Corps.

SCOPE

e

The report addresses all wetlands under the jurisdiction of the Corps. It represents the current state-of-the-art and is meant to compliment and extend information presented in the Institute for Water Resources report, "Wetland Values: Concepts and Methods for Wetlands Evaluation". The assessment of the four functional areas presented in this report was based on available data; it did not use original sampling or testing. Where guidance is overly general or seems lacking, it is a reflection of the limited and often conflicting data reported in the literature so far. This was particularly a problem in the areas of water quality improvement and groundwater recharge, although the data base for all four functional areas was not sufficient to allow development of detailed, quantifiable evaluation procedures.

ORGANIZATION AND USE

The report is organized by the four functional areas, with each area comprising a chapter. Within each chapter a discussion of the literature is presented, general conclusions are identified, and criteria that influence the ability of a wetland type to perform the function are delineated. To the extent possible, specific procedures are then outlined that allow the application of these criteria to specific sites. Finally, a research program is outlined. The degree of detail and the approaches developed for each of the four functions were determined by the extent of data available. Consequently, each function utilizes a unique approach.

The classification system being developed by the Fish and Wildlife Service for the Nationwide Wetlands Inventory was used as a framework for the discussion. For this application only the first order of classification, the system, was utilized. The system, as defined by the FWLS, includes both wetland and deep-water habitats. For the purpose of this report, the discussion focuses on associated wetlands. Thus, the classification employed in this manual included:

Marine - Wetland areas exposed to the open ocean, with water regimes determined by ebb and flow of oceanic tides; salinity exceeding 30 percent.

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

Estuarine - Includes tidal habitats and tidal wetlands which are usually semi-enclosed by land but have partial or intermittent access to the ocean.

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

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

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

Lacustrine - The Lacustrine System includes wetlands and deepwater habitats with all of the following characteristics: 1) situated in a topographic depression or a dammed river channel;

2) lacking trees, shrubs, persistent emergents, nonaquatic mosses or lichens with greater than 30 percent areal coverage; and 3) greater than 8 hectares (20 acres) in size. Similar wetlands and deep-water habitats smaller than 8 ha are also included in the Lacustrine System if an active wave-formed or bedrock shoreline feature forms all or part of the boundary, or if the water depth in the deepest part of the basin is greater than 2 m at low water. Lacustrine waters may be tidal or non-tidal, but salinity is less than 0.5 percent.

The Lacustrine System is bounded by upland or by wetland dominated by trees, shrubs, persistent emergents, nonaquatic mosses or lichens. Lacustrine systems formed by damming a river channel are bounded by the contour approximating the normal spillway elevation or normal pool elevation except where palustrine wetlands extend lakeward of that boundary. Where a river enters a lake, the extension of the lacustrine shoreline forms the riverine/lacustrine bound

Palustrine - The Palustrine System includes all non-tidal wetlands dominated by trees, shrubs, persistent emergents, nonaquatic mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 percent. It also includes wetlands lacking such vegetation, but with all the following characteristics: 1) size less than 8 hectares (20 acres); 2) absence of an active wave-formed or bedrock shoreline feature; 3) water depth in the deepest part of basin less than 2 m at low water; and 4) salinity due to ocean-derived salts less than 0.5 percent.

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

WATER QUALITY IMPROVEMENT

INTRODUCTION

Several problems arise in assessing the value of wetlands for improving water quality. Although all wetlands are biologically active systems and thus have the capacity to remove pollutants, the question of what constitutes water quality improvement must be established before attempting to assign values to either general wetland types or to specific wetlands. Beyond the question of defining water quality, the origin, volume, fate, and use or significance of the affected waters are also salient. Moreover, the function of water quality improvement may occur only on a seasonal or annual basis over a localized area; conversely, the function may occur on a daily basis and extend over an entire region.

The term "water quality" has not been well-defined by the scientific or regulatory community. A good working definition of water quality depends on the designated use and users of the water body. Current water quality planning activities use primarily dissolved oxygen concentrations, biological oxygen demand (BOD), nitrogen, or phosphorus as a basis for planning and modeling water quality. The U.S. Environmental Protection Agency (EPA) has developed or is developing numerical criteria and standards for a wide array of inorganic, organic, and physical parameters in water. For the purposes of evaluating specific wetland areas and their values for water quality improvement, local water quality problems and needs must be known and considered. Specific wetlands may be sources of some materials to the receiving water and sinks for other materials.

The water quality improvement function of wetlands has not been explicitly defined in Corps of Engineers' regulations (33 CFR 320) or "Wetland Values: Concepts and Methods for Wetlands Evaluation". The former states that "wetlands through natural water filtration processes serve to purify water", whereas the latter states that "some wetlands can function to naturally purify water by removing organic and mineral particulate matter from rivers and streams". These definitions imply that the water quality improvements function of wetlands pertains to the removal of pollutants or problem-causing materials from ambient waters, rather than their capacity to treat wastewater or storm water runoff.

Thus, the hydrologic interaction of wetlands with adjacent surface waters is an important factor in assessing its value for improving water quality. For example, a perched bog which is underlain by clay or peat soils has limited interaction with surface or groundwaters. Consequently, it contributes little in the way of improving water quality. Tidal marshes, on the other hand, are inundated daily and have at least the potential of signifantly improving water quality in adjacent waters.

In flow-through or open wetlands a distinction among ambient waters, storm water runoff, and wastewater must be made when assessing the water quality improvement value of specific wetland areas. Riverine, estuarine, or lacustrine wetlands may directly improve the water quality in the adjacent water body because the ambient water directly interacts with the wetland; in this case the wetland is providing a direct water quality improvement function in the receiving water. Wetlands that fringe lakes, rivers, and estuaries and that primarily receive storm water runoff from agricultural or urban areas may not directly improve the water quality of the receiving water body. However, they may help maintain its quality by removing pollutants from storm water that otherwise would have reached the receiving water; this type of functioning could be considered water quality maintenance, as opposed to actual water quality improvement. Finally, some wetlands do or have the potential to receive municipal or industrial wastewater and be utilized as tertiary treatment units for individual wastestreams; this type of functioning does not directly improve ambient water quality, but as in the case of storm water runoff, the wetland may help maintain ambient water quality. Wetlands that are close to urban or industrialized areas have the potential to receive wastewaters and therefore, these wetlands have value as potential water quality maintenance areas for ambient waters, even though they are not actively functioning in this capacity.

Assessing the value of wetlands for water quality improvements also depends on one's individual bias or perspective. For example, wetland ecologists have praised wetlands for their production of detritus which provides the basis for detritivore food chains in estuaries; whereas more recently environmental engineers and scientists are viewing wetlands as sewage treatment units that efficiently remove BOD. Detritus is food for the estuary and BOD is a pollutant, yet both are forms of organic matter. In one case the wetlands are valuable because they are removing organic matter and preventing water quality degradation in the receiving water, whereas in the other case wetlands are valuable because they export significant quantities of organic matter that feed aquatic organisms.

The apparent discrepancy is not unreasolvable when site-specific comparisons are made, and perhaps not at single sites when local conditions are investigated. BOD (the pollutant) may be transformed into detritus (the food) by the wetland and thereby improve the quality of the organic matter and the receiving water. Nevertheless, the BOD versus detritus discrepancy illustrates the difficulty of assigning water quality improvement ratings and the problem with defining water quality improvement to wetlands without site-specific considerations.

THE DATA BASE

The objective of this literature search was to identify and review only those publications which contained data for the net exchange of materials between wetlands and their receiving waters or for input-output studies. Water quality measurements are commonly made during wetland studies, but net flux or mass balance calculations for wetland ecosystems are not. Chemical composition and concentration measurements of components of wetland ecosystems and internal material-cycling studies were not considered to be directly relevant to the water quality improvement function of wetlands. For the purposes of this literature review, both the direct water quality improvement of ambient waters and the indirect water quality maintenance function of wetlands via storm water and wastewater treatment were included.

Description of Relevant Literature

Table 1 presents summaries of research studies which contained relevant data on the water quality improvement function of wetlands. Thirty-four studies which examined the natural flux of materials across wetland boundaries or their responses to artificial enrichment were identified. The frequency distribution of the 34 studies among freshwater wetlands, saltwater wetlands, natural flux studies, and artificial enrichment studies is shown below.

Distribution of Water Quality Improvement Studies

	Natural Flux	Artificial Enrichment	Totals
Freshwater Wetlands	8	11	19
Saltwater Wetlands	8	7	15
Totals	16	18	34

The geographical distribution of study sites was primarily along the Atlantic coast states, the northern mid-west states, and Louisiana. Nitrogen and phosphorus were the parameters most commonly measured, but different forms and species of these elements were measured during different studies. Artificial enrichment experiments ranged from laboratory studies of sediment cores to continual long-term application of sewage effluent to large wetland areas. Artificial enrichment and natural flux studies were conducted in riverine, lacustine, and palustrine wetlands. Saltwater wetland studies were limited to salt marshes with the exception of one mangrove study in Fiji.

The data base for the water quality improvement function of wetlands is relatively small compared to the geographical distribution and diversity of wetland types. Experimental approaches and measured parameters varied among the studies and, therefore, exact comparisons between different wetland types and between similar wetland types cannot often be made. Two basic types of water quality improvement studies were reported in the literature. One was the determination of material fluxes between a natural wetland and its receiving water; the other was the artificial enrichment of wetlands combined with partial or complete mass-balance measurements. Both types of studies have been conducted on freshwater and saltwater wetlands.

Nitrogen and phosphorus forms were the more commonly measured water quality parameters, although some researchers measured total nitrogen concentrations and others measured just inorganic forms. The magnitude and

TABLE 1. SUMMARY OF LITERATURE PERTAINING TO WATER QUALITY IMPROVEMENT FUNCTION OF WETLANDS
N AND P DENOTE TOTAL NITROGEN AND TOTAL PHOSPHORUS UNLESS OTHERWISE SPECIFIED

Reference	Wetland Type	Wetland Location	Water Quality Parameters	Methods	Results	Conclusions
WETLANDS UNDER NATURAL CONDITIONS						
Fresh Water Wetlands						
Grant and Patrick (1970)	Riverine Marsh	Pennsylvania	BOD, PO_4, NO_3, NH_3	Two sample input-output obsevation of natural flux	Marsh removed: 30 lbs/ac-day - BOD 19 lbs/ac-day - PO_4-P 17 lbs/ac-day - NH_3-N 539 lbs/ac-day - NO_3-N	• Tinicum marsh does act as a significant water purifier but the heavy organic loads had severe impact on marsh life
Klopatek (1970)	Riverine Marsh	Wisconsin	N, P	Plant tissue, soil and water monitoring	Total N and P retained during growing season but released during fall and spring; net annual exchange not estimated	• Macrophytes act to pump nutrients from sediments • Reduction of inorganic P levels in marsh outflow were positively correlated with above ground macrophytic biomass
McPherson, et al. (1976)	Fresh water Marsh	S. Florida Everglades	Inorganic N PO_4-P	Monitoring	PO_4-P decreased from 0.04 mg/l to 0.01 mg/l and NH_3-N decreased from 0.38 mg/l to 0.17 mg/l across marsh	• Inorganic N and PO_4-P concentrations decreased to background levels within 100 meters across marsh surface
Mitsch, et al. (1977)	Cypress tupelo Swamp	Illinois	P	Monitoring natural conditions	80 g P/m^2-yr floods from river 3.6 g P/m^2-yr sedimented out 0.25 g P/m^2-yr input from [illegible]ndwater, rainfall [illegible] [illegible]noff [illegible].34 [illegible]^2-yr exported back [illegible]iver during non-fl[illegible] period	• Swamp took in 11 times more P than was discharged to river during non-flood period
Novitzki (1978)	Inland fresh water meadow	Wisconsin	P, N, TSS	Input-output monitoring	81 perc[illegible] TSS retained 21 percent total N retained 7 percent toal P retained	• Wetland reduced amount of suspended material and nutrients in water moving through it

TABLE 1 (CONTINUED)

Reference	Wetland Type	Wetland Location	Water Quality Parameters	Methods	Results	Conclusions
Prentki, et al. (1978)	Lakeshore marsh-<u>Typha</u>	Wisconsin	P	Not given	Annual P retention = 0.56 g P/m^2-yr (10 percent of storm water input)	• Lakeshore marshes may be inefficient nutrient traps due to upward nutrient translocation from sediment by plants
<u>Salt Water Wetlands</u>						
Axelrad, Bender and Moore (1974)	Medium salinity salt marshes	Chesapeake Bay	N, P, C	Natural flux	4-35 lb N/ac-yr exported 7-9 lb P/ac-yr exported	• Net loss of P from estuary to marsh; particulate P transformed and exported as dissolved P • Large net loss of N to estuary • Significant export of particulate C and DOC
Delaune, et al. (1976)	Salt marsh; (<u>Spartina aH.</u>)	Louisiana	N	Lab studies and literature review	N budget of streamside marsh area: Gains = 1 g/m^2 Nitrification 1 " Rainfall 4 " New sediment Losses= 2 g/m^2 Denitrification 4 " detrital export	• Results imply that there is no net N exchange between marsh and estuary but that marsh returns rainfall N to atmosphere thru denitrification
Gardner (1976)	Salt marsh (<u>Spartina</u> sp.)	S. Carolina	PO_4	Extrapolation from marsh runoff data	PO_4-P export = 1.39 g/m^2-yr	• Contribution of PO_4 from marsh runoff to S. Carolina coastal waters is probably equal to 80 percent of that from fresh water runoff

TABLE 1 (CONTINUED)

Reference	Wetland Type	Wetland Location	Water Quality Parameters	Methods	Results	Conclusions
Heinle and Flemer (1976)	Low Salinity salt marsh	Maryland	C, N, P	Natural flux	Marsh exported: 7.29 g/m^2-yr particulate C 0.33 " total P 4.1 " total dissolved N	• No consistent pattern of exchange over 2-year period • Net flow of N and P were from marsh to estuary, principally in dissolved form
Settlemyre and Gardner (1975)	Salt marsh (*Spartina* sp.)	S. Carolina	PO_4, coliform, Solids, BOD, Co, Zn, Pb	Natural flux	19.6 g/m^2-yr PO_4 export; no significant net exchange of coliforms, BOD	• Basin exported significant quantities of organic solids and PO-P;
					280 g/m^2-ur Inorg. suspended solids imported 673 g/m^2-yr Organic suspended solids exported 84 g/m^2-yr BOD_7 imported	• Marshes may be an important source of nutrients to coastal waters; • Inorganic sediments are retained by marsh; therefore, marsh reduces turbidity of coastal waters
Valiela, et al. (1978)	Salt marsh (*Spartina*)	Massachusetts	N, PO_4	Natural flux	3200 Kg N net export/yr No significant P exchange	• Net export of N during year • Net import of nutrients during growing season • Groundwater inputs of nutrients are important • Water circulation and presence of a sill affects nutrient exchange
Vernberg, et al. (1976) (W. Kitchens)	Salt marsh *Spartina alt* (short)	S. Carolina	N, P	Nutrient budget in artificial marsh units	Data not reported	• Total phosphorus imported by • Total nitrogen exported by marsh
Windom (1976)	Salt marshes	S. Carolina Georgia N. Florida	Fe, Mn, Cu, Cd, Hg, Pb, Zn	Measured sediment concentration and assumed sedimentation rate	Accumulation rates: Fe = 4.5 x 10^4 mg/m^2-yr Mn = 303 x " Cu = 16 x "	• Salt marshes act as sinks for Fe and Mn while only particulate Cd and Hg accumulate

TABLE 1 (CONTINUED)

Reference	Wetland Type	Wetland Location	Water Quality Parameters	Methods	Results	Conclusions
Windom (1976)					Hg = 10 x " Cd = 2.1 x " Pb = 25 x " Zn = 71 x "	• Pollutant harbor sediments had higher metal concentrations than did marsh sediments
WETLANDS UNDER ARTIFICIALLY ENRICHED CONDITIONS						
Fresh Water Wetlands						
Boyt, et al. (1977)	Hardwood Swamp	C. Florida	N, P, Coliform	Monitoring of swamp receiving sewage and storm water runoff	98 percent P retained 90 percent N retained Coliform bacteria removed in <1 mile	• Hardwood swamp acts as tertiary treatment unit • System required 0.02 ac/person under optimal conditions • No nutrients build-up in sediment of experimental swamp • Increased plant growth
Dierberg and Brezonik (1978) (same study as Ewel and O'Dum 1970)	Cypress dome	N. Central Florida	N, P	1 year monitoring of natural dome and sewage-receiving dome	Majority (>90 percent) of 12 g N/m^2-yr and 11 g P/m^2-yr was assimilated or stored by domes	• Surface water quality within the domes was degraded but there was little or no surface runout and pollutants were not getting out into the percolate • Fate of pollutants had not been entirely determined
Dolan, et al. (1978)	Fresh water marsh-mixed vegetation	C. Florida	N, P	2 degree sewage effluent added to enclosed natural marsh without surface discharge	78 percent of total N input (0.12 g/m^2-day) was lost to atmosphere; 21 percent of total N input infiltrated groundwater; 97.6 percent of total P input (0.12 g/m^2-day) was retained in plots; balance infiltrated groundwater	• Marsh system effectively renovated wastewater with application rates of 0.5, 1.5, and 4 in/week • No surface discharge occurred because experimental plots were enclosed

TABLE 1 (CONTINUED)

Reference	Wetland Type	Wetland Location	Water Quality Parameters	Methods	Results	Conclusions
Engler and Patrick (1974)	Intermittently flood fresh water swamp	Louisiana-Mississippi River	NO_3	NO_3 removal in undistrubed sediment cores	3.5 Kg N/ha-day removed after initial NO_3 coal= 25 ppm	• Denitrification affected by depth of overlying water, organic matter content of soil, aerobic-anarobic zone at mud-water interface, and NO_3 diffusion rate to mud-water interface (concentration gradient)
Ewel and O'Dum (1978)	Cypress-dome	N. Central Florida	P	Estimates from monitoring natural dome and sewage-receiving dome	Natural dome retained 100 percent of 0.2 g P/m^2-yr input. Sewage dome retained 15.6 of 17.2 g P/m^2-yr (91 percent) of total input	• After 4 years of study, it appears that cypress domes may be capable of serving as a form of advanced wastewater treatment
Hickok, et al. (1977)	Fresh water lacustrine wetland, mixed grasses, cattails, willow, dogwood	Minnesota	P, NH_3	Monitoring enclosures receiving storm water runoff	Total P retention 156 g/m^2-yr (78 percent) TSS P retention 52 Kg/m^2-yr (94 percent) NH_3 net export 320 g/m^2-yr	• Storm water is renovated by wetlands through physical entrapment, microbial transformation, and biological utilization
Kadlec and Tilton (1970)						
a) Houston Lake	Lacustrine sedge/shrub marsh	Michigan	NO_3+NO_2-N, NH_4-N, Total dissolved P	2 degree sewage effluent irrigation-low nutrient concentration (TDP= 0.4 mg/l, TDN= 0.4 mg/l)	99 percent, 71 percent 95 percent immobilization of NO_3+NO_2, NH_4, TDP within 30 meters of discharge	• Good immobilization of dissolved nutrients by marsh receiving low input rates (13, 2.1, 14 mg/m^2-day of NO_3+NO_2, NH_4, TDP, respectively) during June-September
b) Bellaire	Lacustrine	Michigan	NO_3+NO_2, NH_4, TDP	2 degree sewage effluent irrigation	88 percent TDP and 80 percent DN removal of total input of 9.9 mg P/m^2-day and 24 mg N/m^2-day during 9 months	• High temperatures, high residence times, large effective areas, and presence of foliage contribute to high nutrient removal

TABLE 1 (CONTINUED)

Reference	Wetland Type	Wetland Location	Water Quality Parameters	Methods	Results	Conclusions
Richardson, et al. (1976)	Peatland	Michigan	N, P	Simulated sewage effluent addition	55 Kg P/ha retained, 170 Kg N/ha denitrified or retained	• Peatland systems have good potential as biological filters • Long-term sorption capacity not known yet
Spangler, et al. (1976)	Fresh Water Riverine Marshes	Wisconsin	BOD, COD, P, Turbidity, NO_3, Coliform, pH, solids	Long-term (14 months) monitoring, upstream-downstream of marsh receiving sewage effluent	13 percent P reduction 80 percent BOD reduction 51 percent NO reduction 86 percent coliform reduction 8 percent solids increase 43 percent turbidity reduction	• Natural marsh only effective for P removal during growing season but annual P output = annual P input • Most P removed in first 100 meters of stream channel below sewage outfall
Steward and Ornes (1975)	Fresh Water Swamp Sawgrass	S. Florida Everglades	N, P	Single and Weekly application of N and P	Single application (11 g/m^2 of N and P) 8 percent N removed by plants 20 percent removed by plants Weekly application; assimilative capacity for P passed in 8 weeks, stressed in 3 weeks; P capacity <2 g P/m^2	• Sawgrass community cannot be used efficiently to renovate wastewater • Marsh system has limited capacity for assimilating nutrients
Toth (1972)	Lacustrine needs	Hungary	N, P	Measured concentration differences across reeds receiving sewage effluent	96-99 percent decrease in total N and P concentration across reeding area	• Fringing reeds of lake removed N and P during growing season only and dampen effect of local contamination from sewage effluent
Salt Water Wetlands						
Bender and Correll (1974)	Medium salinity salt marshes	Chesapeake Bay	P	Fertilization	Application of 430 mg P/m^2-day exceeded assimilative capacity	• Utility of any type for nutrient removal is questionable

TABLE 1 (CONTINUED)

Reference	Wetland Type	Wetland Location	Water Quality Parameters	Methods	Results	Conclusions
Bender and Correll (1974)						• Need 0.5 ac/capita to remove P from 2 degree effluent
Chalmers, et al. (1976)	_Spartina_ _alt._ (Short)	Georgia	N	Fertilization with dry sludge; 12 months	50 percent N remained on plots	• Sludge application not efficient disposal method because 50 percent N exported
Engler and Patrick (1974)	Salt Marsh	Louisiana	NO_3	NO_3 removed in undisturbed sediment cores	7.4 Kg N/ha-day removed after initial NO_3 concentration = 25 ppm	• Denitrification affected by depth of overlying water, organic content of soil, aerobic-anaerobic zone at mud-water interface, and NO_3 interface (concentration gradient)
Hull (1976)	_Spartina_ _alt._	Rhode Island	N, P, Zn, Cd	Fertilization: single application	8 g N/m^2 recovered in plants 1 g P/m^2 recovered in plants 21 percent Cd and Zn recovered in plants	• Tidal marsh grasses are efficient sinks for surface-applied nutrients
Nedwell (1975)	Mangrove	Fiji	NO_3, NH_3	Input-Output; 2 24-hour studies; sewage effluent to tidal river	Inorganic N mass decreased by 56 percent, 2.5 km downstream of sewage outfall: NH_3 decreased by 63 percent NO_3 decreased by 30 percent	• Assumed NH_3 loss was due to assimilation by primary producers in water column of river and NO_3 loss was by denitrification at sediment water interface
Patrick and Delaune (1976)	Salt Marsh (_Spartina_ _alt._)	Louisiana	N, P	Fertilization	29 percent of 200 Kg N/hr was recovered in above ground portion of plants; 1 percent of added P recovered	• Mass balances not performed
Valiela, et al. (1975)	Salt Marsh	Massachusetts	N, P, Pb, Zn, Cd	Sewage sludge fertilizer application	80-94 percent N retained 91-94 percent P retained 98 percent Pb retained 82 percent Zn retained 44 percent Cd retained	• Salt marshes assimilate sewage • Upper limit for assimilation is unknown

TABLE 1 (CONTINUED)

Reference	Wetland Type	Wetland Location	Water Quality Parameters	Methods	Results	Conclusions
Woodwell (1977)	Artificial Marsh-pond	New York	N, P	2 degree effluent; recirculating flow-through system	84-91 percent N reduction 94-98 percent P reduction	• Artifical marsh-pond system can provide 3 degree to 2 degree effluent • 50 ac marsh-pond accomodates 10,000 people
Loucks and Watson (1978) (cited in Livingston and Louck, 1979)	Lacustrine	Wisconsin	Dissolved Reactive P	Input-output mass balance	0.127 kg P/day annual retention (10 percent annual 83 percent P retention in summer	• Amounts of water and P input to marsh is low in summer but retention is high • Lacustrine wetlands play critical system-level role by retaining nutrients in summer and allow them to enter lake in spring
Kitchens, et al. (1975)	Riverine-Swamp	S. Carolina	PO_4, Total P NO_3, NH_4, NO_2 Coliform Turbidity	Transect studies of concentration; b times January-April	PO_4 and TP conc. seduced by 50 percent NH_4 change variable No change for NO_3, NO_2, coliforms, or turbidity	• Swamp acts as provisional sink for certain nutrients, particularly PO_4

direction of net nitrogen and phosphorus exchange between wetlands and their receiving water varies substantially among different wetland-types and among different wetlands of the same type. The existing data base for the natural flux of nitrogen and phosphorus suggests that freshwater wetlands tend to retain or have no effect on these nutrients, whereas saltwater wetlands tend to export or have no effect on the nutrient concentrations of the flooding water.

The variability of measured nutrient forms; of the duration, frequency, and seasonality of observations; and of the time units for flux values makes meaningful quantification of net exchange rates impossible. Several researchers observed seasonality to the direction and magnitude of nutrient exchange; nutrients were retained during the growing season and subsequently released during the fall and spring. Transformation of inorganic nutrients to organic forms by wetlands has been observed, particularly in salt marshes; inorganic nutrients are removed from flooding waters, converted to organic forms, and exported as detrital or dissolved organic material.

The artificial enrichment studies demonstrated that freshwater and saltwater wetlands can remove/retain nitrogen and phosphorus that is artifically applied; however, removal efficiencies vary markedly. For example, the observed ranges of nitrogen and phosphorus removal efficiency by wetlands was 8-99 percent and 1-99 percent, respectively. For the purposes of evaluating natural wetlands, these types of studies are useful for estimating the potential rather than the actual in situ value of wetlands, and for indicating their upper limit of pollutant assimilative capacity. Utilizing these types of data to quantify the water quality improvement function of natural wetlands would be misleading.

Discussion

Available literature indicates that different wetland types and different wetlands of the same type function differently under different conditions. Some wetlands retain some compounds either seasonally or on an annual basis, whereas some wetlands export some compounds either seasonally or on an annual basis. All studies were conducted over a relatively short time period and included infrequent and few observations. Therefore, the effects of storms and the "first flush" phenonemon was not included in most net exchange calculations.

All studies of freshwater wetlands and their capacity to exchange or retain nutrients from inputted water indicate that freshwater wetlands do act as sinks for nitrogen and phosphorus during some periods. Mass balance calculations were not made in all studies and only inorganic species of nitrogen and phosphorus were measured during several of the studies. Van der Valk, et al. (1979) reviewed the water quality improvement aspects of freshwater wetlands and observed that all the wetlands trapped P and/or N to some extent at least seasonally. The key observation with respect to wetland values for water quality improvement is that freshwater wetlands retain materials to some extent and during some parts of the year. On the other hand, Klopatek (1978) and Prentki, et al. (1978) illustrate that lacustrine and riverine marshes may be inefficient nutrient traps because they are open, leaky systems and their macrophytic vegetation effectively pumps nutrients from the sediments and prevents permanent burial below ground. Klopatek (1978) reviewed the nutrient dynamics of freshwater riverine marshes and concluded that their open characteristic results in a continual subsidy and withdrawal of nutrients, with the specific patterns in a given wetland being dependent upon seasonal hydrological fluctuation and biological activity. Attempts to relate soil and water nutrients with levels in emergent macrophytes have been unsuccessful, although Klopatek did find significant correlations between soil nutrients and plant nutrients for individual plant species. These results suggest that using aboveground biomass quantities as indicators of a specific wetland area's functioning for water quality improvement and pollutant detention would not be a defensible evaluation criterion; too many other factors and their variabilities determine the relationship between plant biomass and pollutant removal in wetlands. Intuitively, one would expect densely vegetated wetlands to retain more nutrients and pollutants than less densely vegetated wetlands, but the lack of demonstratable correlations over a wide range of biomass values makes such an indicator rather limited in its utility and sensitivity. Perhaps more data for all types of wetlands and their materials balances and more synthesis of existing data would show that plant biomass is a valid indicator of the water quality improvement or pollutant removal value of wetlands.

Prentki, et al. (1978) utilized a conceptual input-output model for nutrient movements in lacustrine marshes and selected data from the literature to propose that lakeshore marshes cannot be effective nutrient traps and sinks. Inventorying all sources and sinks of nitrogen and phosphorus for aboveground plant material, they illustrated that most sources of N and P were relatively insignificant compared to nutrient translocation or nutrient pumping from the soil by the plants during the growing season. Trapping of P from storm water runoff was inefficient (less than 10 percent) on a annual basis for their example marsh, Lake Wingra, WI. Using a teleological argument, they concluded that lakeshore marshes may be ineffective nutrient traps. The marsh needs to conserve nutrients and does so by pumping nutrients from the soil to aboveground structures, thereby avoiding loss by permanent burial in the deep sediments.

Richardson, et al. (1978) found that the capacity of acid peatlands to store or assimilate P on a long-term basis appears limited and that the natural yield of bogs are well within the range and may exceed the outputs from upland terrestrial ecosystems. Wetlands may be efficient filtering systems but total losses of nutrients may be high because internal nutrient reservoirs or external loadings are large. Their analysis of nutrient dynamics in northern fens, bogs, swamps, and marshes is not conclusive for understanding the value of wetlands for water quality improvement. Their results suggest that productivity in the Michigan fen may be limited by the availability of plant nutrients and, therefore, that additional assimilitative capacity for nutrients and pollutants exists within the wetland. However, other wetland areas which yield significant quantities of nutrients may be naturally leaky or may have reached their saturation point for nutrients.

The study of phosphorus inputs and outputs of a forested riverine wetland in Illinois by Mitsch, et al. (1977) illustrates the difficulty in assessing the water quality improvement value of natural wetlands. Mitsch found that a cypress tupelo swamp received 80 g P/m^2-yr from river flooding, of which 3.6 g P/m^2-yr sedimented out in the swamp. The swamp also received 0.25 g P/m^2-yr from groundwater, rainfall, and runoff inputs and exported 0.34 g P/m^2-yr back to the river during non-flood periods. From these results, Mitsch concluded that the swamp took in 11 times more P than was discharged to the river during non-flood periods; therefore, the swamp appears to be an efficient P sink. However, the major source of P to the swamp was river flood (80 g P/m^2-yr) and the swamp only retained four percent (3.6 g P/m^2-yr) of the river input. The swamp did have a net retention of 3.5 g P/m^2-yr but this quantity was only an insignificant fraction of flood-stage P transport by the river. From the standpoint of river water quality, the swamp did not have much value for water quality improvement. Moreover, the swamp delivered more P to the river during non-flood conditions than it received from precipitation, groundwater, and runoff.

The studies of nutrient retention by freshwater wetlands under artificially enriched conditions indicate that all types of freshwater wetlands are capable of removing and retaining nutrients on at least a short-term basis. However, the artificial nutrient loads, percentage nutrient retention, assimilative capacity, experimental conditions, wetland type, measured parameters, study duration, geographical locations, and hydrological regime varied considerably among the studies and, therefore, defining any trends was not possible. For example, Steward and Ornes (1973) found the assimilative capacity of a south Florida palustrine wetland for phosphorus to be less than 2 g/m^2, whereas Hickok, et al. (1977) found a lacustrine wetland in Minnesota retained 156 g P/m^2-yr from storm water runoff.

The studies of nutrient exchange between saltwater wetlands and their adjacent estuaries indicate that saltwater wetlands under natural conditions tend to export nutrients or have no net exchange, rather than import or retain nutrients. Although the wetland areas were primarily *Spartina* salt marshes, the reported parameters, and experimental conditions were similar enough and the data base large enough to identify more meaningful trends and determinant factors. Heinle and Flemer (1976) found no consistent pattern of nutrient exchange in over two years of intensive study at a single marsh. Their findings are applicable to the entire data base of salt marsh studies.

The ability and significance of salt marshes to assimilate nutrients or pollutants under artificially enriched conditions is also unclear. All artificially enriched saltwater wetlands did remove added materials to some extent. The observed ranges of N and P removal efficiency was 8-99 percent and 1-99 percent, respectively. Researchers are similarly variable in their conclusions about wetland values for water quality improvement; Hull (1976) found that tidal marsh grasses are efficient sinks for surface applied nutrients, whereas Bender and Correll (1974) concluded that the utility of any type of wetland for nutrient removal is questionable.

The flux movement of materials other than nitrogen, phosphorus, and carbon, particularly heavy metals and toxic organic chemicals, across wetland boundaries has received little attention from wetland researchers. Windom and Hull (1976), and Valiela, et al. (1975) illustrate that wetlands do retain heavy metals to varying degrees, but the fate and effects of heavy metals entering wetlands has only been partially documented for a few wetlands. Metal-soil-water-plant interactions for individual metals are extremely complex (Patrick, 1977); therefore; making generalizations about the value of wetlands for removing heavy metals from ambient waters is premature. The capacity of wetlands to retain heavy metals is potentially much higher than for nitrogen and phosphorus; Windom (1976) observed that polluted harbor sediments had higher metal concentrations than did marsh sediments. However, the implications of excessive accumulation of heavy metals and toxic compounds for wetland ecosystems and their food chains are severe. Competing uses of wetlands for water quality improvement and wildlife habitat becomes a significant issue with regard to heavy metals and toxic compounds.

Novitzki (1979) developed a classification scheme based on the location and the hydrologic characteristics of wetlands. The classification is useful for understanding and placing into perspective the water quality improvement functions of wetlands. Novitzki's hydrologic classification system includes four classes: surface-water depression wetlands, surface-water slope wetlands, groundwater depression wetlands, and groundwater slope wetlands. Surface-water depression (generally palustrine wetlands) are hydrologically isolated from other surface water bodies and the local groundwater systems and receive their water from precipitation and overland flow (see Figure 1). Surface-water slope wetlands occur along rivers and lakes (riverine and lacustrine wetlands) and receive their water primarily from overland flow and flood waters from the adjacent lake or river (see Figure 2); these wetland types only extend up the slope as far as occasional flooding extends. Groundwater depression wetlands (usually palustrine) are hydrologically isolated from other surface-water bodies and receive their water from overland flow, precipitation, and groundwater inflow (see Figure 3). Groundwater depression wetlands are similar to surface-water depression in that neither type has any surface-water discharge, but they are different from surface-water depression wetlands because they are hydrologically connected to the local water table and receive significant inputs from the water table. Groundwater slope wetlands receive a majority of their water from groundwater seepage or springs on a continual basis and subsequently discharge their water by overland flow to downstream water bodies (see Figure 4); these wetland types typically occur along hillsides where geologic conditions prohibit infiltration and percolation. Groundwater slope wetlands differ from groundwater depression wetlands in that the former have surface-water discharges whereas the latter do not.

Novitzki's classification of wetlands is useful for assessing the value of a specific wetland area for both water quality improvement and water quality maintenance because the system categorizes wetlands on the basis of the origin and fate of water in the wetland. For a wetland to be valuable for water quality improvement, it must detain or retain a significant amount of pollutants that would otherwise reach surface-waters. For a wetland to be valuable for water quality maintenance, the wetland must renovate

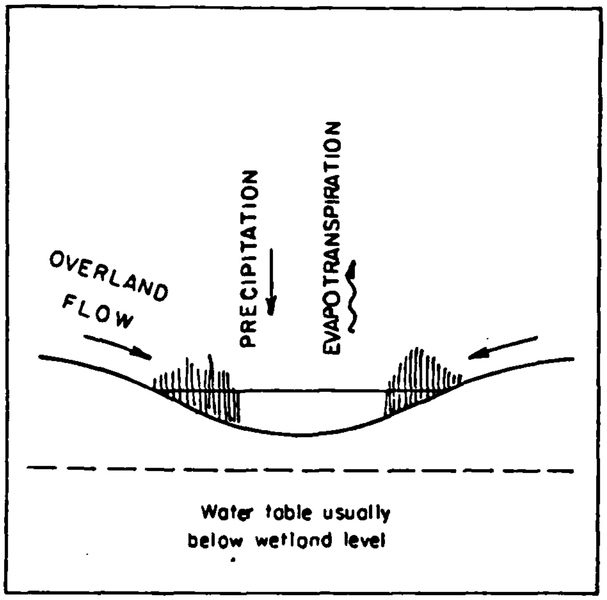


Figure 1. Hydrologic characteristics of surface-water depression wetlands.

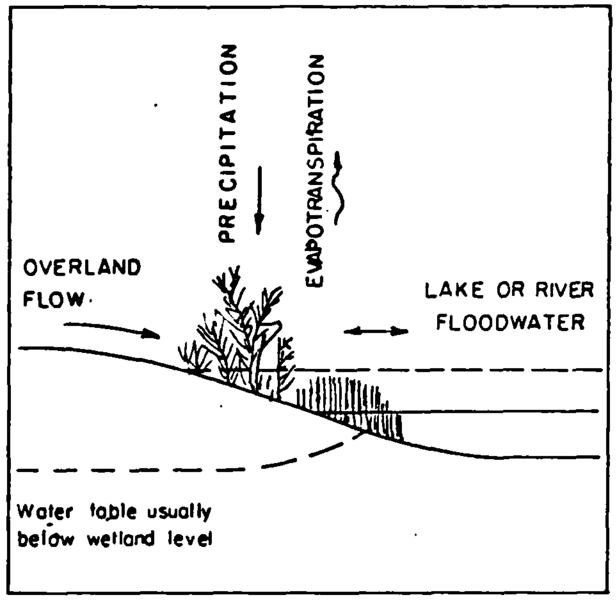


Figure 2. Hydrologic characteristics of surface-water slope wetlands.

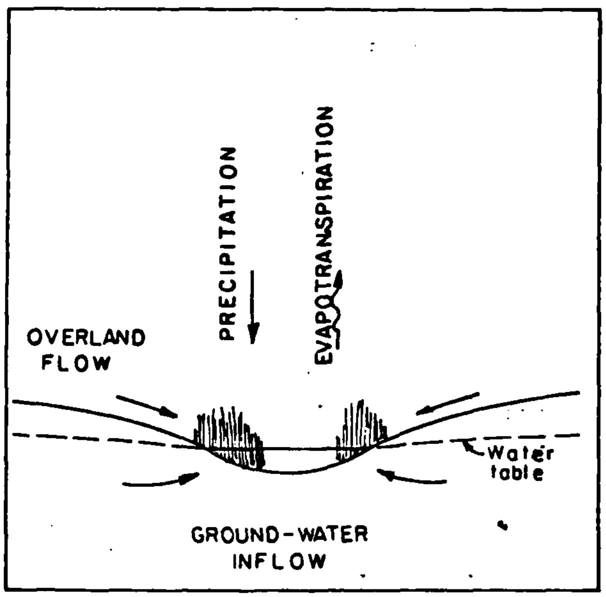


Figure 3. Hydrologic characteristics of ground-water depression wetlands.

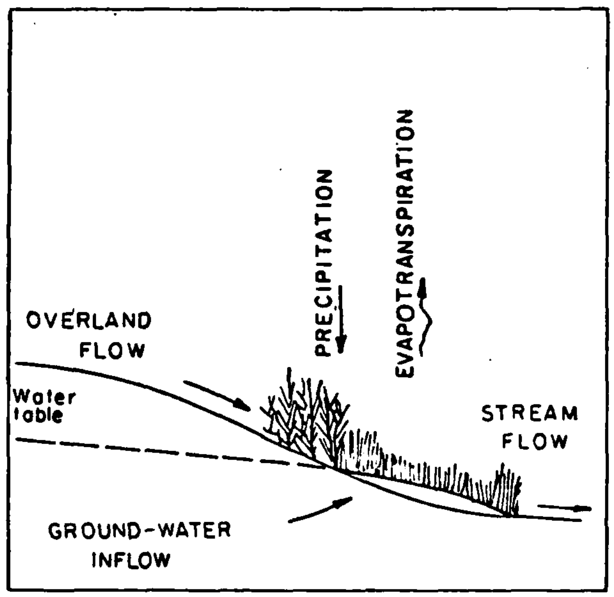


Figure 4. Hydrologic characteristics of ground-water slope wetlands.

of pollutants that would otherwise reach surface-waters. For a wetland to be valuable for water quality maintenance, the wetland must renovate contaminated runoff. The first part of the discussion will relate Novitzki's classification system to water quality improvement; subsequently, water quality maintenance will be addressed.

Surface-water depression or groundwater depression wetlands naturally accumulate materials that cannot be flushed out because no surface-water discharge occurs in these types of wetlands, but they do not directly benefit water quality because there is no discharge. Depression-type wetlands may indirectly benefit water quality in local surface-waters by retaining pollutants that would otherwise reach the surface-waters; but only site-specific analyses can determine whether the pollutant and hydraulic load to the wetland would have had a significant effect on local surface-waters if the depression wetland was absent. Depression-type wetlands are very efficient sinks for materials, but under natural conditions the pollutant loads are relatively small; therefore, depression-type wetlands have only moderate value for water quality improvement.

Surface-water slope and groundwater slope wetlands have a greater potential to directly improve water quality because the wetlands are hydrologically connected to surface-water bodies. In addition, pollutant-free water leaving the wetland can increase the dilution capacity of the receiving water. However, the pollutant removal efficiency for this type of wetland is lower than the depression-type, and the flow-through volume per unit area is generally not significant in relation to the volume of receiving water; therefore, slope-type wetlands can in general only have moderate value for water quality improvement.

Groundwater slope wetlands cannot significantly improve ambient water quality unless the groundwater source is contaminated. Since a majority of inputted water to a groundwater slope wetland is from groundwater, the wetland does not receive and cannot purify significant amounts of surface-water. Individual groundwater slope wetlands may be receiving heavily contaminated runoff from agricultural or urbanized areas, in which case the wetland may be serving a valuable filtering function. Similarly, a surface-water slope wetland cannot have a significant value for water quality improvement unless contaminated ambient water, overland flow, or precipitation enters the wetland and is significantly improved.

Novitzki's wetland classification system does not include estuarine wetlands, which as intertidal wetlands should be classified as surface-water slope wetlands in most cases. Some salt marshes, however, may have signficant inputs of groundwater along the upland areas; therefore, estuarine wetlands (also riverine and lacustrine wetlands) may be groundwater slope wetlands in some sections and surface-water slope wetlands in other sections. For example, Valiela, et al. (1978) report that springs are common at the landward edge of salt marsh vegetation on Cape Cod and that inputs of nitrogen by groundwater can be important to the marsh.

Intertidal estuarine wetlands have higher flow-through volumes than riverine or lacustrine wetlands and concomitant lower water residence times. The higher volume of flow provides the wetland a greater opportunity to significantly affect the water quality of the receiving water. However, the lower residence times and demonstrated trend of saltwater wetlands to export N and P indicate that estuarine wetlands have little value for water quality improvement, from a eutrophication standpoint. From the standpoint of heavy metals and toxic pollutants, estuarine wetlands may be quite valuable for water quality improvement, because flow-through water volumes are high and the retention efficiency for these pollutants does not have to be high to allow the wetland to significantly affect the pollutant levels in receiving waters.

The value of wetlands for wastewater or storm water renovation or ultimate waste disposal depends on the same factors that affect natural wetlands, except the nature and magnitude of the pollutant load becomes more important. Most artificial enrichment or pollutant loading studies have shown that wetlands are capable of assimilating or retaining additional materials to varying degrees. The efficiency of pollutant removal largely depends on the hydrology of the wetland. Depression-type wetlands are efficient wastewater disposal sites because surface-water discharges do not exist (see Odum, et al., 1976), whereas intertidal wetlands are less efficient wastewater renovation systems because the water residence time is too short for effective treatment.

The impacts of and the assimilative capacity for wastewater additions to wetlands is just beginning to be evaluated. Current research indicates that wetlands are most efficient for wastewater renovation if they are managed or altered (see Sloey, et al., 1978, Kadlec, 1979). However, if wetlands are altered and managed they may not serve their important roles for fish and wildelife systems. Inherent in wetland value for water quality improvement is a waste disposal or storage function that is a valuable service for society. However, if inputs of wastewater and pollutants accumulate to the point where wetland sediments are classified as hazardous material, then the value of wetlands for water quality improvement or wastewater renovation is a short-lived asset. In the long-term, wetlands that are very efficient for pollutant removal may become a environmental liability, analogous to open dumps that now must be upgraded or permanently closed in a proper manner. The U.S. Environmental Protection Agency is just beginning to learn the environmental hazards of poorly designed and maintained waste disposal sites and the costs of upgrading or closing such sites.

Treatment of storm water runoff by wetlands is also currently considered a valuable service for society. Wetlands that receive urban or agricultural runoff and remove and retain N, P, BOD, heavy metals, pesticides, and other toxic compounds are serving a natural treatment and storage function that would otherwise be performed by the receiving lake or river with a concomitant loss of water quality. The efficiency with which individual wetlands trap and retain pollutants from storm water runoff is highly variable. Prentki, et al. (1978) report that a Wisconsin lacustrine marsh retained only 10 percent of annual P input from storm water runoff, whereas Hickok, et al. (1977) found that an altered and managed lacustrine wetland in Minnesota retained 78 percent of P in storm water input. Few additional studies of storm water renovation by wetlands exist, and the fate and effects of heavy metals and toxic compounds in wetlands have not been documented. The factors that determine the efficiency of wetlands to renovate storm water runoff and wastewater are most likely the same as those that determine the effectiveness of conventional wastewater treatment processes. Long water residence times, low velocities, and high pollutant inactivation and retention capabilities are the general attributes for good treatment. But unlike conventional treatment units, the performance of different types of wetlands under different conditions for storm water and wastewater treatment has not been documented and analyzed, therefore, the establishment of evaluation criteria for assessing the pollutant removal efficiency of specific wetland areas must be subjective judgement.

The bias and prejudices of researchers, as well as their individual perception of what constitutes the value of wetlands, is evident in the literature. As indicated in the Introduction to this section, freshwater wetlands were considered valuable for nutrient removal; conversely, salt water marsh ecologists found considerable value in a marsh's ability to export nutrients. Both perspectives are valid; the contradiction emanates from different perspectives on what constitutes value.

FACTORS AFFECTING WATER QUALITY IMPROVEMENT BY WETLANDS

The actual or potential values of wetlands for water quality improvement or wastewater renovation currently cannot be confidently established, because the number of potentially determinant factors for this functioning is large and their interactions are extremely complex and poorly understood on an ecosystem scale. More than 20 factors have been identified in the literature as having significant effects on the movement of nutrients and other materials within and across wetland boundaries. These factors have been grouped into biological, chemical, and physical factors and are listed below.

Biological Factors

Biological factors are primarily related to internal nutrient cycling characteristics:

- Nutrient/material uptake rates of vegetation (Hickok, et al, 1976, Novitzki, 1979, Odum and Ewel, 1976, Richardson, et al., 1976 and Toth, 1972);

- Vegetation type (Klopatek, 1975 and 1978, Prentki, et al., 1978, Sloey, et al., 1978) - some species translocate nutrients into underground storage whereas other species act as nutrient pumps; only in the case of large trees can the nutrient storage capacity be considered permanent;

- Primary production rates, plant size, and biomass per unit area (Valiela, et al., 1976, Sloey, et al., 1978);

- Diversity and number of biotopes (Blumer, 1978) - although Whigham and Bayley (1979) found no trends with diversity;

- Denitrification potential (Axelrad, et al., 1974, Engler and Patrick, 1974, Richardson, et al., 1976, Valiela, et al., 1976 and 1978) - denitrification potential depends upon the depth of overlying water, organic content of sediment, nature of aerobic-anaerobic zone, and diffusion of nitrate; and

- Microbial activity (Hickok, et al., 1976, Toth, 1972).

Chemical Factors

- Material input rate to wetland (Sloey, et al., 1978, Prentki, et al., 1978);

- Pollutant type;

- Sediment physiochemical conditions - Eh, pH, and salinity (Patrick, 1977);

- Sediment binding capacity for materials (Bender and Correll, 1974, Odum and Ewell, 1976, Richardson, et al., 1976) - although sediments have no binding capacity for nitrogen; and

- Organic content of substrate (Whigham and Bayley, 1979).

Physical Factors

- Water retention time on wetland (Huber, et al., 1976, Kadlec and Tilton, 1978);

- Hydroperiod (Sloey, et al., 1978, Heinle and Flemer, 1976);

- Water circulation patterns in adjacent water body (Valiela, et al., 1978);

- Sedimentation/physical entrapment (Hickok, et al., 1977, Novitzki, 1979, Valiela, et al., 1976, Spangler, et al., 1976);

- Aeration of surface sediment (Sloey, et al. 1978);

- Diffusion rates of intertidal water into overlying water (Gardner, 1976);

- Ice scouring (Heinle and Flemer, 1976);

- Size of wetland area (Kadlec and Tilton, 1978);
- Orientation of wetland to wind for removal of floating material (Valiela, et al., 1978); and
- Season of year (Sloey, et al., 1978, Kadlec and Tilton, 1978).

The above factors have been thought to be significant in determining the pollutant and nutrient removal efficiency or exportation rate of materials by specific wetlands. None of the studies have been performed under controlled experimental conditions where the effect of a single factor has been evaluated and all other factors held constant; therefore, the effects of any of the factors have not been quantified. Moreover, the experimental conditions, methods, measured parameters, and time frame were not consistent across most studies and, therefore, valid comparisons between studies are not possible. For these reasons, determining what factors are important and under what conditions is not possible. The current state-of-the-art of determining what factors control the water quality improvement functioning of wetlands is analogous to attempting to solve simultaneous equations for which there are many more unknowns than there are equations.

EVALUATION CRITERIA AND PROCEDURES FOR THE WATER QUALITY IMPROVEMENT FUNCTION OF WETLANDS

General Evaluation Criteria

Many factors influence wetland functioning for water quality improvement. The data base for material fluxes through wetlands is too small to quantify the effects of individual factors and their interactions. Therefore, the development of quantitatively defensible criteria and procedures to determine the nature and magnitude of material fluxes for general wetland types and specific wetland areas is not possible. Furthermore, assigning a "value to society" of observed or predicted attributes of a wetland requires a value judgement by the evaluator. A commonly accepted definition of the term "wetland" is only now emerging through regulatory processes, and a variety of functional and descriptive classification schemes for wetlands have been proposed. Historically, wetlands were considered wastelands that ought to be reclaimed for the benefit of society; subsequently, wetlands were viewed as valuable habitats for fish and wildlife and as critical components of natural ecosystems. Now, wetlands are being promoted as natural treatment units for water and wastewater improvements, i.e., "wastelands".

Significant advances are continually being made by wetland scientists in their attempts to understand the role and functioning of wetlands in natural and human systems. The 1978 National Symposium on Wetlands (see Greeson, et al., 1979) was an excellent effort to integrate scientists' knowledge of wetlands and regulators' needs for decision-making rules; regulators do not have many facts upon which to base dredge-and-fill permitting decisions and scientists are reluctant to provide guidance without facts. Nevertheless, the purpose of this study was to review the state of our knowledge with respect to several wetland functions and to generate evaluation criteria and procedures. Therefore, the authors have developed the following general rule and procedures to assess the value of general wetland types and specific wetland areas for water quality improvement.

The following general rule was formulated based on the literature review:

> The values of general wetland types for water quality improvements under natural conditions and on a per unit area basis are all equal and their value is minimal for this function. Specific wetland areas may be valuable to society as water purifiers, but only site-specific analyses can determine whether their direct or indirect effects on regional water quality is ecologically or socially sigificant.

This general rule is based upon our literature review and the assumption that a wetland must significantly benefit local water quality to have a significant value for water quality improvement, rather than for a waste disposal function. In order to significantly affect local water quality, a wetland must have a high surface-water output volume and a high pollutant removal efficiency; otherwise, significant quantities of pollutants cannot be removed or prevented from entering the receiving water. The following ratings for these attributes of the four major wetland types have been assigned based upon the existing data base and hydrologic characteristics:

Wetland Type	Surface Discharge Rate	Pollutant Removal Efficiency
Estuarine	high	low
Riverine	medium	medium
Lacustrine	medium	medium
Palustrine	low	high

By this evaluation scheme estuarine, riverine, lacustrine, and palustrine wetlands have equal value to society for water quality improvement because the combination of surface discharge volume and pollutant removal efficiency for a given pollutant loading and receiving water quality tends to make them equally significant.

Site-Specific Evaluation Criteria

Our general rule for evaluating wetlands for water quality improvement is that no a priori reason for assigning a high value rating to one type of wetland over another exists; estuarine, marine, riverine, lacustrine, and palustrine wetlands have been assumed to have the same minimal value to society for water quality improvement under natural conditions and on a per unit area basis. For specific wetland areas, any or all of the factors which potentially affect the water quality improvement functioning of wetlands (listed previously) may be important. Only direct measurement of pollutant retention by a wetland area and assessment of its significance to local water quality can determine the true value of a wetland area for water quality improvement. Establishing quantitative site-specific evaluation criteria and value-rating scales for the water quality improvement function of wetlands cannot be justified on the basis of the existing data base. However, the following general guidelines or criteria may be useful for modifying the general rule of minimal value for water quality improvement by considering site-specific conditions.

Wetland Vegetation--

All vegetated wetlands store materials as plant tissue during the growing season and over a longer period for woody plant species and, therefore, have the potential to assimilate potential pollutants. The greater the aboveground plant biomass for individual plant species, the greater is the potential to assimilate pollutants. However, most researchers agree that material uptake by rooted plants primarily occurs through the root system and from the sediments. Therefore, plant growth does not directly contribute to water quality improvement and only woody plants directly contributes to water quality improvement by long-term storage of potential pollutants. Annual plants may actually contribute to water quality degradation by pumping pollutants from the sediments and releasing them to the overlying water for export during plant decay.

Plant stem density would appear to be a valid evaluation criteria for the value of a wetland for water quality improvement, not from a biological standpoint, but from a physical entrapment standpoint. High densities of root stems effectively reduce water velocities through a wetland and, thereby, enhance sedimentation and physical entrapment of solids.

Epiphytic plants, non-rooted plants on the sediment surface and animals improvide the water quality potential by directly removing pollutants from the water, analogous to a trickling filter unit in a waste treatment plant. Therefore, wetlands with dense epiphytic and edaphic biotic communities have a higher value for water quality improvement than wetlands with low densities of these plants. Furthermore, wetlands with dense epiphytic and edaphic growths and with flow-through hydrologic characteristics must improve water quality, because the dense growths are supported by high material concentrations in the flowing water.

Local Water Quality--

Wetlands cannot have a significant value for water quality improvement unless there are local water quality problems. This criteria applies primarily to estuarine, riverine, and lacustrine wetlands because these wetland types are surface-water slope wetlands and receive their water form the adjacent water body. If local water quality is excellent, then fringing wetlands cannot be improving water quality. However, all wetland types may help maintain good water quality by acting as buffers against water quality degradation. If the distribution of pollutants among the plant, soil, and water components of a wetland are in some sort of equilibrium under steady state conditions, then an increase in pollutant concentration in incoming water should cause an increase in pollutant storage in the wetland. Similarly, if a wetland is filling in or accreting, then the increased sediment volume should contain corresponding increases in pollutant storage; as an example, Delaune, et al. (1978) estimated that the input rate of N and P to a Louisiana salt marsh by sedimentation was 210 and 16.5 Kg/ha-yr, respectively. All deposited pollutants do not remain in the wetland, but a net increase in sediment volume should result in a net increase in pollutant storage.

Wetland Size and Subareas--

Large wetlands have greater value for water quality improvement than do small ones simply because there is more surface area for pollutant removal processes to proceed. For a given pollutant loading, the total pollutant removal efficiency will be greater in a large wetland, even though the removal efficiency per unit area may be the same throughout the wetland. However, the value per unit area of wetland may not be equal throughout a large wetland or the incremental value of additional surface area in large wetlands may be minimal because all sections of a wetland may not be removing the same amount of material. The center of a riverine, lacustrine, or estuarine wetland may not receive the same pollutant load as the edges because most of the pollutants are retained by the upland or waterside sections of the wetland or the flow-through water volume at the center may be less than that near the edges. The situation is analogous to overland flow treatment of wastewater: a fixed land area under defined conditions is necessary for a given level of treatment and waste load; any additional downhill land area is not utilized for treatment.

In depression-type wetlands the center portions are perhaps the most active and valuable for pollutant retention because materials tend to accumulate on the bottom of the depression; as an example, cypress domes are dome-shaped because tree growth and material uptake are greatest in the center of the depression.

Wetland Shape--

Elongated wetlands or wetlands with a high circumference to surface area ratio have a higher value for water quality improvement than do circular wetlands with the same area. The magnitude of pollutant removal is presumed to be greatest at the edges of a wetland and removal efficiency is presumed to be maximized if water flows diffusely over a wetland. Therefore, the greater the edge distance per unit wetland area, the greater will be the pollutant removal efficiency per unit area.

Wetland Location--

Wetlands close to existing sources of pollution have a greater water quality improvement value to society than do wetlands in remote areas. Wetlands that fringe agricultural or urbanized areas and that receive non-point runoff from these land-uses can be extremely valuable for trapping pollutants, particularly sediment, heavy metals, pesticides, and other toxic compounds, if the wetlands are able to slow water velocities to less than one foot per second and retain the runoff at least one hour for sedimentation to occur. However, narrow fringes of wetlands around agricultural or urban areas probably do not remove a significant proportion of the pollutant load in storm water runoff because the water residence time in the wetland area is too short.

Wetlands near point-source discharge points for municipal or industrial wastewater have a potentially high value for water quality improvement because they may provide significant additional treatment to the wastewater before it leaves the mixing zone. The wastewater must flow over the wetland prior to reaching the receiving water, otherwise this evaluation criteria is the same as the local water quality criteria. The effectiveness of natural wetlands for wastewater renovation is currently an area of active research (see Good, et al., 1978 and Greeson, et al., 1979 for discussions). However, without sufficient wetland area available for treatment, the value for wastewater renovation cannot be significant; for example, an experimental 50 acre artificial marsh-pond system provided approximately 90 percent N and P removal from secondary sewage effluent of 10,000 people in New York (Woodwell, 1977).

Water Residence Time and Velocity--

Long water residence times and low water velocities in wetlands provide good pollutant removal efficiences by allowing biological uptake and physical settling of pollutants to occur. If the hydrology, physical characteristics, and pollutant loading to a specific wetland area are known, then the pollutant removal efficiency and magnitude for the particular wetland and particular pollutant could be estimated using conventional sanitary engineering principles. In conventional settling basins, good particle settling is achieved in eight hours with water velocities less than one foot per second. Flow-through time for a secondary treatment works is typically on the order of one day, whereas the residence time in a sewage lagoon is seldom less than 30 days. Silt-size particles will settle in stagnant water within two hours, whereas clay-size particles will not. However, without detailed site-specific calculations, the significance and the value of an individual wetland for water quality improvement, even based strictly upon physical settling, cannot be reasonably estimated.

Hydraulic Loading--

The hydraulic load to a wetland does not directly relate to the value of a wetland for water quality improvement unless the pollutant removal efficiency of a wetland type is known to be constant for a wide range of hydraulic loads. If the pollutant removal efficiencies and pollutant loads of two wetlands are equal, then the wetland with the greater hydraulic load should have a greater value for water quality improvement because it retains more pollutant. However, hydraulic load and pollutant removal efficiency are assumed to be inversely proportional, e.g., high hydraulic loads per unit area do not permit high pollutant removal efficiency. Therefore, hydraulic loading is not a useful single indicator of wetland value.

Water residence time and the distribution in time and space of the hydraulic load must also be considered when evaluating the significance of a given hydraulic load. If water inputs to a wetland are uniformly distributed over time and space, then water residence time in the wetland should be relatively constant during the year and the wetland should have maximum pollutant removal capabilities. A wetland that receives much of its annual hydraulic load during a few storm events and does not retain the water for several days cannot have a significant value for water quality improvement because the flow-through time is too short. For example, Mitsch, et al. (1977) found that a riverine swamp retained less than 5 percent of P input from flood waters.

On the other hand, wetlands cannot have much value to society for water quality improvement unless they improve the quality of a significant volume of water or retain a significant amount of pollutant that would otherwise reach a receiving water. Intertidal wetlands may have the same pollutant removal efficiency for heavy metals, for example, regardless of the hydraulic load; therefore, if this is true, tidal wetlands with greater tidal ranges should have a greater value for heavy metal removal than tidal wetlands with lower tidal ranges. The water residence time on a tidal wetland will depend on the tidal frequency and not the tidal amplitude (hydraulic load). Whether the water velocities and settling efficiency on the wetland will change significantly with differences in tidal amplitude depends upon local hydraulic characteristics.

Some wetlands may have a low hydralic loading rate and low surface discharge volumes but receive and retain significant amounts of pollutants from agricultural or storm water runoff. These types of wetlands indirectly benefit local water quality by preventing pollutants from reaching surface- waters and, therefore, are quite valuable from a water quality maintenance standpoint.

RESEARCH NEEDS

From a regulatory standpoint, Corps of Engineers personnel need to be able to assess the value to society of specific wetland areas for water quality improvement. The environmental impacts of a proposed dredge and fill activity can only be accurately assessed if the value of a wetland area can be determined for existing conditions and reasonably estimated for future conditions. This study has shown that the existing data base for water quality improvement functioning of wetlands is too small to formulate defensible guidelines, rules, or models for assigning value to specific wetland areas without intensive site-specific investigations. The basic need is more relevant quantitative information about all types of wetlands under widely varying conditions and for all types of pollutants. In addition to quantitative information about wetlands and water quality, better definition of societal values and significance levels for water quality improvement is needed.

To provide useful information for 404 permit application reviews on a nationwide basis for all wetland and pollutant types, a nationwide data collection program is required. The program must be coordinated, designed, directed, and evaluated by a single organization; otherwise, the existing data base for the water quality improvement functioning, which is inconsistent, incomparable, and incomplete, will only become larger without becoming more useful. Furthermore, the program must be interdisciplinary, involving hydrologists, biologists, chemists, geologists, climatologists, and sanitary engineers.

The need to coordinate and standardize a research program is obvious from reviewing the information in Table 1 of this report. Different researchers are studying different wetland types for varying lengths of time, measuring different parameters, reporting different units for the same parameters, and making different conclusions based on similar results. Academic scientists strive to maintain their own identity and, therefore, often to utilize novel and innovative approaches and techniques in their studies. Consequently, few data among studies are directly comparable. Too many potentially important factors that determine the biological, chemical, and physical pollutant removal value of wetlands in the United States need to be evaluated without including factors for analytical techniques and field approaches.

Coordination among sponsoring organizations also needs to be implemented to maximize the collection of useful information. Numerous federal, state, and private organizations need answers to similar questions about wetlands and water quality and could contribute resources and knowledge to a joint research program. However, just as academic researchers need their own identity, so do governmental agencies. The outlook for a comprehensive interagency research program for evaluating the water quality improvement functioning of wetlands is not good.

Identifying specific research needs and approaches for filling the gaps in knowledge relative to assessing wetland values for water quality improvement is not the optimal plan at this time. From the standpoint of Corps information need- to administer the dredge and fill permit program, there are more gaps in knowledge than there are entries. For example, if the value of U.S. wetlands for water quality improvement could be based on just four factors, 1) wetland type, 2) geographical region location, 3) pollutant loading, and 4) hydraulic loading, and Corps personnel only had to deal with four wetland types, six geographical regions, three levels of pollutant loading, and three levels of hydraulic loading during permit review, then there are 216 unique combinations of these factors that could be encountered by Corps personnel. Since our review of the literature only identified approximately 30 relevant studies, most of which did not report comparable data, the futility in attempting to fill data gaps, rather than develop an entire research program, is apparent. For these reasons, a structured, coordinated, and nationwide research program with several phases is recommended in order to develop useful and valid information for assessing the water quality improvement value of wetlands throughout the United States.

A three-phased research program for determining and understanding the water quality improvement functioning of wetlands should be implemented:

- Phase I - Nationwide Survey of Material Fluxes through Wetlands;
- Phase II - Model Development and Verification; and
- Phase III - Detailed and Long-Term Field Studies.

This type of program would provide an initial comprehensive data base for estimating the pollution control value of specific wetlands throughout the United States and longer-term efforts to understand and better predict the water quality improvement function of wetlands.

Phase I. Nationwide Survey Of Material Fluxes Through Wetlands

This phase would be an extensive short-term data collection effort to obtain information of material fluxes through many different types of wetlands under widely varying conditions. Input and output measurements for many potential pollutants and for approximately 400 wetland sites would provide an adequate data base from which the effects of physical, chemical, and biological factors could be assessed. The primary objective of Phase I is to explore the relationships among material fluxes through wetlands and easily measured wetland attributes and to generate simple descriptive expressions that will estimate material fluxes through any wetland with minimal data input. A large diverse data set can be explored using a variety of multivariate statistical techniques and the conclusions from the statistical analyses will be immediately useful for Corps personnel who must know the magnitude of pollutant removal of an individual wetland area without necessarily understanding the mechanisms. Phase I should be accomplished in four tasks.

Task I - Planning--

The objectives of Phase I and the probable effectiveness of meeting these objectives must be clearly defined. The sampling design and proposed statistical analyses must be defined in detail. Site selection criteria and field and laboratory methods must be selected and standardized. A data management plan must be formulated and tested. Resources must be made available and budgeted.

Task II - Site Identification--

Development of a detailed sampling design will indicate how many and what type of wetland sites are necessary. If five major wetland types (estuarine, riverine, lacustrine, marine and palustrine), six geographical regions, three hydraulic loading rates, and three pollutant loading rates are to be evaluated for their effects of material fluxes through wetlands, then 270 unique combinations of these factors are required for a factorial sampling design. Two wetlands (replicates) with same factor combinations should be sampled so that the interactive or synergistic effects of these factors can be evaluated; therefore, 540 wetland sites with defined attributes must be identified. Estuarine wetlands do not exist in all sections of the U.S. and, therefore, the factorial design cannot be complete.

Once the number and types of wetland sites in each geographical region have been determined, then eligible sites with the appropriate attributes must be identified. The National Wetland Inventory, state governments, federal agencies, and wetland ecologists will be useful sources of information during the search for eligible sites. Site selection can be random from the list of eligible sites in each category or intentionally based on maximum variability of other wetland characteristics.

Task III - Data Collection--

Once the sites, methods, parameters, and contractors have been selected, data collection can proceed. Ideally, data sampling collection at each site would be conducted on a seasonal basis over an entire year. Annual water budgets for each site will be necessary and mass loadings of materials from all sources and outputs will have to be estimated.

Task IV - Data Analysis and Interpretation--

If 540 sites are sampled 4 times in a year for 15 or more water quality parameters and 20 or more physical attributes are also recorded, then the size of the resultant data base would be substantial. Statistical analysis techniques such as principal component analysis, factor analysis, and canonical correlations are useful multivariate techniques for examining the structure and interrelationships of large data bases and would indicate what factors appear to be associated and their relative importance in relation to material fluxes through wetlands. Stepwise multiple regression analyses could be utilized to generate descriptive equations that would best estimate material fluxes for individual wetlands on the basis of one or more easily measured wetland attributes. Such statistical techniques yield valid tools for predicting the water quality improvement value of specific wetlands but they do not elucidate the causes or mechanisms of pollutant removal. Regression expressions would be useful for Corps personnel to estimate the value of individual wetlands because they are derived from observed facts rather than subjective judgement.

Phase II - Model Development And Verification

This phase would utilize the data base and output from Phase I to formulate and calibrate deterministic models for the water quality improvement functioning of wetlands. The statistical approach in Phase I provides information on the easily measured factors that seem to be significantly associated with material fluxes through wetlands, but it does not necessarily identify causal factors. Ecosystem modeling, either simple or complex, would be the next step in attempting to understand causal relationships in wetlands and perhaps refine the predictive capabilities for water quality improvement functioning of wetlands. Systems ecologists would review the results and conclusions of Phase I, identify the seemingly important ecosystem components for pollutant removal, and develop, calibrate, and verify predictive models during this phase. This objective of Phase II could be accomplished in four tasks:

- Task I: Planning - develop work plans and assemble project personnel and resources;
- Task II: Model Development - modeling strategy should emphasize simplicity and generality as primary objectives;
- Task III: Model Calibration - utilize the material flux data from Phase I; and
- Task IV: Model Verification - select new wetland sites for additional sampling to verify the validity of models.

Phase III - Detailed And Long-Term Field Studies

This phase of the program will include pure and applied research. The results of Phase I and II will indicate what factors are useful for predicting the water quality improvement functioning of wetlands and those factors that seem to be important but need more study to be fully understood. The regression equation from Phase I will most likely find associations between certain wetland attributes and the level of material flux through the wetlands that appear to be absurd. The modeling efforts in Phase II will attempt to sort out the absurd associations into sensible causal factors. Sensitivity analyses of Phase II models will identify the wetland components and transfer functions most critical to material fluxes through wetlands. Therefore, Phase I and II will indicate aspects of wetland dynamics that need additional research in order to improve the predictive ability for material fluxes through wetlands.

Long-term and continuous monitoring of material fluxes through selected wetland sites should also be conducted during this phase. Phase I will only provide short-term "snapshots" of material movement through wetlands. Long-term verification and tuning of Phase II models should be performed. One specific question regarding the reported net P export of salt marshes is where the P comes from on a long-term basis; if P is pumped from the sediments on an annual basis; then the marsh must have had a net P accumulation in the past.

Pure research into the fate and effects of pollutants in wetlands, particularly heavy metals and toxic organic compounds, should be sponsored under this phase. The transport pathways and mechanisms of pollutants within wetlands is not directly relevant to assessing wetland values for water quality improvement, but additional knowledge of wetland dynamics enhances predictive capability. The EPA has produced a list of 129 compounds that have been called priority pollutants and is conducting fate and effects studies in aquatic systems; similar studies in wetland systems would compliment this work and further understanding of wetlands and pollutants.

Artificial enrichment of wetlands could be included in the Phase I studies in order to obtain high pollutant loading conditions for all wetland types. Enrichment studies need to be conducted on a long-term basis to determine the long-term effects of pollutant loadings and threshold loading values for natural wetlands. Several such studies are active in the country but more should be initiated, particularly involving heavy metals and toxic organic compounds. Natural wetlands should be utilized in these studies, rather than artificial or altered wetlands, because the wetland regulations primarily pertain to natural wetlands and not to those that are designed for wastewater renovation.

GROUNDWATER RECHARGE

INTRODUCTION

Much has been written and said about the capacity of wetlands to act as groundwater recharge areas, but there has been only preliminary research performed on this function and the data does not support the contention that wetlands, in general, serve as recharge areas.

For this report, groundwater recharge has been defined as the ability of a wetland to supplement groundwater storage through infiltration/percolation of surface-water to the saturated zone. The function may occur on a seasonal or annual basis. Also considered in this section, and closely related to the capacity of wetlands to function as recharge areas, is the capacity of wetlands to augment base flow during periods of low flow. The available information, which is not extensive, suggests that some wetlands, in some specific geologic settings, can function as recharge zones on some occassions. The more general case seems to be that wetlands serve as discharge areas or in the case of perched wetlands, tend to loose more water through evapotranspiration than similar topographic areas that do not have wetland vegetation.

In assessing the value of a wetland to perform the function of groundwater recharge and base flow augmentation, several complications arise. For instance, in cases where a multi-aquifer system with several potentiometric surfaces exists, the wetland may simultaneously serve to remove water from one aquifer while recharging another. More important perhaps is defining groundwater. Wetlands often occur at the interface of surface- and groundwaters. Indeed, there often is no clear line delineating surface-water from groundwater. More often, particularly in topographic and geologic conditions that favor wetland development, the hydrologic properties are not clear cut and are in a state of flux, varying both spatially and seasonally.

THE DATA BASE

The data base for evaluating this functional characteristic of wetlands is punctuated by two factors: it is sparse and what data exists is concentrated in specific geographic areas, notably the north central states, Florida, and New England. The aim of this literature search was to identify studies of specific wetlands that had developed quantifiable data such as water budgets. More general discussions were used as background information, but have not been included in this discussion unless they were found to be extremely useful.

Description of Relevant Literature

The literature search identified 16 publications that related to groundwater recharge by wetlands. Table 2 summarizes relevant information presented in each of these sources. A few equations for infiltration rates were derived, but few observed data exist. Most of the values for recharge

TABLE 2. SUMMARY OF LITERATURE PERTAINING TO GROUNDWATER RECHARGE FUNCTION OF WETLANDS

Reference	Wetland Type	Location	Significant Parameters	Conclusions
Bay (1967)	Forested Peat Bogs	Minnesota	Position of water table within bog	• Due to hydrogeology of the bogs considered, seepage to the underground basin was considered negligible. This assumption is supported by measurements of deep water table which indicated no correlation between bog water table levels and fluctuations in underground basin storage
Black (1973)	Inald Wetlands	Connecticut		• Hundreds of small dams in Connecticut have increased the number of wetlands, the associated biota, and ground water recharge
Boyt, et al. (1977)	Mixed Hardwood Swamp	Florida	Permeability and potentiometric gradient	• Ground water recharge estimated as a function of permeability and potentiometric gradient • V = Ki (units m/yr) Velocity = permeability X potentiometric gradient For study site, V = .001 m/yr or 0.047 percent of total wetland water budget = 0.047 percent total
Heelgy (1973)	Wetlands	General	Soil permeability, slope, saturation	• Wetlands may serve as recharge areas whenever the head of water on a wetland deposit is higher than that of the underlying aquifer
Hickock, et al. (1977)	Lacustrine Marsh	Minnesota		• Water balance equation is developed which includes ground water seepage term. In the case cited, due to local conditions, the term is set to zero
Holzer (19/3)	Inland Wetlands	Connecticut	Permeability	• During flooding, a wetland may reduce the peak flood flow by temporary storage as ground water

TABLE 2 (CONTINUED)

Reference	Wetland Type	Location	Significant Parameters	Conclusions
Holzer (1973) (Continued)				• Recharge may also be induced by heavy pumping from wells adjacent to wetlands
Huber, et al. (1976)	Marshes/Swamps	Florida		• Basin lakes/wetlands serve to maintain a favorable ground water table for water supply during the periods of deficient rainfall
Larson, et al. (1973)	Freshmeadows Shallow Fresh Marshes Deep Fresh Marshes Shrub Swamps Wooded Swamps Bogs	Massachusetts and northeast U.S.	Transmissivity Storage Capacity	• When baseflow of streams out of wetlands is greater than in-flow, there probably is considerable ground water movement and storage beneath the wetlands • The low flat surfaces of wetlands gather runoff from adjacent hills and allow build-up and slow release, thereby reducing peak flood flows • After flooding wetlands may recharge water-bearing formations or aquifiers for several weeks; for an even longer period, wetland water storage augments the low-flow of streams
Mitsch, et al. (1977)	Cypress, Tupelo Floodplain Swamp	S. Illinois	Permeability	• Recharge was a major outflow path of water from a wetland • Ponds hold waters long enough for them to recharge ground water table; also, wetlands are source of baseflow
Novitzki (1978)	Surface Water Slope Surface Water Depression Ground Water Slope Ground Water Depression	Wisconsin		• Impact on recharge depends on type of wetland: 1. Depression types reduce flood peaks and total streamflow in spring, increase ground water recharge, and thereby increase baseflow in fall

TABLE 2 (CONTINUED)

Reference	Wetland Type	Location	Significant Parameters	Conclusions
Novitzki (1978) (Continued)				2. Slope types reduce flood peaks but increase total streamflow in spring, decrease ground water recharge, and thereby reduce baseflow in the fall • Magnitude of recharge by wetlands ranges from 0 to 55 percent of water budget
O'Brien (1977)	Freshwater Swamp	E. Massachusetts		• Ground water flow was the major mechanism of outflow and accounted for 93 percent of total annual discharge from both wetlands studied • Baseflow was depressed at both sites during periods of low-flow • Lack of low-flow augmentation results from rapid ground water discharge from a shallow upper layer of the ground water body
Odum, et al. (1978)	Cypress Swamps/Domes	Florida		• Cypress domes serve, during the rainy season, as dischargers of excess shallow ground water and during the dry season as rechargers to shallow ground water system
Odum, et al. (1976)	Cypress Domes	Florida	Water table level, permeability, water table thickness	• Domes are closely coupled to ground water; they sit high on the water table and water spreads radially outward recharging ground water; as water table falls, hydraulic gradients steepen and infiltration rates increase • Infiltration ranges 10-40 percent of out-flow, depending on season

TABLE 2 (CONTINUED)

Reference	Wetland Type	Location	Significant Parameters	Conclusions
Rykiel (1977)	Swamp	Georgia		• Different calculations of seepage to ground water from swamp yield values in which numbers differed by a factor of 30+. Highest was still less than 10 percent of water budget • Ground water recharge was considered negligible and omitted from water budget calculations
Sander (1976)	Peat Bog	Minnesota		• Bogs do not act as sponges during rains nor do they augment flow during dry periods; instead, they release excess during wet periods and deplete supply during dry months
Wharton, et al. (1977)	Swamp	Florida		• Example discussed: Gordon River Swamp in Naples, Florida, "The GR Swamp passes water slowly from high ground in the north, southward to the estuary .... Because deep aquifiers are salt-laden, water supplies are drawn from superficial aquifiers in sands of former beach ridges near the surface. These sands border the Gordon River Swamp, and the waters of the swamp exchange with waters in the sands, maintaining the water levels with gradual recharge from the swamp... This aquifier has only a year or so storage and is dependent on the regular supply of new water form the swamp each year"

were estimated from water budget studies or by subtraction of observed parameters. The following general conclusions can be made:

- All studies of groundwater recharge by wetlands addressed freshwater systems;

- Wetland types included freshwater swamps (both forested and shrub swamps), inland fresh meadows, marshes, bogs, and cypress domes; Novitzki (1978) described four general wetland types based on hydrologic characteristics;

- Areas covered by the research were the northeastern United States, north central United States, Georgia, and Florida as well as Western Siberia, U.S.S.R.;

- Most researchers agreed that groundwater recharge is a possible function of wetland areas. In practice, however, little or no recharge was attributed to wetland areas. Recharge values typically were less than 10 percent of total output in water budget studies;

- Groundwater recharge is a highly site-specific function, depending on factors such as: height of water table, water storage capacity, soil permeability, wetland slope, and human factors; e.g., amount of well pumping within the vicinity. The recharge potential of a wetland was dependent on its relationship to the aquifer. Three cases were identified in many of the articles: 1) a water table wetland (groundwater discharge); 2) a perched wetland, and 3) an artesian wetland (groundwater discharge). In general, only perched wetlands have the capacity to recharge aquifiers; and

- Opinions on the base flow modification function were divided. Some researchers proposed (Huber, et al., 1976, Larson, et al., 1973, Mitsch, 1977) that wetlands retain water during the wet season and subsequently serve as a source of base flow during dry periods. Novitzki (1978) however, concluded that the degree of base flow modification was dependent on wetland type; slope-type wetlands reduce base flow in the fall while depression types increase it. Another opinion (Sander, 1976) is that bogs do not act as sponges; rather they release excess moisture during wet periods and deplete supply during dry months.

R. R. Bay, (1967) in a study on forested peat bogs in Minnesota, found groundwater recharge from both perched bogs and water table aquifers to be negligible. He attributed this to the relative impermeablility of the peats which underlay the wetlands studied and to the impact of evaportranspiration, capillarity within mosses, and other factors. With regard to base flow, Bay's research indicated that in perched peat bogs and similar wetlands, perennial storage is available to sustain flow during dry periods.

A study conducted by Black (1973) on inland wetlands in Connecticut, however, found that wetlands created from small dams had significantly increased groundwater recharge in severeal areas. The increased recharge was attributed to the combination of increased head that the dams afforded. These conditions were frequently associated with permeable soils. It should be pointed out that these wetlands are not frequently duplicated in a natural setting.

Boyt, et al., (1977) in a study of a mixed hardwood swamp in Florida established a water budget for the swamp. The amount of water infiltrating into the groundwater was established as less than 0.05 percent of the total water entering the system. Infiltration was measured based on permeability, and the potentiometric gradient. The velocity was measured using the following equation.

$$V = ki$$

where:

V = velocity
k = permeability (1.21 ft/y)
i = potentiometric gradient (.00158)

R. W. Heeley (1973), in a report on the wetland hydrogeology of Massachusetts, identified several factors contributing to a wetland's potential for recharging groundwater. Much of the discussion was based on a reconnaissance study of groundwater in northeastern Massachusetts done by Baker, et al., in 1964. Favorable conditions established in this study include:

- Sufficient head;
- Permeable soils and unconsolidated deposits exposed at the surface;
- Low to very low slopes; and
- Materials at the surface which are not saturated.

Generally wetlands are associated with organic (and relatively impermeable) soils and saturated conditions. The implication of the latter is that the wetlands examined in this report functioned as recharge areas on a seasonal basis. In this study, wetlands recharged aquifers only in spring. Over the remainder of the year and for the year as a whole, there was a net loss of groundwater in the water budget through discharge.

Hickok, et al., (1977), found that a small wetland over a glacial aquifer that was hydrologically connected to a lake in Minnesota was a discharge area. The stated purpose of this publication was the "identification and determination of the feasibility of improving the quality of storm water runoff by utilizing natural wetlands. Scientific data required to help justify the protection of natural wetlands were also obtained". Thus, it seems that the authors had a distinctly positive view of wetland functional characteristics. In spite of this perspective, they attributed no value to the wetland for groundwater recharge.

A study by Holzer (1973) on marshes in Connecticut pointed out the impact of man on the hydrologic balance of a wetland. Specifically, he found that excessive extraction of groundwater from wells near a riverine wetland, enhanced the recharge potential of the area. The head of the wetland was increased significantly, resulting in an increased potential for groundwater recharge.

He went on to point out that most wetlands in Connecticut formed either in topographic lows, or in areas that were underlain by nearby impermeable crystalline rock. In either case, the effect was that the wetlands tended to function as areas of groundwater discharge.

Huber, et al. 1976, in a study of marshes and swamps in Florida, Odum in a study of cypress swamps/domes in Florida, and Mitsch in a study in southern Illinois cypress swamps and cypress domes concluded that basin lakes and wetlands can recharge groundwater during dry periods. Huber developed the HLAND model to depict interrelations of precipitation, evaporation, storage, base flow, and groundwater. The function attributed to basin lakes and wetlands is not recharge in the sense of providing a net increase in storage over the course of a water year; rather, it is more of a regulatory function--a thermostat that monitors and controls extremes in precipitation and flow by moderating the time response to both inflow and outflow.

In a study of fresh water wetlands in Massachusetts, New England, and other glacial terrain, Larson (1976) lists useful criteria for evaluating the adequacy of wetlands for groundwater supply. If test wells have been drilled and the geology of the wetland area is known, the following are useful:

- Transmissivity;
- Storage; and
- Quality.

He identifies two general types of wetlands in the study area; a shallow perched zone fed by flooding surface streams and a zone created by the action of artesian groundwater. Larson stated that wetlands are frequently associated in a geographic sense with aquifers that are well suited for development of water supplies, but he does not imply that they necessarily function as recharge areas. Like Odum and Huber, Larson identifies the primary function of a wetland (regarding groundwater) as that of a regulatory or moderating force, storing excess water during periods of high inflow and releasing it during dry periods. Larson, too, recognizes the impact of man on hydrologic regimes. He states that for each wetland/aquifer system, there is a "safe yield". "Safe yield" is defined as "that amount of water that can be pumped without depleting the aquifer or without impairing the quality of the aquifer". He recommends that detailed field investigations be made on a site specific basis to determine potential impacts of extraction on wetlands.

In contrast to the findings of Larson, Mitsch and Huber; O'Brien (1977) found in a study of two specific wetlands in eastern Massachusetts that these wetlands served to exacerbate both low flow and high flow conditions. Based on his investigation, O'Brien found that groundwater flow accounted for 93 percent of the total annual discharge from the wetlands on an annual basis. One of the wetlands served to recharge the aquifer on a temporary basis during an extremely dry period in the late summer and early fall. Significantly, the water table was at the lowest point during this period; this afforded the greatest hydrologic head.

O'Brien's study covers some of the same geography as Larson's, but reaches substantially different conclusions. For example, O'Brien found that groundwater entered the streams rapidly following a rain and contributed significantly to storm crests. The study indicates that a possible reason for this behavior is that horizontal permeability at both sites was greater than vertical permeability and that vertical permeability decreased with depth. These findings agree with studies done by R. R. Bay and Boelter and Verry in the Northern Lake States. The effect of this difference in permeability is to cause rain to move as interflow; e.g., water that infiltrates into the unsaturated zone and moves laterally, usually to a discharge point such as a stream or lake.

In an earlier study by Odum, et al. in 1976, cypress domes in Florida were found to function as recharge zones in many cases. These domes frequently represented high areas of the potentiometric surface and recharge flowed radially from the domes to the aquifer. The study also found that groundwater, in many cases, discharged to the swamps when the swamps were at a low point relative to the surrounding potentiometric surface. The head of the cypress dome was an important factor in determining the extent of recharge occurring; greater recharge accompanied a falling or low water table.

Sanders (1976) conducted a study on a small peat bog in north central Minnesota and constructed an electric analog model to simulate storm effects, bog discharge and recharge behavior, and to predict responses to a variety of conditions. He concluded that the peat bog has no value for recharging groundwater; rather, the bog tended to release excess water during wet periods and deplete available supplies during dry periods. Moreover, predictions of the model, which were verified, indicated that the bog would not augment base flow.

A comprehensive account of the main swamp ecosystems was developed by Wharton, et al. in 1977. Within the study, the Gordon River swamp was cited as an example of a wetland that functioned to recharge an aquifer. Groundwater in the Gordon River system is found in deep aquifers and in shallow, superficial aquifers found in the sands of former beach ridges which lie near the surface. The deeper aquifer is extremely saline and consequently supplies are taken from the shallow aquifer which has only about a one year storage. The sands border the Gordon River swamp and the swamp serves to recharge the aquifer at a relatively gradual rate.

Discussion

It is significant to note that while nearly every researcher acknowledged that groundwater recharge was a possible function of wetlands, in studies utilizing actual field measurements, only one (Odum, 1976) assigned a significant recharge value to the wetland(s) studied. In the case of Odum's study, an important factor in assessing a wetlands capacity to recharge an aquifer was the location of the site on the potentiometric surface. The greater the head, the higher the potential for recharge.

The research showed a disproportionate amount of palustrine wetlands studied. Of these, the studies focused on glacial terrain. Three classifications applying to palustrine and upland wetlands appeared in the literature consistently, particularly relating to peat bogs:

- Water table wetlands include areas where the groundwater table intersects the surface. They are primarily groundwater discharge areas.

- Perched wetlands include wetlands that are underlain by highly organic soils such as peat or extremely fine grained soils such as fine glacial tills or clays. These are frequently hydrologically isolated and receive water from overland flow and in some case, interflow.

- Artesian wetlands occur where a confining layer, such as peat or clay or even consolidated rock is interrupted by a fracture or fissure. Artesian pressure can force the groundwater to the surface where it collects over the impermeable layer forming a bog or swamp. It is a discharge area and has little potential for recharge.

Another factor discussed in several publications, was that soils in upland wetlands frequently showed marked differences in horizontal and vertical permeabilities. In most cases, horizontal permeabilities were found to be significantly higher than vertical permeabilities. Moreover, vertical permeabilites decreased significantly with increasing depths. The result was that precipitation would not reach the water table; rather it would move as interflow until it was discharged to a surface-water body or utilized by plants.

Evapotranspiration played a significant role in the hydrologic regime of wetlands. In several studies, the evapotranspiration was found to equal or approach potential evapotranspiration (PET) as calculated by the Thornwaite method. The implications of this are particularly important in assessing the base flow augmentation function. In most cases, low flow conditions and maximum evapotranspiration rates occur either simultaneously or within a reasonably short time frame. Thus, wetlands frequently use a maximum amount of water through evapotranspiration at the expense of stream flow.

DEVELOPMENT OF CRITERIA

Several factors common to all wetland types must be present for recharge to occur. Most importantly a wetland must have hydraulic head relative to the aquifer. For the general case, this rules out estuarine and marine wetlands as potential sources of groundwater recharge since they occur at or near sea level. However, under some specific conditions, these wetlands may play an important role in recharging or maintaining an aquifer. These conditions will be discussed later in this chapter.

Other factors that are important include:

- Soils - The porosity, permeability, transmissivity, and storage capacity of underlying soils and/or rock. Also, whether the soils are mineral or organic. Predominantly organic soils may not follow Darcy's law, and may have differential permeabilities in the horizontal and vertical direction.
- Wetland Size and Configuration - In general, larger wetlands and wetlands with large edge to surface area ratios have higher potentials for recharge.
- Evapotranspiration Rate - ET can significantly impact the potential of a wetland to recharge groundwater or augment base flow.
- Vegetation - The type, age, and density of vegetation in a wetland influences infiltration, runoff, and ET.
- Climate - The prevailing weather conditions influence ET and availability of water.
- Wet/Dry Cycles - Seasonal or other changes in the water table and in water levels of the wetland enhance the potential for recharge.
- Presence of a Multi-Aquifer System - Several aquifers with varying potentiometric surfaces increase the potential for recharge.
- Water Quality - For some types of wetlands, TDS values may indicate whether recharge is occurring.
- Retention Time - Longer retention times favor recharge for some wetland types.

Other criteria exist; indeed the list is extensive. However, those identified above are the most significant. In the following discussion, these criteria are assessed relative to wetland types.

As stated earlier, estuarine and marine or intertidal wetlands are, in general, discharge areas. Consequently they show little potential for recharge. Moreoever, the waters associated with these systems are saline, or at best, brackish. Thus, they have no value for recharging groundwater, even where the hydraulic gradient and soils foster recharge. An important exception to this is non-tidal freshwater wetlands on barrier islands. In many cases, these serve to recharge shallow freshwater lenses overlying deeper saline water. Even in this instance, much of the precipitation may be lost through evapotranspiration. This same "ponding" of freshwater lenses on denser saline water can also provide locally usable groundwater on near shore environments.

In the discussion that follows, these criteria are applied to the palustrine, riverine, and lacustrine wetlands. For each type of wetland, methodologies useful for evaluating specific sites are developed.

Evaluation of a specific site requires that the criteria identified be applied to the specific site and then evaluated. Table 3 outlines the information required and possible sources of the information.

The approaches developed here are at best preliminary in nature. The extent of research and state of knowledge for this function are not sufficient to justify detailed, quantitative methodologies for wetland evaluation. As a result, the approaches outlined below involve a general assessment of factors. They are not intended to provide definitive answers; rather, they are intended to provide general guidance based on the state-of-the-knowledge.

Palustrine Wetlands

General Criteria--

Palustrine wetlands were the most intensively studied wetland type relative to the groundwater recharge function. The majority of the studies did not identify recharge as a function of palustrine wetlands over the course of an annual water budget; however, in some instances (O'Brien) recharge was observed seasonally for short periods, particularly during the drier times of the year. Relevant criteria for evaluating the effectiveness of palustrine wetlands are presented below.

Soils--Wetland soils are either mineral or organic, and in palustrine wetlands, they are generally impermeable. Typically, upland wetlands develop on finely pulerized glacial tills or drift, clay, or peat. Other factors held equal, recharge potential is highest through course sands or gravels and successively lower in shallow fibric peats, silts, clays, and deep sapric peats.

Hydraulic Head--The hydraulic head of the wetland as stated earlier, is perhaps the single most important factor for groundwater recharge. The literature identified three types of upland wetlands based on hydraulic conditions: 1) water table wetlands, 2) perched wetlands, and 3) artesian wetlands. Artesian and water table wetlands are discharge points for groundwater and generally have little value for recharge. Perched wetlands, on the other hand, correspond to Novitzki's surface-water depression wetlands and

TABLE 3. INFORMATION SOURCES

Required Data	Source
Hydraulic Head	Estimated from well logs in the vicinity; estimated from depth to groundwater maps from USGS or state geological survey offices.
Soils	Field reconnaissance; SCS soil maps; porosity, permeability and transmissivity may be available from USGS, state and local governments, and universities.
Wetland Size and Configuration	Field reconnaissance; USGS 7.5 minute quadrangle maps, rotometers, chartometers.
Evapotranspiration and Climatological Data	Estimated from Thornwaite, Blaney-Criddle, Radiation, Penman, or Evaporation pan methods; and/or use of published NOAA data.
Vegetation	Field reconnaissance.
Water Quality	Sampling and analysis.
Seasonal Wetting Cycles	Observation and interviews with cognizant individuals; meteorologic data from NOAA.
Retention Time/TDS	Observation, Sampling.
Multi Aquifer System	Piezometers; geological investigations.

receive water primarily from overland flow and incident precipitation. These wetlands usually have impermeable bedrock, clay, or peat beneath them. As a result, they are frequently isolated hydrologically from underlying aquifers. However, under some conditions, such as lithologic changes in soil types around wetland edges, reduced evapotranspiration rates, or lowered water tables, recharge may occur.

Closely related to this factor is the presence of a multi-aquifer system. In some cases a local water table aquifer may feed a wetland area. The wetland in turn, may feed a larger regional aquifer. This phenomena has been observed in the Northeast in a number of studies. Again, the critical factor contributing to recharge is that sufficient head exists to stimulate recharge.

Thus, perched wetlands, multi-aquifer systems, depressed water tables, and lithologic changes favor potential recharge. On the other hand, high water tables, artesian or water table wetlands, single potentiometric surfaces, and uniformly impermeable soils discourage recharge.

Water Quality--A factor that may be particularly valuable in evaluating isolated, upland wetlands is water quality. It has been suggested that where recharge is occurring at a significant rate, TDS will be relatively lower than in cases where water is contained for relatively long periods. Stewart and Kantrud in 1972, studied prairie potholes and suggested that TDS in potholes where recharge is occurring was generally less than 500 mg/l; where no recharge was occurring TDS was typically greater than 15,000 mg/l.

Evapotranspiration Rate--The rate of evapotranspiration (ET) is often a critical factor. Actual ET approaches potential ET (PET) in wetlands during the periods when groundwa er levels are lowest, and low flow conditions prevail. ET equal to or nearly equal to PET limits the potential for recharge.

Vegetation--Closely related to ET is the type and density of vegetation present in the wetlands. R. R. Bay and A. A. Molchanon indicated that the rate of ET varies by tree species, vegetable cover, climatic area, density, and stage of development (both seasonal and stand age). Similarly, runoff and infiltration are influenced by vegetation type and density. A study by Molchanon, in the Soviet Union ranked mixed forests, spruce, birch, and pine in decreasing order of interception and transpiration capacities. For tree stands in general, optimum evapotranspiration occurs in stands approximately 30 to 50 years in age and descends thereafter.

Wetland Size and Configuration--The total size and configuration of the wetland, particularly the edge length, are also important determinant factors in groundwater recharge. Since--when recharge does occur--it frequently is concentrated along the edges of the wetland area. Thus, wetlands with a high circumference to surface area ratio have a higher capacity for groundwater recharge. This favors elongated or elliptical wetlands over rounded wetlands.

Procedures and Methodologies for Evaluating Specific Sites--

Table 4 outlines an approach useful in evaluating specific sites. With sufficient data, it is possible to weight the criteria and apply the approach as a "scoring" or quantified judgement system. However, the extent of knowledge does not justify such an approach at this point.

Riverine

General Criteria--

Research on wetlands associated with river systems was not extensive. Three studies by Holzer, Mitsch, and Wharton addressed riverine systems. Of the wetland types, riverine wetlands show the most promise for groundwater recharge. They are subjected to intermittent wetting cycles, they are frequently associated with changes in soil lithologies, and they are often elongated in configurations.

Soils--In broad floodplains, back swamps frequently develop behind point bar deposits. These swamps frequently cover a variety of soil types as they shrink and swell with seasonal changes. Soil deposition associated with developed floodplains can range aerially from fine silts and clays to coarse sands and gravels. These lithologic changes encourage recharge. Moreover, these areas are frequently hydrologically associated with good aquifers.

Hydraulic Head--Streams and even large rivers may alternate between influent and effluent conditions over the course of a single storm event and/or seasonally, depending on the water table elevation. For this reason, it is difficult to identify the utlimate fate of precipitation and channel overflow. A technique that has been used to separate the groundwater component of a storm event in a hydrograph from channel precipitation, runoff, and interflow is hydrograph separation. The technique, developed by Langbein (1978), is only semi-analytical, but takes advantage of a time base characteristic of base flow. The resulting data can be used to assess the magnitude of recharge and identify whether the river is influent or effluent relative to the groundwater. It is important to determine whether the groundwater is flowing into the river. If this is the case, recharge will be transitory in nature and of little value to water supplies over the long-term. If the river or stream is influent, recharge occurring from surrounding wetlands could last significantly longer. In either case, the wetland could have positive hydraulic head relative to the aquifer; however, the relationship of the associated river or stream to the aquifer could serve to neutralize recharge under some conditions.

Floodplain Age--In general, wetlands on a mature, well developed floodplain will have a higher potential for groundwater recharge than those associated with young, immature streams and rivers. Older streams and rivers usually have extensive alluvial depositions, which often function as good aquifers. Moreover, they are associated with more varied lithologies and greater depths to bedrock.

TABLE 4. EVALUATION OF PALUSTRINE WETLANDS -.GROUNDWATER RECHARGE

Criteria	High Potential	Medium	Low Potential
Hydraulic Head	Water table is lowered by draught cycles or excessive groundwater extraction	Perched or multi-aquifer system	Artesian or water table wetland
Soils	Gravel —— Course Sand —— Sand ——	Fibric Peats —— Silts ——	Clays —— Sapric Peats
Wetland Size and Configuration	Circumference to surface area ratio high, elliptical or elongated		Circumference to surface area ratio low; rounded
Evapotranspiration Rate	ET < PET		ET $\simeq$ PET
Vegetation	Sparse vegetation grasses etc.		Mixed hardwood, spruce, fir, dense vegetation
Water Quality	TDS $\leq$ 500 Mg/l		TDS $\geq$ 1500 Mg/l
Seasonal or other Wet/Dry Cycles	Yes, with seasonal and single rainfall events contributing to fluctuations	Predominently seasonal fluctuations	No, constant water level with only slight fluctuation

Frequency of Flooding--Since overbank storage can contribute substantially to groundwater recharge, higher frequency and duration of flooding can enhance the recharge potential of streams and rivers.

Other Criteria--The remaining criteria which have significance for riverine wetlands include wetland size and configuration, vegetation, evapotranspiration rate, and the presence of a multiple aquifer system. These are not discussed separately here since they were discussed under palustrine wetlands and their impact is essentially the same with riverine wetlands.

Procedure and Methodologies for Evaluating Specific Sites--

Table 5 outlines a method that may be used to evaluate the recharge potential of specific sites. As with Tables 4 and 6, the approach should be viewed as preliminary in nature. Nevertheless, it may be useful as a screening tool that can yield qualitative conclusions on groundwater recharge potentials.

Lacustrine Wetlands

General Criteria--

Lakes and associated wetland areas may be classified hydrologically similarly to palustrine wetlands; they are either 1) areas where the topography intercepts the groundwater table resulting in a lake, 2) areas where surface runoff collects and "perches", 3) or areas where artesian pressure penetrates up through a confining layer and collects on the surface. Although similar to palustrine systems, they respond to a number of unique criteria. Important factors include:

- Soils;
- Hydraulic head;
- ET rates;
- Vegetation;
- Lake age;
- Size and configuration of the lake and drainage basin; and
- Frequency and degree of water level fluctuations.

Criteria that are unique to lacustrine wetlands are lake age and size and configuration of the lake and drainage basin. The other factors listed above were discussed under palustrine systems and are similar in function and impact. Consequently, they are not discussed in detail here. An exception is the configuration of the lake edge or shore, which is discussed.

TABLE 5. EVALUATION OF RIVERINE WETLANDS - GROUNDWATER RECHARGE

Criteria	High Potential	Medium Potential	Low Potential
Hydraulic Head	Local river is influent relative to aquifer		Local river is effluent relative to aquifer
Soils	Gravel — Course Sand — Sand —	Fibric Peats — Silts —	Clay — Organic Soils Sapric Peats, etc.
Wetland Size and Configuration	Circumference to surface ratio high; ellipitical or elongated		Circumference to surface area ratio low; rounded
Evapotranspiration Rate	ET $<$ PET		ET $\simeq$ PET
Vegetation	Sparse vegetation		Dense stands
Frequency of Floodplain Innundation	Regular occurrence with large storm events	Occassional	Almost never
Floodplain Age	Mature well developed floodplain, with buried ox-bow lakes, etc.		Young stream channel with relatively high flow velocities

Lake Age: The age of the lake determines the nature of sediments within it. Younger lakes have sandy or rocky bottoms with less deposition c. organics. Thus, other factors being equal, wetland areas associated with younger lakes have a higher potential for recharge.

Size and Configuration of Lake and Wetland Area: Lake bottoms are often covered with sediments, and as a result are frequently nearly impermeable. Both wetlands and recharge are a function of shore development. An equation that is used to calculate shore development is:

$$SD = \frac{L}{2\sqrt{\pi A}}$$

where:

SD = Shoreline development
L = Length of the shoreline
A = Lake area

Using this expression, a perfectly round lake would have a value of 1. Irregular lakes would have higher values and higher capacities for recharge. The length of the shore can easily be obtained by using a mechanical map measurer such as a rotomer, or chartometer in conjunction with an accurate large-scale map.

Procedures and Methodologies for Evaluating Specific Sites--

Table 6 details a generalized approach for evaluating specific sites relative to their potential for groundwater recharge.

RESEARCH NEEDS

The research needs identified below are oriented towards enabling researchers and planners to predict the behavior of various types of wetlands to dredge and fill operations and other man induced impacts. The same problems and needs identified in Chapter 1, Water Quality, are present for the groundwater recharge function; the existing data base is inconsistent, incomparable, and incomplete. What is needed is a comprehensive nationwide study, conducted by a single entity on the relationship of groundwater to wetlands. It is not currently possible to identify specific methodologies for assessing the potential of wetland types or individual wetlands for groundwater recharge.

To accomplish this goal, research efforts should be focused in the following areas:

- Development of standardized methods for defining water budgets; these sampling and testing procedures should be easily applied and

TABLE 6. EVALUATION OF LACUSTRINE WETLANDS - GROUNDWATER RECHARGE

Criteria	High Potential	Medium Potential	Low Potential
Hydraulic Head		Lake is "perched" or multiaquifer system is present	Lake is coincident with groundwater table
Soils	Gravel —— Course Sand —— Sand ——	Fibric Peats —— Silts ——	Clay —— Sapric Peats
Lake and Wetland Size Configuration	SL >>1		SL $\simeq$ 1
Evapotranspiration Rate	ET << PET		ET $\simeq$ PET
Vegetation	Sparse		Thick stands; dense
Lake Age	Young lake		Older lake bed
Frequency and Degree of Water Level Fluctuations	Frequent	Occassional	Seldom
Size and Topography of Drainage Basin	Large basin, deep slopes		Small basin; gentle slopes
Origin of Lake Basin	Solution basin (karst lakes, etc.)	Glacial basins, stream action (ox-bow lakes, fluviatile dams)	Tectonic basins; volcanic basins

yield accurate, meaningful data. Subsequently, a nationwide collection of data using the standardized methodologies should be conducted.

- Based on the results of initial studies, refinement or development of a wetland classification system that meaningfully represents the hydrologic characteristics of wetland behavior.

- Use of the classification system and study data to refine existing models and develop new models and methodologies that allow accurate predictions of wetland responses to construction activities.

- Further studies to provide empirical data that will allow confirmation of the accuracy of the predictive models and methods.

- Revision and refinement of the models based on data from long-range studies.

These needs can be accomplished and integrated within a three-phased approach as outlined in Chapter 1, Water Quality. Indeed, the research requirements for shoreline protection, stormwater storage, and groundwater recharge are all similar and can best be accomplished in an integrated research program. The three phases outlined in Chapter 1 include:

- Phase I - Nationwide Survey;

- Phase II - Development of Model and Verification; and

- Phase III - Detailed and Long-Term Field Studies.

Phase I - Development Of A Nationwide Data Base On Hydrologic Properties of Wetlands

Due to the random nature of previous investigations, the existing data base on wetland hydrology does not allow development of methodologies for evaluating wetlands. Phase I would develop a systematized cohesive investigatory approach that would produce meaningful corelative data. Phase I requires three tasks;

- Task I - Development of standardized sampling and testing methodologies;

- Task II - Selection of sites for investigation that would permit statistically defensible data collection; and

- Task III - Data collection.

Task I - Development of Standardized Sampling and Testing Methods--

Development of standardized test methods is required if any kind of nationwide systematic evaluation of wetlands is to occur. Over the course of the literature review, it became obvious that one source of contradictory conclusions was the use of different methods in data acquisition. Evapotranspiration, for example, is commonly estimated using one of five methods (Thornwaite, Blaney-Criddle, Radiation, Modified Penman, or Evaporation pan). The methods, when applied to a single site will yield considerably different results. Moreover, the accuracy of one technique over another varies based on type of data available, climate, and region. The Thornwaite method, for example was developed for humid conditions in the east central United States. Because of its relative simplicity, however, it has been used in areas for which it is not well suited. In the arid Southwest, the Thornwaite method results in substantial under-prediction of ET rates. Thus, guidance on using methods for estimating evapotranspiration is needed, as well as some analysis of the sensitivity of the estimates to factors such as climate, latitude, duration of testing and other factors.

An effective methodology for measuring infiltration and movement of water in organic soils is also necessary. Application of traditional tools (such as Darcy's Law) which were developed in mineral soils have not often yielded accurate, reliable results in organic soils.

A standardized water year should be utilized so that water budgets can be meaningfully evaluated and compared. In establishing water budgets, the approach followed thus far has been to use the following equation, or some variation of it:

$$P + SWI + GWI = ET + SWO + GWO + \Delta S$$

where:

P = Precipitation
SWI = Surface water inflow
GWI = Groundwater inflow
ET = Evapotranspiration
SWO = Surface water outflow
GWO = Groundwater outflow
ΔS = Change in storage

Determination of each of the individual water budget components may not be simple and there are errors associated with each. Moreover, each may be measured by one of several methods; with each methodology yielding different values. Perhaps the greatest source of error, however, lies in the selection of one (or more) of the variables as the residual factor(s) in the equation. Typically, the groundwater component is selected as the residual in the equation. As a result, errors in estimates of precipitation, evapotranspiration, and streamflow, as well as non-channelized surface flow, are often included in the groundwater term.

The above represents some of the problems relative to standardized testing and data aquisition procedures. Others exist: the equipment used, the placement of observation wells and testing equipment, and similar factors are all sources of potential inconsistencies.

Task II - Site Selection, Identification--

A preliminary estimation of the number, type and location of various wetlands required for an adequate data base should be developed. An existing classification system that adequately delineates wetlands by hydrologic characteristics could be used initially. Novitzki's classification system developed for wetlands in Wisconsin could be extended to apply to wetlands in general.

Following this, candidate sites should be selected for intensive, simultaneous investigation. The number of sites selected, as well as the number of each wetland type and its region, climate, and size should be sufficiently representative to provide statistically valid data.

Task III - Data Collection--

When standardized methodologies have been developed for data aquisition, and the sites have been identified, observation and data collection can begin. The aim of this task is to compile an extensive data base to be used in wetland management. To the maximum extent possible, data collection activities should occur simultaneously; i.e., the water year investigated should be a standardized year for all sites. In addition, the investigations should be under the supervision of a single entity, although the actual task of observation and data collection could be conducted by various groups, providing sampling and testing protocals are clearly defined.

Phase II - Development/Refinement of Models, Field Verification

The purpose of this phase would be to develop or refine predictive models. These models will provide a framework in which available data can be integrated, new hypotheses tested and revised, and alternative management strategies evaluated. The phase involves two tasks; 1) development or refinement of models, and 2) field verification of the models.

Task I - Development and Refinement of Models--

This task will use the data from Phase I and existing models as a base for developing accurate predictive models for wetlands. Existing models follow one of three approaches:

- Analysis of wetlands as part of a larger system, such as a drainage basin;

- Modeling of the individual wetland; and

- Modeling of an individual component process, or processes within a wetland.

The three approaches complement one another in many cases. The thrust of this task would be to identify significant components of hydrologic phenomena in wetlands, define parameters, establish boundary conditions, and subsequently to develop and calibrate predictive models.

Task II - Verification--

Verification of these models would require selection of additional sites, and subsequent sampling and observation to verify the validity of the models.

Phase III - Detailed, Long-Term Field Studies

The aim of this phase will be to resolve data gaps and inconsistencies resulting from the Phase I investigation, and to identify long-term, life cycle behavior of wetlands relative to groundwater recharge. In addition, this data could be used to further "fine tune" predictive models and testing and sampling methodologies. Another area that would require intensive, long-term investigations is the impact of basin development outside the wetland itself on the wetland. The impacts of paving recharge areas, excessive groundwater extraction, and flood control activities would all require extensive, long-term testing.

In sum, the most productive approach for wetland study relative to groundwater recharge would utilize a major study effort that was funded and administered by a single agency. The program should examine the entire hydrologic regime, since examination of a single component such as recharge becomes meaningless without an understanding of the entire process. Further, the program should follow a three-phased approach; data collection, development of predictive models, and long-term studies aimed at refining the data base.

STORM AND FLOOD WATER STORAGE

INTRODUCTION

The storm and flood water storage function of wetlands has been defined in this study as the interception and detention of flood and storm water flows by wetlands systems. Temporary storage of storm or flood waters, which otherwise would contribute to open-channel flow, serves to modify flow and reduce the damage potential of flood or storm waters, primarily through reduction of peak flows. Many wetlands may be important for water storage and flow retardation during periods of flooding but there is little evidence to support that contention at this point.

On the other hand, a Federal Interagency Task Force prepared a report on the status of our wetlands in 1978. That report, entitled "Our Nation's Wetlands" was coordinated by the U.S. Council on Environmental Quality. It states, "Only in the past decade or so has the role of wetlands as storm buffers been understood. A flood may be less destructive when marshes and swamps slow velocity and desynchronize peaks of tributary streams as the waters flow through their impeding vegetation and into the main stream. Their action reduces the flood peak along the main stream although it may lengthen duration of the flood".

The importance of the link between floods and wetlands is emphasized by the findings of the Water Resources Council. In its Second National Water Assessment, "The Nation's Water Resources, 1975-2000", the Council identifies flooding and wet-soils drainage and wetlands as critical water and related land problems. The Water Resources Council points out that the 74 million acres of wetlands in the United States not only provide habitat for fish and wildlife but also can retain flood water and trap pollutants.

In spite of these assertions, there has been little evidence from studies to support these contentions. While there is little doubt that <u>some</u> wetlands have the capacity to limit flood damage in some cases, the findings of specific studies are not indicating that the funciton is ubiquitous.

DATA BASE

Limited previous research has been conducted to demonstrate the effects that wetlands have in terms of flood water storage. Publications identified during the literature search contained some reference to the storm and flood water storage function of wetlands, but the need for detailed, quantitative studies remains.

Description of Relevant Literature

Sixteen publications were found during the literature search that contained some reference to the storm and flood water storage function of wetlands. Little substantive information and no quantitative data were contained in these studies. Table 7 displays summary information from the 16

TABLE 7. SUMMARY OF LITERATURE PERTAINING TO STORM AND FLOOD WATER STORAGE FUNCTION OF WETLANDS

Reference	Wetland Type	Location	Significant Parameters	Conclusions
Bay (1967)	Forested Peat Bogs (Spruce and Aspen)	Minnesota	Permeability water table Water elevation Peat type Storm characteristics	• Position of the water table within a bog determines the storage capacity at any given time • Bogs are not effective for long term storage; however, low peak flows indicate bog effectiveness as storage areas for storm runoff, particularly when bog water tables are low • Data are presented for water level response to high and low intensity rainfall in two bogs and change related to to peat type
Boelter and Verry (1978)	Freshwater Peatlands	North U.S.	Physical characteristics of peat soil saturation	• Floods are not a function of the kind of basin; perched or groundwater. Rather, they are affected by watershed size, the amount of water in the snowpack, the rate of snowmelt, infiltration characteristics of the soil, and percentage of peatland in a watershed • Storage capacity depends greatly on the level of the water table on peat profile • Peatlands may draw out recession curves on hydrograph
Bulavko (1971)	Marsh	U.S.S.R.	Hydrophysical properties peat	• Marsh drainage network increase runoff and may increase river flow up to 30 percent
Craig and Day (1977)	Salt and Freshwater Marshes	Coastal Louisiana		• Salt marshes act as storm buffers by absorbing wave energy and providing a reservoir for stormwater storage
Gagliana, et al. (1975)	Deltaic River Plain	Louisiana		• Floodplain/wetlands are important as natural floodways and ought to be preserved

TABLE 7 (CONTINUED)

Reference	Wetland Type	Location	Significant Parameters	Conclusions
Holzer (1973)	Inland Wetlands	Connecticut	Bedrock permeability	• During flooding, the direction of groundwater flow in a wetland or floodplain may reduce the peak flood flow by storing flood water temporarily as groundwater
Huber, et al. (1976)	Marshes, Swamps	Florida		• Basin lakes can "provide floodwater storage to reduce the rates of runoff to the river as well as to conserve floodwaters and maintain a favorable groundwater table for water supply during the periods of deficient rainfall"
Kadlec (1976)	Peatland	Michigan	Precipitation (p), evapotranspiration (e), water level in peatland	• General equations for water balance and storage were developed. The storage equation considers only precipitation and evapotranspiration rates: $h = \frac{dh}{dt} = p-e$
Larson, et al. (1976)	Freshwater Riverine	Massachusetts		• Floodplains have a "high" flood control potential as compared to dam construction • Wetland preservation for flood control yields annual benefit of $80/acre-year
Larson, et al. (1973)	Freshwater Riverine	Massachusetts and New England		• Flood stages increase following encroachment on wetlands • Wetland losses of over 25 percent are likely to result in significant flood damage • Loss of 10 percent wetland flood storage causes stage increase of 1.5 feet; loss of 50 percent, a 3 feet increase

TABLE 7 (CONTINUED)

Reference	Wetland Type	Location	Significant Parameters	Conclusions
Novitzki (1?78)	Surface Water Depression Surface Water Slope Groundwater Depression Groundwater Slope	Wisconsin	Wetland type; i.e., depression versus slope	• Depression type wetlands reduce flood peaks and total stream flow in spring and increase recharge and baseflow in fall. Slope type wetlands do opposite; increase peaks and runoff in spring and decrease recharge and baseflow in fall • Flood peak reduction up to 80 percent where wetlands cover 40 percent of basin; 50 percent of flood peak reduction is accounted for by the first 5 percent of wetlands in basin
O'Brien (1977)	Freshwater Swamp	Massachusetts		• Wetlands within the regional aquifier act as discharge zones; following a rain, groundwater discharges rapidly to streams aided by high density of drainage channels within the wetlands • Groundwater drainage was 93 percent of the total annual discharge
Sander (1976)	Peat Bog	Minnesota		• Bogs do not act as sponges during rains and do not augment flow during dry periods. Instead, they release excess during wet periods and deplete supply during dry months
Shabman, et al. (1979)	Estuarine wetlands	Virginia		• Flood storage can be accomplished in one of three ways; 1) the sponge effect of peat, 2) reduction in flood velocity, and 3) acting as a reservoir • In the wetlands studied, the first two mechanisms were not in evidence. Moreover, wetlands showed no advantage over othr flat topographies in functioning as a reservcir

TABLE 7 (CONTINUED)

Reference	Wetland Type	Location	Significant Parameters	Conclusions
Wharton, et al. (1977)	Swamps, Strands, Marshes	Florida		• Floodplain and vegetation are storage areas during flood flows and protect shoreline from excessive erosion by flood • Swamp ponds and strands are superior to reservoirs as means of holding storm waters long enough for ground water recharge to take place

documents. The following observations can be made about the information base for this wetland function:

- Most of the studies dealt with swamps and marshes (both salt and freshwater); three addressed peatlands; one categorized all wetlands into four basic types and discussed the attributes of each;

- Relevant research was conducted primarily in the northeastern and north central United States, but additional studies were done in Louisiana, Florida and the U.S.S.R;

- Most discussions were general and focused on wetland types and their typically associated vegetation, although one report specifically analyzed a forested peat bog and one, a cypress-type floodplain swamp;

- Some authors concluded that wetlands act as temporary storage areas which serve to reduce flood peaks and, thereby, lessen stormwater damage potential; others found that wetland areas did not contribute to flood storage more effectively than similar topographic areas and, two researchers believed that wetlands actually increase flows;

- The water storage capacity of wetlands was generally considered to be a function of the physical characteristics of the underlying materials and the level of the groundwater table at the time of a storm;

- Floodplain storage was analyzed relative to comparable dam storage (Larson, et al., 1976) and an annual benefit of $80/acre-year was assigned to wetland preservation for flood control;

- Two investigations (Novitzki, 1978; Larson, et al., 1973) related percentage of wetland in a drainage basin to flood stage and concluded that 5 percent of a basin in wetlands can reduce flood peaks up to 50 percent; that 80 percent reduction may be obtained where wetlands cover 40 percent or more of a basin; and that a loss of 25 percent of wetlands is likely to result in significant flood damage; and

- Hydrological studies were made by the U.S. Army Corps of Engineers, New England Division, to determine how flood waters were distributed in the upper, middle, and lower reaches of the Charles River Watershed in Massachusetts. Investigators found that wetlands in these areas were acting as natural controls to retain flood waters. Storm water was effectively stored in the numerous wetland areas and released so gradually into the main channels of the river that damage was held to a minimum for some distance downstream.

Discussion

Relatively little data were found on the storm and flood water storage function of wetlands. The opinion is generally held that wetlands do serve a function in temporary storage of flood waters and thereby reduce storm water damage potential. Investigators felt that this was true under most circumstances; however, Sander (1976) expressed the opinion that wetlands in fact release excess moisture during wet periods and deplete water supply during dry months, and O'Brien (1977) concluded that groundwater discharge from two small wetland basins contributed significantly to storm crests.

Among the authors who felt wetlands do serve a positive function, storage capacity was attributed to a number of factors including, percentage of wetland area within the drainage basin, physical characteristics of wetland (i.e., slope or depression type), underlying substrata permeability, storm characteristics, and water table level at the time of a storm.

The actual value of a given wetland in terms of flood protection was quantified by two researchers. Larson, et al., (1976) compared flood control potential of floodplains to dam construction and derived a benefit value of $80/acre-year for floodplains. Larson, et al., (1973) concluded that a loss of more than 25 percent of wetlands in a drainage basin is likely to result in significant flood damage by increasing flood stage 1.5-3.0 feet. Novitzki (1978) concluded that a 50 percent flood peak reduction is accounted for by the first 5 percent of lakes and wetlands in the basin and that flood peak reduction of up to 80 percent may be obtained where wetlands cover 40 percent of a drainage basin.

In its study of the Charles River Basin the Corps of Engineers estimated the annual flood control benefits of the Natural Valley Storage Plan at $1,203,000. This is the difference between estimated annual flood damages based on present land use and conditions, including extensive wetlands, and an estimate of those damages which would occur with the projected loss of 30 percent of valley storage by 1990.

Any evaluation of the impact of wetland alteration on flooding should take into consideration alternative land uses. For example, studies have indicated that wetlands encroachment resulted in an increase in flooding. The implication is that the wetlands afforded protection against flooding. However, increased flooding is a natural consequence of much development. Large areas are frequently black topped, storm drainage systems installed, and existing tributary streams culverted. The impact is to synchronize and speed storm impacts, thereby increasing flood stages.

Current opinions on the value of wetlands for storm and flood water storage are mixed. However, recent studies indicate that their value has been overstated. Indeed, a recent study (Shabman and Batie, 1979) found that wetlands offered no significant advantage for flood and storm water storage over open fields, or forested areas. Nevertheless, there is evidence that under some circumstances, some wetlands may reduce flood impacts. The following section discusses criteria that will influence a estuarine wetland's ability to perform this function.

It should be noted that there is widespread recognition of the lack of accurate data and the need for extensive data collection and analyses related to the flood storage capabilities of wetlands. Thus, the conclusions presented in the following section should be viewed with scepticism. They do not represent facts, rather they are a compilation of current opinion, based on research performed to date.

DEVELOPMENT OF CRITERIA

Available reports were examined to identify those factors which affect the flood storage capabilities of the various types of wetlands. Special attention was given to any measurements of the degree of effectiveness in providing flood storage. The following factors were identified:

- Area - total wetland and percentage of drainage area in wetland;
- Water table - the level of water on or under the wetland at the time a storm occurs;
- Soils - permeability and water holding capability of various soil combinations;
- Precipitation - intensity and duration; and
- Topography - flatness or slope of wetland.

Marine Wetlands

General Criteria--

One of the functions of intertidal lands is to serve as a natural barrier against hurricanes and storm floods. On one hand, marine wetlands constitute a natural equilbrium surface which will not change its topography too drastically, even during severe coastal storms. On the other hand, coastal wetlands are, by their nature, low lying and act as reservoirs which receive storm-induced high waters and release them slowly as the storm recedes.

According to Craig and Day, salt marshes act as an important buffer, absorbing the energy from the waves created by strong winds and providing a water reservoir for storm waters. This was demonstrated in a study by Teal and Teal (1969) off the coast of England. In 1953, a severe storm along the coast of Lincolnshire caused considerable damage. Most beaches and shoreline structures were destroyed. However, the areas lying landward of salt marshes suffered little damage. Lefor (1973) suggests that the loss of life and the destruction of property along the southwestern coast of Connecticut from the storm of June 18-19, 1972 might have been less if the tidal marshes in these areas had not been filled.

On the other hand, in a more recent study of wetlands in and near the Chesapeake Bay, Shabman, et al., (1979) found no evidence that wetlands perform this function, they state, "marine wetlands provide protection from coastal flooding to adjoining land parcels in the sense that any open area between housing and the ocean provides flood protection. However, it is not the wetlands in their natural state that provides that protection, since a filled wetland would also protect neighboring parcels from flood damage as would a parking lot, an open field, or a forested area".

Another type of marine wetland, the "overwash mangrove island", they provide shore protection. Overwash mangrove islands are abundant in the Ten Thousand Islands of south Florida and the south coast of Puerto Rico. During periods of rough seas, the dense red mangrove prop roots and the multiplicity of islands in a given bay dissipate wave energy.

These coastal wetlands are quite distinct from other wetlands. They are a buffer between open ocean and shore. They would appear to provide shore protection similar to that provided by reefs or barrier islands.

Again, although the capacity of a wetland to perform this function has not been verified, certain factors increase the probability that a particular wetland may perform this function. These factors are discussed below.

Location--The wetland should be adjacent to low-lying shoreline developments that are susceptible to damage from a surge or high wave action.

Size--Larger wetlands, or several smaller wetlands in combination, have greater capacity for minimizing flooding. Shape and configuration also impact on the ability of a wetland to control flooding; wetlands with greater breadth are more effective than narrow wetlands of the same area.

Permeability--Unsaturated, permeable soils contribute to storage.

Slope--A long shallow slope extending seaward would appear to have a greater effect in dissipating wave or surge energy than a sharp dropoff.

Roughness--Wetlands covered with plant growth or with rocky bottoms have more impact on storm crests and tidal influences.

Procedures and Methodologies--

Without considerable additional research only a simple decision tree approach is possible. Table 8 outlines a general methodology for evaluating specific marine wetlands and identifying flood and damage reduction potential.

Estuarine Wetlands

General Criteria--

As with marine wetlands, studies have indicated that estuarine wetlands also function as natural barriers against hurricane and storm floods. These coastal wetlands control flooding by acting as reservoirs which receive storm-induced high waters and release them slowly as the storm recedes. However, it is not clear that wetlands provide an advantage over other similar topographies. In short, the reservoir effect of wetlands has been observed in flat, unvegetated topographies.

TABLE 8. EVALUATION OF MARINE WETLANDS - STORM AND FLOOD WATER STORAGE

Criteria	High Potential	Medium	Low Potential
Proximity to developed area	Adjacent to or immediately offshore from developed areas; developed area at low elevation.	Adjacent to or immediately offshore from developed areas; developed areas at higher elevation than wetland.	Little or no development near wetland; or developed area at much greater elevation.
Depth of inundated wetland area	Shallow for more than 1/2 mile, undulating topography.	Shallow for more than 1/2 mile, level topography or, shallow for less than 1/2 mile.	Level topography; shallow for less than 1/2 mile.
Density and type of vegetation	Vegetation density >30% primarilly woody vegetation.	Vegetation density >30% primarily non-woody emergents.	Vegetation <30%; or vegetation primarily submergent and floating leaved species.
Soils and percent saturated	Highly permeable soils, not frequently saturated; gravels, sands, sandy loams.	Silty loams, silt; saturated on a seasonal basis.	Clay, peat; permanently saturated.

According to Carter, et al., flooding in tidal rivers and estuaries is complicated by the action of wind and tide combined with stormflows generated higher in the basin. Temporary storage of flood water may be a primary function of wetlands adjacent to estuaries and tidal rivers, but their storage effect may be either minimized or maximized by the tidal stage during flooding.

Wharton et al. (1977), state that coastal mangrove swamps, bottled with tidal and river exchanges, hold the lands, protect against hurricanes, and provide nutrition for fisheries and wildlife.

Most investigators felt that an important factor governing an estuarine wetland's ability to control flooding was the permeability and percent saturation of the soil. Highly permeable soils in an unsaturated condition were found to store water, either by groundwater recharge or interflow or both. However, wetlands are frequently expressions of discharge areas associated with regional or local (perched) aquifers and thus are often saturated. In addition, they are most often associated with relatively impermeable organic soils or clays. Indeed, some investigators contend that wetlands excerbate flooding by saturating surface soils and thereby limiting the storage capacity.

Nevertheless, some factors do increase the probability for marine wetlands to limit the impact of flooding. The following criteria are applicable to the flood storage and damage reduction capability of estuarine wetlands.

<u>Location</u>--The wetlands should be located between potential damage areas and the river or sea sources of floods. The adjacent property should be subject to flooding and have a high development value.

<u>Size</u>--Larger areas will have higher potentials for stormwater storage for a given discharge.

<u>Permeability and Water Table Elevation</u>--Dry or partially dry, highly permeable soils permit temporary storage as groundwater or interflow. However, where soils are permanently saturated the storage capacity is neutralized.

<u>Slope</u>--A long shallow slope away from land toward the estuary would appear to offer more opportunity for storage and wave and surge protection than an abrupt drop-off to deeper water.

<u>Roughness</u>--Dense stands of vegetation may desynchronize flood peaks and reduce flood impacts.

Procedures and Methodologies--

As with the marine wetlands, only a simple procedural system can be applied to screening estuarine wetlands for flood storage and damage reduction potential. Table 9 outlines the approach.

TABLE 9. EVALUATION OF ESTUARINE WETLANDS - STORM AND FLOOD WATER STORAGE

Criteria	High Potential	Medium	Low Potential
Location	Adjacent to or immediately offshore from developed areas; developed area at low elevation.	Adjacent to or immediately offshore from developed areas; developed areas at higher elevation than wetland.	Little or no development near wetland; or developed area at much greater elevation.
Size	>40% of basin in wetlands	5 to 40% of basin in wetlands	<5% of basin in wetlands
Permeability and percent saturation	Vegetation density >30% primarily woody vegetation.	Vegetation density >30% primarily non-woody emergents.	Vegetation <30%; or vegetation primarily submergent and floating leaved species.
Vegetation/Roughness	Highly permeable soils, not frequently saturated; gravels, sands, sandy loams.	Silty loams, silt; saturated on a seasonal basis.	Clay, peat; permanently saturated.
Slope	Long shallow slope toward estuary		Steep dropoff to deep water

Riverine Wetlands

General Criteria--

Wetlands linked hydrologically to river systems are thought to be important for water storage and flow retardation during periods of flood or storm discharge.

Some investigators claim that vegetated floodplains offer considerable protection against downstream flooding and siltation.

However, Shabman (1979) found that once flood waters exceeded the height of vegetation, the vegetation did not significantly reduce the velocity of flood waters. Thus, forested wetlands would seem to be most effective, while marsh grass, etc. would provide only limited protection. River and creek swamps have the capacity to absorb heavy rains, releasing waters gradually but not holding them so long that trees and other plant life are killed. The ability of a wetland to absorb rains is dependent to a large extent on the permeability of the soils and the percent saturation.

The Okefenokee serves as a large headwater swamp which stores flood water and contributes moderate stream discharge for long durations. When peak periods of high water are retarded, the mangrove forest becomes a storage basin adding considerable buffering to such events as floods and hurricane-induced storms. In the cypress stands, vegetation can grow in the river bed, further slowing water flow and spreading it over an even wider area.

Joseph S. Larson in reporting on a study of the Neponset River Basin in Massachusetts states that a loss of 10 percent of wetland flood storage results in a flood stage increase of 1.5 feet for the 100-year flood. If 50 percent of the wetland flood storage is lost, flood stage increases to 3 feet. These increases are considered very significant if a wide flood plain is affected. Larson also reported that the Corps of Engineers' study of the Charles River Basin indicates that a 40 percent reduction of the basin wetlands would result in an increase in flood stages of 2 to 4 feet for a flood similar to that experienced in 1968.

In a later report, Larson bases an estimate of the value of Charles River Basin wetlands on the Corps of Engineers study. The benefits from preserving wetlands with high flood control potential average about $80/acre-year. Using a 5.375 capitalization rate, he estimates their per acre value at $1,488.

Army engineers estimate that upstream areas of the Charles River Basin temporarily stored 50,000 acre-feet of flood water, the equivalent of an average Corps reservoir in New England, during a 1968 storm. The last of this volume reached downstream areas 1 month after the storm.

Larson states, "Wetlands which lie along or in developed floodplains of slow moving streams can be considered as possessing high value for flood control benefits".

Larson bases his conclusions in part on the impact of wetland alteration on flooding; in short on observed phenomena; e.g., wetland alteration results in increased flooding. It should be noted that most alteration and development of other parts of the drainage basin also results in increased flooding. Thus, it may be that the increased flooding results not from the abscence of wetlands, but from the nature of alteration. This is an important area for investigation. Trends in flood behavior relative to various cultural/land use characteristics shoud be identified in order to identify the impact of wetlands on flood behavior.

Criteria that are applicable to the flood storage and damage reduction capability of riverine wetlands are listed below. These should be viewed as tentative. Much of the data used to arrive at these conclusions needs to be verified. Moreover, the studies to date have not been unanamous in assigning any value to wetlands for this function.

<u>Location</u>--Wetlands that are situated upstream from developed floodplains and that are adjacent to or in stream channels may contribute to reducing flood impacts. Also, wetlands located along tributary streams and rivers appear to store flood waters.

<u>Size</u>--Wetlands should constitute a relatively large portion of the drainage basin, although as little area as 5 percent of the total in wetlands may significantly affect flood peaks.

<u>Permeability Percent Saturation</u>--Highly permeable soils with deep or fluctuating water tables provide higher storage capabilities, and thus greater potential for stormwater storage through groundwater recharge and or interflow.

<u>Slope</u>--Where the slope of the wetland is less than that of the river, flood waters may be delayed and desynchronized.

<u>Roughness</u>--Dense vegetation and undulating topography reduce velocity of flood waters.

Procedures and Methodologies--

The following simple procedural system is proposed for screening riverine wetlands as potential areas for flood water storage and damage reduction (see Table 10).

<u>Lacustrine Wetlands</u>

General Criteria--

Lacustrine wetlands appear to have a role in protecting lakeshore property similar to the role of marine and estuarine wetlands in protecting coastal property. In particular, wetlands associated with lakes that have influent and effluent streams, can markedly reduce storm crests.

TABLE 10. EVALUATION OF RIVERINE WETLANDS - STORM AND FLOOD WATER STORAGE

Criteria	High Potential	Medium	Low Potential
Location	Wetlands along tributary streams or upstream from developed areas.		Wetlands primarily downstream from developed area.
Size	>40% of basin in wetlands	5 to 40% of basin in wetlands	<5% of basin in wetlands
Soils and Permeability	Vegetation density >30% primarily woody vegetation.	Vegetation density >30% primarily non-woody emergents.	Vegetation <30%; or vegetation primarily submergent and floating leaved species.
Vegetation/Roughness	Highly permeable soils, not frequently saturated; gravels, sands, sandy loams.	Silty loams, silt, saturated on a seasonal basis.	Clay, peat; permanently saturated.
Slope	Wetland slope much less than river bed.		Wetland slope approaching that of river.

Persistent, strong wind lengthwise of a lake, piles water up and initiates rocking of the water body, causing waves known as seiches. Seiches achieve heights of less than 3 feet on most of the Great Lakes but on Lake Erie an 8.4 foot seiche at Buffalo is on record. Seiches occasionally do considerable damage to marshes and lakeshore property by inundation and wave action.

Lacustrine wetlands receive water from lake flooding and this water can drain back into the lake as the lake level is reduced.

Flood control is provided by forested swamps which surround many of the lakes in Florida.

Criteria that can be applied to determine the potential of lacustrine wetlands to protect lakeshore property from flood damages are listed below.

Location--Wetlands located adjacent to low-lying developed shore property that are subject to wind driven waves or seiches can limit the impact of floods. Also, wetlands located along a stream or river channel can store and desynchronize flood peaks.

Size--The wetlands should constitute a large enough area to reasonably act as a barrier to the waves and seiches.

Permeability--Highly permeable soils, and deep or fluctuating water tables provide storage and thereby reduce flood potentials.

Slope--A gentle slope away from the developed property toward the source of flood flows reduces flooding potential.

Roughness--A wetland covered with dense undergrowth or undulating topography has a greater impact on flooding than a relatively open, flat area.

Procedures and Methodology--

A simple procedure for screening lacustrine wetlands as to their flood damage reduction potential follows in Table 11.

Palustrine Wetlands

General Criteria--

Palustrine wetlands provide flood storage to the extent of their basin capacity and control outflow of these waters through underlying soils to the extent of their permeability. Much of this water is consumed by evapotranspiration and does not enter a stream system. They are important flood storage areas if the alternative is to drain them, because they then contribute directly to the stream system and flood flows.

Criteria for evaluation of flood storage and damage reduction effects of palustrine wetlands are somewhat different than for other wetlands.

TABLE 11. EVALUATION OF LACUSTRINE WETLANDS - STORM AND FLOOD WATER STORAGE

Criteria	High Potential	Medium	Low Potential
Location	Adjacent to or immediately offshore from developed areas; developed area at low elevation.	Adjacent to or immediately offshore from developed areas; developed areas at higher elevation than wetland.	Little or no development near wetland; or developed area at much greater elevation.
Size	Wide, large wetlands; relative to maximum fetch.		Wetland is small or narrow relative to maximum fetch.
Permeability	Vegetation density >30% primarily woody-vegetation.	Vegetation density >30% primarily non-woody emergents.	Vegetation <30%; or vegetation primarily submergent and floating leaved species.
Slope	Long shallow slope toward estuary		Steep dropoff to deep water
Soils and Permeability	Highly permeable soils, not frequently saturated; gravels, sands, sandy loams.	Silty loams, silt, saturated on a seasonal basis.	Clay, peat; permanently saturated.

Location--Wetlands located in the upstream area of a system having a highly developed downstream floodplain will reduce flood impacts.

Size--Although palustrine wetlands are individually small, the cumulative size of all the wetlands in a basin can be significant. Where the total constitutes a significant part of the drainage area of the basin, these wetlands can store flood waters and, through evapotranspirtation, interflow, and to a lesser extent groundwater recharge, limit the impact of a storm event.

Permeability--Underlying soils that are relatively permeable and wetlands which are usually dry and well-drained prior to flood season reduce flooding.

Slope--Not applicable.

Roughness--Not applicable.

Procedures and Methodologies--

The role of palustrine wetlands resembles that of a reservoir, as contrasted with the overland flow retention of other wetlands. Criteria for screening palustrine wetlands is somewhat different than those for other wetlands. It has not been determined whether these wetlands offer any advantage for this function over other similar areas. Studies indicate that the value of vegetation and wetlands in general may have been over estimated and that the reservoir effect can be found in other open areas. Table 12 outlines a general approach that can be used to evaluate palustine wetlands.

RESEARCH NEEDS

The comprehensive research program outlined in the previous chapter, Groundwater, was meant to pertain to this chapter. The aim of the program is to obtain data on the total hydrologic cycle; including surface and groundwater relationships, responses to storm events, the various influences of vegetation on the hydrologic regime and other factors.

As a result of a seminar series in 1979 concerning Emerging Issues in Wetland/Floodplain Management, the Water Resources Council identified a gap in research between water program management agencies and basic research agencies. Several priority research items are not being addressed because they are too management oriented to be funded by basic research agencies and too basic to be funded by program management agencies.

The priority research items which are not currently being adequately addressed because they fall between basic research and management oriented research have been identified by the Water Resources Council, as follows:

- Wetland/Flooding Interrelationships - Investigations should include wetland/flood storage values, relationships of wetlands to regulatory floodways, importance of wetlands in reduction of coastal storm damages, and the effects of pothole drainage and diking of areas,

TABLE 12. EVALUATION OF PALUSTRINE WETLANDS - STORM AND FLOOD WATER STORAGE

Criteria	High Potential	Medium	Low Potential
Location	Adjacent to or immediately offshore from developed areas; developed area at low elevation.	Adjacent to or immediately offshore from developed areas; developed areas at higher elevation than wetland.	Little or no development near wetland; or developed area at much greater elevation.
Size	Cumulative size of wetlands in drainage basin >4%.	Cumulative size of wetlands in drainage basin >5 to 40%.	Cumulative size of wetlands in drainage basin <5%.
Permeability	Vegetation density >30% primarily woody vegetation.	Vegetation density >30% primarily non-woody emergents.	Vegetation <30%; or vegetation primarily submergent and floating leaved species.

etc. The implications of changes both on and off of floodplains and wetlands should be further investigated;

- Wetland and floodplain/pollution control interrelationships;

- Wetland and floodplain/groundwater recharge and water quantity interrelationships;

- Spatial interrelationships of wetlands and floodplains, including the relationship of these areas to broader systems;

- Rapid and inexpensive techniques for assessing wetland and floodplain values and hazards, including the suitability of areas to particular uses and their sensitivity to uses;

- Improved techniques for evaluating short-term and long-term project impacts and impacts of uses such as agriculture;

- Improved technology for wetland and floodplain mapping and other data gathering and forestry;

- Improved techniques for dealing with existing uses in floodplain areas; and

- Evaluation of wetlands and floodplain management techniques in the context of national resource needs, such as minimizing energy use and minimizing the number of capital-intensive resource uses.

Priority research specifically relating to flood storage and discussed at the Council seminar included:

- Additional studies to determine the important of wetlands as flood storage areas, flood conveyance areas, and retardants to storm surge or wave action (coastal areas). Buildings upon the work of Novitzki, Carter, and others, these studies would include both an evaluation of the hazard reduction potential for particular types of wetlands and the development of rapid field techniques for estimating the importance of specific wetlands. Techniques for estimating individual and cumulative importance and the impact of uses should also be developed.

- Studies to compare various wetland definitions with various frequencies of flooding. Although it does not appear practical to define wetlands in relationship to the 100 year floodplain, it may be possible to use 1 or 2 year flood boundaries. Conversely, wetland vegetation might be used, in some instances, as a reliable indicator of flooding at that frequency.

- A specific research need for functional area is identification of roughness coefficients of vegetation as related to species, stand density, and morphology. Manning's n (the roughness coefficient) should be determined for different vegetation types. More research is needed on the measurement and hydraulics of sheet flow and its effect upon the development of peatlands and the distribution of peatland vegetation.

SHORELINE PROTECTION

INTRODUCTION

Shoreline protection function of wetlands has been defined in this study as the shielding by wetlands of natural shorelines, coasts, and channels from wave action, erosion, or storm damage, through dissipation of wave energy and storm surges. Protection may be proffered through vegetational cover, areal extent, fetch, offshore topography and/or related human activities, and development.

Many of the factors contributing to shoreline protection are not unique characteristics of wetlands. Areal extent and favorable topographies can be found in non-wetland areas.

This function is potentially most significant among wetlands fringing high energy exposed shorelines and coasts but may also be significant in large lakes and riverine environments. A distinction between shoreline erosion control and hurricane/storm protection of inland areas has not been made in the Corps' regulations or in this literature search; both aspects of shoreline protection have been included in this potential function of wetlands.

DATA BASE

Description of Relevant Literature

Eighteen publications which addressed the shoreline protection function of wetlands were identified and reviewed. Table 13 displays a summary of these documents. Virtually no relevant quantitative information was reported, only qualitative discussion. Inspection of Table 13 leads to the following observations:

- Of the 18 articles, 16 were directed to salt water systems, and two discussed both salt and freshwater marshes;
- Wetland areas examined included salt and freshwater marshes, a mangrove swamp, bays, estuaries, and lagoons;
- The bulk of research was centered throughout the southern Atlantic Coast of the U.S. with additional studies from the Bahamas, Hawaii, the Great Lakes, and the Western Pacific region;
- The two major vegetation types discussed were salt marsh grasses and mangroves. In both cases, effectiveness of the plants for shoreline protection was attributed to the combined actions of the root systems in stabilizing sediments and the aerial parts in forming a mass which serves to dissipate wave energy; and
- There was some conflict of opinion over the effectiveness of the mangrove for shoreline protection; some researchers (Carlton, 1974)

TABLE 13. SUMMARY OF LITERATURE PERTAINING TO SHORELINE PROTECTION FUNCTION OF WETLANDS

Reference	Wetland Type	Location	Significant Parameters	Conclusions
American Water Resources Association (1976)	Estuarine Marshes	Chesapeake Bay		• Need a management program to preserve wetlands for shore erosion control
Bellis, et al. (1975)	Estuary	North Carolina	Bank height and composition, vegetative cover, wind exposure, fetch, offshore topography, human activity	• Natural shoreline protection is provided by cypress bulkheads and offshore shoals, both of which are products of the erosion process
Camfield (1977)	Marsh	General	Fetch length, density of vegetation	• Wave decay over a flooded area is a function of factors including bottom roughness, friction factors are derived for a number of surface coverings, including marsh grasses
Carlton (1974)	Mangrove	Florida Western Pacific Indo-Africa		• Ability of mangroves to protect open coastlines from erosion was questioned because (1) there is some evidence that they root only on accreting coasts, and (2) they also seem only to affect rates of erosion or deposition rather than direction • They can be useful stabilizers of substrates in conjunction with planned filling and seawall construction
Clark (1977)	Coastal Wetlands, Swamps, Marshes	Eastern U.S.		• Wetlands in general can stabilize estuarine shorelines and prevent erosion • Planting of marsh vegetation can be a successful means of shoreline protection
Craig and Day (1977)	Salt and Freshwater Marshes	Coastal Louisiana	Substrate type, erosive forces/currents	• Salt marshes act as important storm buffers, absorbing wave energy and acting as natural protective "breakwaters"

TABLE 13 (CONTINUED)

Reference	Wetland Type	Location	Significant Parameters	Conclusions
Craig and Day (1977) (Continued)				• Marsh and island-protected coasts suffer comparatively little damage even in fierce hurricanes
Dodd and Webb (1975)	Low-lying Salt Marshes	Texas	Wave impact	• Natural establishment of vegetation is prevented by wave action • Planting of various species reduces erosion
Environmental Quality Lab, Inc. (1977)	General	General		• Using vegetation to stabilize shoreline or banks is an alternative to structural solution
Garbish (1977)	Salt and Freshwater Marshes	Maryland	Width of marsh area	• Rate of erosion control by wetlands is a function of: marsh width; its efficiency in trapping sand; fraction of sand in bank, bank height; and the vertical distance between elevation of the top of the bank and that of the man storm high water
Garbish, et al. (1975)	Salt Marshes	Chesapeake Bay Region	Width of vegetated area; ability of vegetation to entrap sediment; shore elevation and reduction of wave energetics	• Marsh creation for erosion control is feasible if a graded shore is available or can be created • Success of erosion abatement is dependent on the listed parameters • Stabilization time depends on slopes, sediment type and aerial dimensions
Gosselink, Odum and Pope (1974)	Coastal Marshes	Atlantic Gulf Coast		• The importance of salt marsh as a storm buffer; i.e., absorbing wave energy and preventing erosion, is a significant but non-quantifiable function

TABLE 13 (CONTINUED)

Reference	Wetland Type	Location	Significant Parameters	Conclusions
Hall, et al. (1975)	Coastal Wetlands	Great Lakes	Wave Energy	• Plants alone are not a sufficient means of erosion control due to high level of wave activity, but are useful in conjunction with artificial barriers
Knutson (1976)	Salt Marshes	General	Transplant or tidal inundation, salinity, and wave climate	• Plants are effective in erosion control in protected coastal areas • Effective because (1) root system stabilizes sediments; and (2) aerial parts dissipate wave energy
Shabman, et al.	Coastal Marshes	Virginia		• Wetlands erode at the same rate as fastlands when exposed to similar winds, tides, currents and storms • Wetlands exist in areas with low erosion potentials. Thus, the observed phenomena of wetland areas not eroding actensively is a function of location, not of protective mechanisms associated with wetlands
Scoffin (1970)	Lagoon	Bahamas		• Discussion of plant role is sediment stabilization; author cites others who have "observed the ability of marine grasses to reduce current strength locally and trap sediment that may otherwise not have been deposited"
Teas (1977)	Mangrove	Florida Hawaii	Wave Energy	• Mangroves are a successful erosion control system; however, they are only truly effective in areas not subject to excessive wave, current, or boat-wake energy

TABLE 13 (CONTINUED)

Reference	Wetland Type	Location	Significant Parameters	Conclusions
Wayne (1975)	Coastal Marshes	Florida	Width of marsh, density of grasses	• Marsh and sea grasses reduce wave energy and can significantly change sediment distribution patterns by formation of a layer of higher viscosity which slows the net drift velocity of water and induces sedimentation within the bed • The percent of wave height reduction is species and density dependent as is the efficiency of binding and stabilization • Wave energy reduction values of 3.3-4.6 percent per meter of grass were reported
Woodhouse, et al. (1976)	Salt	North Carolina		• Erosion control by marshes was evidenced by accelerated shoreline loss after marsh removal for a construction project • Marsh was successfully re-established in one growing season along exposed shoreline

suggested that they affect only the rate of erosion or deposition rather than direction, while others (Teas, 1977) cited examples of successful erosion control through planting.

Discussion

The majority of the information reviewed described shoreline protection functions on marine and estuarine wetlands. Very little of the data dealt with riverine wetlands or lacustrine and palustrine wetlands. Palustrine wetlands do not have enough fetch to support the type of wave action that could contribute to shoreline erosion.

Little quantitative data were found that related to the shoreline protection function of wetlands. The bulk of information focused on man-made protective structures; however, repeated reference was made to the effectiveness of wetland vegetation in absorbing wave energy, in acting as a storm buffer, and in stabilizing sediments against erosion.

The success of shoreline protection through wetlands vegetation was seen as being dependent on a number of factors including bank height and composition, and wave, current, or boat-wake energy. The general tenor of the literature reviewed was that in many cases erosion control through vegetation establishment compared with equivalent costs and environmental impacts of man-made protective structures.

Shabman and Batie (1979) could find no evidence that wetlands provided any more protection than fastland. Their findings did indicate, however, that wetlands occur in areas with low erosion potentials. They go on to state that this may explain the common observation that where wetlands exist, there is often little erosion. However, they state, this is not because wetlands provide superior erosion protection, but rather they exist where erosion forces are minimal.

There is a general lack of quantitative data--especially for the palustrine and lacustrine and, to a lesser degree, riverine wetlands. Moreover, some investigators could fined no evidence that wetlands provided erosion protection. Because of the lack of data, ranking of wetland types, criteria development, and development of specific methodologies and approches must rely to a greater extent on the reviewer/evaluator's subjective judgment.

Wave action is one of the primary forces which cause erosion. Waves can be propagated from normal tidal action, the wind, storm surge, and boat wakes. Obviously, the larger the waves, the more energy they contain. When the waves break up in shallow water or against the land, they release their energy. This release causes turbulence which in turn erodes or tends to erode the soil. The mechanics of wave action have been well-documented in the literature.

Currents in streams, rivers, estuaries, and coastal waters are another cause of erosion. Velocities great enough to scour away soil are common.

The conditions which create these scouring velocities may be present continuously or only in high energy situations such as during storms or spring run-off.

The above two factors represent the cause of the majority of erosion, although other factors cause small amounts of erosion in and near wetlands.

DEVELOPMENT OF CRITERIA

Evaluation of wetlands can best be accomplished by evaluating the specific criteria which affect their capability to provide shoreline protection. Many of these criteria are common to all types of wetlands. Each of the criteria will be discussed in this section. In addition, sources of information that can be useful in developing data for the various criteria are also discussed.

Existing Conditions--One of the first steps in evaluating wetlands is to determine the existing conditions with respect to erosion. Erosion of the wetland and/or adjacent area will be an indication of the wetland's present role. Absence of erosion could indicate two conditions. The first would be that high energy conditions are not occurring and therefore not causing erosion. The second condition could be that the wetland is effectively preventing erosion, even though erosion conditions are occurring. In any event, evaluation of other factors and criteria will be necessary. However, this information will impact the manner in which additional data will be obtained.

Aerial photographs can be used extensively to delineate boundaries of wetlands as well as defining areas where erosion may be occurring. These aerial photographs can be obtained at county or town offices, the U.S. Geological Survey, the Soil Conservation Service, and in some instances, the Coastal Zone Management Division of State Planning Offices. Following review of the photographs, on-site inspections should be undertaken to determine whether erosion has occurred. Local extension offices as well as the Soil Conservation Service can be used to provide this service.

In conjunction with this and other criteria, the climatological data should be analyzed. This will indicate the frequency and intensity of storms, which will be a general indicator of flooding (high energy) conditions. At the same time, the U.S. Coast Guard, the Corps of Engineers, and local meteorological agencies can provide data on flood levels.

Extent and Type of Vegetation--Once the area of the wetland has been defined, an attempt should be made to characterize the wetland with respect to the types of vegetation present and the area covered by each. The broad types of vegetation to be concerned with are:

- Shrubs and arboreal species;
- Non-woody emergents; and
- Submergents and floating leaved species.

The relative percentage of each type of vegetation will indicate, on a broad level, the amount of protection available. Trees and shrubs will produce significant reductions in wave air current energy, while submergents will have little impact. Obviously, a highly vegetated area will provide more protection than a sparsely vegetated area.

Information on the extent and type of vegetation may be obtained by on-site inspections by qualified personnel from local universities and appropriate state and federal agencies. Actual extent and density of the various types of vegetation can be determined by field checks and use of aerial photography. Maps and overlays can be developed to show the relationship between vegetation types and their locations.

Soil Type--Soil texture and structure affect the rate of erosion. In general, erosion is least in areas with clay and organic soils and increases with silts, loams, and sands. Soil data is available from SCS soil maps, local extensions of the SCS and local universities.

Frequency of Inundation--Erosive conditions are almost always present during periods of flooding. The frequency of flooding will be a measure of the real or potential damage. A wetland which is inundated frequently but is experiencing little or no erosion may be providing a valuable service. A wetland which is eroding under similar circumstances may also be performing a valuable service--especially if one considers the damage that might occur to surrounding areas if the wetland were removed. A wetland which is rarely if ever flooded is not as valuable as one which is.

As mentioned previously, the frequency of inundation can be determined by obtaining records from the U.S. Coast Guard, the U.S. Geological Survey, the Corps of Engineers, and local universities. In addition, floodplain mapping may be available.

Location and Elevation of the Wetland--The location and elevation of a wetland relative to water bodies with erosive power are important factors in erosion control. Specifically, the bank height and the vertical distance between the elevation of the top of the bank and that of the mean storm high water determine the extent of erosion control afforded. Greater elevations tend to minimize offsite erosion. The slope of the wetland basin also may contribute to the control of erosion, with greater slopes affording more protection.

The location, elevation, and slope of wetlands can be determined from 7.5 minute topographic quadrangle maps available from USGS or through visual inspection.

Fetch--Fetch is defined as the distance over which wind can be directed across an open body of water unimpeded. Wave action is a function of this distance. Larger distances (fetches) create larger waves which in turn have higher potential erosive energy. Correspondingly, shorter fetches drive smaller waves which have less energy. A wetland located in an area with a high fetch is potentially more valuable than one located in a short fetch.

Again, by using aerial photographs, and/or large scale maps (such as 7.5 minute quadrangles) fetch can be determined easily. Climatological data, particularly a wind rose, can indicate wind direction frequencies and areas most susceptible to wind action.

Bottom Roughness--Wave decay over flooded areas is determined to a large extent by bottom roughness. Uneven topography, extensive vegetation, and other frictional factors can contribute to dampening wave energy, and thus limit the erosive power of wave actions on near shore areas.

Bottom roughness may not be readily apparent. It is best determined by on-site inspection. If the wetland is only intermittently flooded, it may be discernible from USGS topographic maps or aerial photographs.

Cultural Development--Another factor which must be considered is the value of the property which a wetland protects. That value is a function of the population density, the type of development, and the assessed value of buildings and land. A wetland protecting a highly developed area will be potentially more valuable than a wetland protecting rural land. This criteria will, by nature, be highly subjective.

Housing densities can be determined from aerial photographs, zoning maps, assessor's maps, or actual field checks. Property value can be determined from the assessor's records as well.

To determine the relative value of the five types of wetlands, we must look at a number of determinant factors such as:

- The frequency with which high energy situations occur and affect a given wetland type;
- The relative role which the various wetland types play in preventing erosion; and
- The impact to adjacent properties if erosion occurs.

A summary of the results of the evaluation is shown in tabular form (Table 14). A review of that table shows that marine and estuarine wetlands are the most valuable. Riverine wetlands are the next most valuable. Lacustrine and palustrine wetlands are the least valuable.

Procedures and Methodologies

The data base does not permit development of specific assessment methodologies for the various types of wetlands individually. However, a general division between wave erosion (most prevalent in lacustrine, estuarine and marine systems) and flood-induced erosion (most frequently associated with the riverine wetlands) is possible. Accordingly, Tables 15 and 16 present methods appropriate for evaluating these wetlands.

TABLE 15. EVALUATION OF EROSION CONTROL, MARINE, ESTUARINE AND LACUSTRINE WETLANDS

Criteria	High Potential	Medium Potential	Low Potential
Existing Conditions	No erosion occurring; flooding frequent	No erosion occurring; flooding not frequent	Erosion occurs frequently
Extent and Type of Vegetation	Dense, 80-100 percent coverage; Shrubs and Arboreal	Moderate, 30-80 percent coverage; Non-Woody Emergents	Light, 0-30 percent coverage; Submergent and Floating leaved species
Fetch	5 or more miles	1 to 5 miles	Less than 5 miles
Soil Type (Bank and Wetland)	Well sorted clay or organic soils	Silts Loams	Poorly sorted sands
Location and Elevation of Wetlands	Low to water levels; intertidal range	High water levels on edge of marsh	Hydrologically isolated systems
Bottom Roughness	Undulating surface topography; significant slope	Moderately undulating topography; some slope	Relatively smooth topography; limited slope
Frequency of Inundation	70 percent or more	30 to 70 percent	Never to 30 percent
Cultural Value	Urban environment; building density high; property values high	1) high property values; low density; 2) high density low property values; 3) moderate value and density	Low density; low property values

TABLE 16. EVALUATION OF EROSION CONTROL, RIVERINE SYSTEMS

Criteria	High Potential	Medium Potential	Low Potential
Existing Conditions	No erosion occurring; flooding frequent	No erosion occurring; flooding not frequent	Erosion occurs frequently
Extent and type of vegetation	Dense, 80-100 percent coverage Shrubs and Arboreal	Moderate, 30-80 percent coverage Non-woody emergents	Light, 0-30 percent coverage Submergent and floating-leaved species
Frequency of Inundation	>50 percent of the time	20 to 50 percent of the time	>20 percent of the time
Soil Type	Well sorted clay gravel	Silts Loam	Sand Poorly sorted sands
Location/Elevation of Wetland	Bank height exceeds elevation of mean storm high water	Bank height approximately equals mean storm high water	Bank height is less than mean storm high water
Cultural Value	Urban environment; building density high; property values high	1) high property values; low density; 2) high density low property values; 3) moderate value and density	Low density; low property values

Any attempt to reduce the subjectiveness of the evaluation process is difficult without more data. The limited amounts of research for this function of wetlands precludes any attempt at quantifying the evaluation process. Again, intuitive engineering judgement must be relied upon.

Evaluation of a wetland for shoreline protection by the above methods will enable an evaluator to come up with a qualitative judgement. With experience and further research, ultimate determinations of relative value will reflect actual conditions.

RESEARCH NEEDS

Obviously, the state-of-the-art of quantifying the nature and extent of shoreline protection offered by wetlands is not well advanced. Very little actual quantitative information exists. Information that could be developed to help with this evaluation procedure would include:

- Investigation of wetlands to obtain the relationship of frequency and intensity of flooding, to the extent of fetch;
- Investigation of wetlands to obtain the relationship between erosion occurrence and the density of vegetation;
- Investigation of wetlands to determine the relationship between erosion occurrence and the extent of flooding relative to the cross section of the wetland; and
- Investigation of wetlands to establish relationships between the occurrence of erosion and the frequency of flooding.

The areas of investigation should be performed for all five types of wetlands with emphasis on marine, estuarine, and riverine types.

Again the research and findings should be integrated into the total hydrologic regire. Thus, efforts for this function should compliment research performed for the other functional areas. Moreover, areas of overlap, such as analysis of vegetation distribution within wetland types, should be conducted without repetition. This approach would be facilitated by a single sponsoring agency as part of a carefully planned and administered research program.

SUMMARY AND CONCLUSIONS

The purpose of this study was to develop procedures and methodologies that could be used to assess the value of wetlands in performing four functions: water quality improvement; groundwater recharge; flood water storage; and shoreline protection. The procedures and methodologies were to be used by U.S. Army Corps of Engineers district offices in conjunction with permitting activities under Section 404 of the Clean Water Act.

Existing studies were reviewed, and based on this data factors that contributed to a wetland's ability to perform the indicated function were identified. The literature search was exhaustive, employing an extensive review of journals, research projects in progress, texts, and other publications. The tools employed included computerized data bases, containing 5.3 million literature citations. Of these, 1,400 met the selection criteria and abstracts of these were screened for relevance to the subject functions. More than 300 references remained, and the most relevant of these were reviewed in detail to identify factors and criteria considered useful for assessing the four functional characteristics of wetlands. Based on these factors, criteria were identified to assist in assessing various types of wetlands relative to the functional areas. Procedures and methodologies that could be used to apply these criteria to specific sites were then developed.

Research in the field to date has not resulted in an large data base. Indeed, data were limited; often contradictory or incomparable; and--in the main--qualitative. Thus, many of the criteria presented in this study are based on qualitative data and subjective interpretations of data. The impact of each factor and the relative weight assigned to these factors were delineated based on scientific and engineering judgement.

Finally, for each functional area, research needs were identified. In general, the programs required were broad-based and comprehensive, since research to date has been spotty.

The results of the investigation are summarized below.

WATER QUALITY IMPROVEMENT

The investigation focused on identifying those publications which contained either data on the net exchange of materials between wetlands and their receiving waters or data on input-output studies. The literature identified two distinct facets of water quality improvement: the first was direct improvement of ambient water quality, and the second was water quality maintenance which included improvement of contributing water such as storm water or wastewater.

A total of 34 studies were identified. Of these studies, the majority were conducted along the Atlantic Coast, in the northern mid-west states, and Louisiana. Nitrogen and phosphorus were the most commonly measured parameters in the studies, and the natural flux studies focused on riverine, lacustrine, and palustrine wetlands. Several problems limited the usefulness of the existing data base:

- The data base was small relative to the geographical distribution and diversity of wetland types;
- Experimental approaches and measured parameters varied among the studies;
- Where studies were comparable, results were contradictory in some cases; and
- Investigator bias often influenced the definition of what constituted water quality improvement and the interpretation of results.

The investigation showed that in some conditions water quality was improved by wetlands; the investigation found no consistent trend indicating that one type of wetland contributed to the water quality improvement function more effectively than other wetland types. This was a result of both the limitations of the data base and the influence of site-specific variables.

Criteria

The following factors were identified as having an impact on water quality improvement:

- Type of Vegetation - vegetation has the capacity to assimilate potential pollutants. High aboveground biomass for an individual species, high plant stem density, high percentage of woody plants, and high proportions of epiphytic and edaphic plants favor pollutant removal. Wetlands with lower percentages of these plants have a relatively lower potential for water quality improvement.
- Wetland Size and Subareas - total size and edge length are important criteria. Larger wetlands and wetlands with large edge to surface area ratios have higher potentials for water quality improvement.
- Water Residence Time and Velocity - wetlands that afford longer residence times for influent water have higher capacities for pollutant removal. Similarly, lower velocities permit greater removal efficiencies.
- Hydraulic Loading - although hydraulic load and pollutant removal efficiency are inversely proportional, higher hydraulic loading permits greater improvement for wetlands having an equal capacity for water quality improvement.
- Wetland Location - proximity to existing sources of pollution determines the relative value of a wetland for water quality improvement.

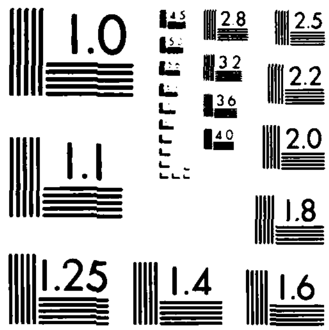
AD-A149 377 ANALYSIS OF SELECTED FUNCTIONAL CHARACTERISTICS OF WETLANDS(U) SCS ENGINEERS RESTON VA J ATCHESON ET AL. FEB 79 DACW72-78-R-0017 2/2

UNCLASSIFIED F/G 8/8 NL

END

FILMED

DTIC


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

Research Needs

The report outlines a comprehensive 3-phased research program that details required areas of research. A research program which was aimed at filling in research gaps was rejected since it was felt that the existing data base was not sufficient to support such an approach. Accordingly, a comprehensive program designed to provide sufficient data to develop, calibrate, and verify predictive models that could be used by the Corps (and other concerned agencies) in permitting and managing wetlands was developed. The program should be carried out by a single agency in order to ensure uniform testing and analysis and development of a meaningful, comparable data base.

GROUNDWATER RECHARGE

The literature review focused on studies that provided water budgets for individual wetlands. Other generally useful literature was also identified, and 16 publications were selected for in-depth analysis. Conclusions were contradictory, although the general findings indicated that recharge was not a common function of wetlands; rather, it was found that under some specific circumstances, and/or on a temporary or seasonal basis, wetlands could recharge groundwater.

Criteria

The following criteria were identified as having an impact on groundwater recharge by wetlands:

- Soils - the porosity, permeability, transmissivity, and storage capacity of underlying soils and/or rock. Also, whether the soils are mineral or organic. Predominantly organic soils may not follow Darcy's law, and may have differential permeabilities in the horizontal and vertical direction. Recharge potential is highest in sands and gravels, and progressively lower in loams, fibric peats, silts, clays, and sapric peats.

- Wetland Size and Configuration - in general, larger wetlands and wetlands with large edge to surface area ratios have higher potentials for recharge.

- Evapotranspiration Rate - ET can significantly impact the potential of a wetland to recharge groundwater or augment base flow. As ET approaches potential ET, groundwater recharge and base-flow augmentation potential are reduced.

- Vegetation - the type, age, and density of vegetation in a wetland influences infiltration, runoff, and ET. Dense vegetation and high proportions of woody plants inhibit recharge.

- Wet/Dry Cycles - seasonal or other changes in the water table and in water levels of the wetland enhance the potential for recharge by increasing hydraulic head.

- Presence of a Multi-Aquifer System - several aquifers with varying potentiometric surfaces increase the potential for recharge by increasing head.

- Water Quality - for some types of wetlands, TDS values may indicate whether recharge is occurring.

- Retention Time - longer retention times favor recharge for some wetland types.

These criteria were then applied to each type of wetland. In general, marine and estuarine wetlands were identified as discharge areas and consequently contributed little to recharge. Riverine, palustrine and lacustrine wetlands were recognized as having some potential for recharge. A preliminary methodology for determining the potential of a specific wetland site for recharging groundwater was developed.

Research Needs

A comprehensive research program similar to the one developed for water quality improvement was recommended. It utilized a three-phased approach that included initial data aquisition; development and refinement of predictive models; and detailed, long-term studies for model verification.

STORM AND FLOOD WATER STORAGE FUNCTION

The storm and flood water storage function of wetlands has been defined in this study as the interception and detention of flood and storm water flows by wetland systems. Temporary storage of storm or flood waters, which otherwise would contribute to open-channel flow, moderates flow quantities and reduces the damage potential of flood or storm waters, primarily through reduction of overland flow velocities.

Sixteen publications were found during the literature search that contained some reference to the storm and flood water storage function of wetlands. Little substantive information and no quantitative data were contained in these studies. The following observations can be made about the information base for this wetland function:

- Most of the 16 studies dealt with swamps and marshes (both salt and freshwater); three addressed peatlands; one categorized all wetlands into four basic types and discussed the attributes of each;

- Research was conducted primarily in the northeastern and north central United States, additional studies were done in Louisiana, Florida and the U.S.S.R.;

- Most discussions were general and focused on wetland types and their typically associated vegetation, although one report specifically analyzed a forested peat bog and one analyzed a cypress-type floodplain swamp;

- Some authors concluded that wetlands act as temporary storage areas which reduce flood peaks and, thereby, lessen storm water damage potential; however, two researchers believed that wetlands actually increase flood flows because of their extensive drainage networks; other investigators found that wetlands had no advantage over fastland;

- The water storage capacity of wetlands was generally considered to be a function of the physical characteristics of the underlying materials and the level of the groundwater table at the time of a storm;

- Floodplain storage was compared to comparable dam storage and an annual benefit of $80/acre-year was assigned to wetland preservation for flood control; and

- Two investigations related percentage of wetland in a drainage basin to flood stage and concluded that 5 percent of wetlands in a basin can reduce flood peaks up to 50 percent; that 80 percent reduction may be obtained where wetlands cover 40 percent or more of a basin; and that a loss of 25 percent of wetlands is likely to result in significant flood damage.

Development of Criteria

The following criteria contributing to a wetlands ability to desynchronize flood peaks and limit damage follow:

- Area - total area and percent of drainage area in wetlands; 40 percent of a basin in wetlands can provide an 80 percent reduction in flood peaks;

- Soils and Water Table - water level at the time of storm; where permeable soils and low water tables are present, recharge or interflow can temporarily store storm water;

- Vegetation - dense vegetation may desynchronize flood peaks;

- Roughness - undulating topography reduces velocity of flood waters; and

- Topography - long slopes and steep grades may dampen wave energy and storm surges.

Available data was not sufficient to permit a ranking of the general wetland types. Intuitively, however, riverine, marine, and estuarine wetlands can all significantly contribute to this function, while palustrine and lacustrine wetlands have the least value.

The criteria were applied to each wetland type and subsequently procedures and methodologies applicable to specific sites were developed for each wetland type.

SHORELINE PROTECTION

The shoreline protection function of wetlands was defined for this study as the shielding by wetlands of natural shorelines, coasts, and channels from wave action, erosion, or storm damages through dissipation of wave energy and storm surges.

Eighteen publications which addressed shoreline protection were reviewed. Of these, 16 were directed to salt water systems and two addressed both salt and freshwater marshes. Although the aim of the search was to identify quantitative data, none of the publications contained quantitative data. Discussions were qualitative in nature.

- Wetland areas examined included salt and freshwater marshes, a mangrove swamp, bays, estuaries, and lagoons;

- The bulk of research was centered throughout the southern Atlantic Coast of the U.S. with additional studies from the Bahamas, Hawaii, the Great Lakes and the Western Pacific region;

- The two major vegetation types discussed were salt marsh grasses and mangroves. In both cases, effectiveness of the plants for shoreline protection was attributed to the combined actions of the root systems in stabilizing sediments and the aerial parts in forming a mass which serves to dissipate wave energy; and

- There was some conflict of opinion over the effectiveness of wetlands for shoreline protection; some researchers suggested that they affect only the rate of erosion or deposition rather than direction, while others cited examples of successful erosion control through planting, and still others found that wetlands offered no advantage over fastlands for this function.

Criteria

In developing criteria for this function, the first factor considered was the existing condition; e.g., was erosion occurring presently? When erosion was not evident, two interpretations were possible: 1) high energy conditions were present, but the wetland was providing protection; or 2) erosive conditions were not present. When erosion was evident, the role of the wetland in minimizing the extent of erosion was important, but to a lesser degree. Having considered the existing conditions, the following criteria were considered:

- Extent and Type of Vegetation - shoreline protection is favored by dense vegetation, shrubs, and arboreal species. Non-woody emergents and submergents provide successively less protection.

- Soils - in general, erosion protection is highest in clays and organic soils, and decreases with silts, loams, and sands.

- Frequency of Inundation - wetlands that experience frequent flooding have higher potentials for erosion control.

- Location and Elevation of Wetland - greater bank heights and larger elevation differences between the top of the bank and storm high water tend to minimize erosion.

- Fetch - fetches exceeding 5 miles can produce significant wave action, and consequently, signficantly higher shoreline erosion.

- Bottom Roughness - uneven topography and other conditions contributing to wave decay can limit shoreline erosion.

- Cultural Development - higher building density and high land values increase the potential for this function.

Research Needs

The primary need identified was the development of a data base containing quantitative information for this function. Specifically, the following information would be useful:

- Relationships of flood frequency and/or shoreline damage to the extent of fetch;

- Type and density of vegetation and extent of erosion;

- Erosion and extent of flooding relative to wetland cross section; and

- Degree of protection afforded by a wetland relative to its size and position in the floodplain.

BIBLIOGRAPHY

WATER QUALITY

American Water Resources Association, 1976, The Future of Chesapeake Bay, Washington, D.C., NTIS Report No. PB-263 457/4ST.

Armstrong, N. E. and Gordon, V. N., 1977, Exchange Rates for Carbon, Nitrogen, and Phosphorus in the Colorado River Delta Marshes, Texas University Cent. Res. Water Resour. Tech. Report No. CRWR-153.

Armstrong, N. E. and Gordon, V. N., 1977, Exchange Rates for Carbon, Nitrogen, and Phosphorus in Nueces and San Antonio Bay Marshes, Texas University Cent. Res. Water Resour. Tech. Report No. CRWR-152.

Armstrong, N. E., et al., 1977, Exchange Rates for Carbon, Nitrogen, and Phosphorus in the Trinity River Delta Marshes, Texas University Cent. Res. Water Resour. Tech. Report No. CRWR-154.

Armstrong, N. E., et al., 1975, Biogeochemical Cycling of Carbon, Nitrogen, and Phosphorus in Saltwater Marshes of Lavaca Bay, Texas, Texas University Cent. Res. Water Resour. Tech. Report No. CRWR-121.

Aurand, D. V. and F. C. Daiber, 1973, Nitrate and Nitrite in the Surface Waters of Two Delaware Salt Marshes, Chesapeake Sci. 14:105-111.

Axelrad, D. M., 1974, Nutrient Flux through the Salt Marsh Ecosystem, Ph.D. Dissertation, College of William and Mary, Williamsburg, VA.

Axelrad, D. M., Bender, M. E. and Moore, K.A., 1974, The Function of Marshes in Reducing Eutrophication of Eastern Coastal Plains Estuarines, Grant Completion Report, Office of Virginia Water Resources Research, p. 98.

Bahr, L. M. and Hebrard, J. J., Barataria Basin: Biological Characterization, Louisiana State University, Baton Rouge, Center for Wetlands Resources, NTIS Report No. PB-263 807/OST.

Baker, J. M., 1972, Recovery of Salt Marsh Vegetation from Oil Spill, Env. Pollution, Vol. 4(3), p. 223.

Baker, J. M., 1970, Oil Pollution in Salt Marsh Communities, Marine Pollut. Bull., Vol. 1(2), p. 27.

Baker, S., 1975, Coastal Development and Areas of Environmental Concern, Proceedings held at East Carolina University, Greensville, NC on March 5, 1975, North Carolina State University, Raleigh, NTIS Report No. PB-247 358/5ST.

Banus, M. D., et al., 1978, Lead, Zinc, and Cadmium Budgets in Experimentally Enriched Salt Marsh Ecosystems, Eastern Coast, Mar. Sc.: Vol. 3, p. 421-430.

Banus, M. D., et al., 1974, Response of Salt March Bivalves to Enrichment with Metal-Containing Sewaged and Retention of Lead, Zinc, and Cadmium by Marsh Sediments, Environ. Pollut., Vol. 7(2), p. 149.

Banus, M. D., et al., 1974, Export of Lead from Salt Marshes, Marine Pollut. Bull., Vol. 5(1), p. 6.

Barko, J. W., et al., 1977, Establishment and Growth of Selected Freshwater and Coastal Marsh Plants in Relation to Characteristics of Dredged Sediments, Army Engineer Waterways Experiment Station, Vicksburg, NTIS Report No. AD-A039 495/7ST.

Bartberger, C. E., 1976, Sediment Sources and Sedimentation Rates, Chincoteague Bay, Maryland and Virginia, J. Sed. Petrology, Vol. 46(20), p. 326.

Bay, R. R., 1967, Groundwater and Vegetation in Two Peat Bogs in Northern Minnesota, Ecology, Vol. 48(2), p. 308-310.

Beeftink, W. G., et al., 1977, Analysis of Estuarine Soil Gradients in the Scheldt Estuary, Hydrobiologia, Vol. 52(1), p. 93.

Beeftink, W. G., et al., 1977, Salt Marshes of the Southwestern Netherlands with Special Reference to the Scheldt Estuary, Hydrobiologia, Vol. 52 (1), p. 93.

Bender, M. E. and Correll, D. L., 1974, The Use of Wetlands as Nutrient Removal Systems, Chesapeake Research Consortium, Inc., Baltimore, MD, NTIS Report No. 241 002/5ST.

Bentley, E. M. III, 1969, The Effect of Marshes on Water Quality, University of Wisconsin, Ph.D. Dissertation.

Bitton, G., et al., 1976, Effect of a Secondary Treated Effluent on the Movement of Viruses through a Cypress Dome Soil, J. Env. Quality, Vol. 5(4), p. 370.

Blum, J. L., 1969, Nutrient Changes in Water Flooding the High Salt Marsh, Hydrobiologia, Vol. 34(1), p. 95.

Bookhout, T. A. and White, G. C., 1976, A Stimulation Model of Tritium Kinetics in a Freshwater Marsh, Ohio State University, Columbus, Water Resource Center, NTIS Report No. PB-255 761/9ST.

Bourquin, A. W., et al., 1977, An Artificial Microbial Ecosystem for Determining Effects and Fate of Toxicants in a Salt-Marsh Environment, Environmental Research Laboratory, Gulf Breeze, FL, NTIS Report No. PB-277 181/4ST.

Bourquin, A. W., 1977, Effects of Malathion on Microorganisms of an Artificial Salt-Marsh Environment, Environmental Research Laboratory, Gulf Breeze, FL, NTIS Report No. PB-277 153/3ST, and J. Env. Qual., Vol. 6 (4), pp. 373-378.

Bourquin, A. W., 1976, Degradation of Malathion by Salt-Marsh Microorganisms, Environmental Research Laboratory, Gulf Breeze, FL, NTIS Report No. PB-268 571/7ST.

Boyt, F. L., et al., 1977, Removal of Nutrients from Treated Municipal Waste Water by Wetland Vegetation, J. Water Poll. Control Fed., Vol. 49(5), p. 789-799.

Brezonik, P. L., et al., 1974, Changes in Water Quality in the Cypress Domes, p. 312-375, In: Odum, H. T., et al., (Editor), Ann. Rept. for 1974, Cypress Wetlands for Water Management, Recycling and Conservation, Center for Wetlands, University of Florida.

Brown, R. J., 1978, Salt Marshes, Volume 1, National Technical Information Service, Springfield, VA, NTIS Report No. PS-78 0533/6ST.

Brown, R. J., 1978, Salt Marshes, Volume 2, National Technical Information Service, Springfield, VA, NTIS Report No. PS-78 0533.

Burke, W., 1975, Fertilizer and Other Chemical Losses in Drainage Water from Blanket Bog, Ir. J. Agric. Res., Vol. 14(2), p. 163.

Burns, K. A. and Teal, J. M., 1971, Hydrocarbon Incorporation into the Salt Marsh Ecosystem from the West Falmouth Oil Spill, Woods Hole Oceanographic Institution, MA, NTIS Report No. COM-73-10419.

Canestri, U. and Ruiz, O., 1973, The Destruction of Mangroves, Mar. Pollut. Bull., Vol. 4(12).

Carlozzi, C. A., et al., 1971, Enhancement of Ecologic and Aesthetic Values of Wetlands Associated with Interstate Highways, Massachusetts University, Amherst, Water Resources Research Center, NTIS Report No. PB-204 894.

Carter, M. R., et al., 1973, Ecosystems Analysis of the Big Cypress Swamp and Estuaries, Environmental Protection Agency, Athens, GA, Surveillance and Analysis Division, NTIS Report No. PB-233 070/2.

Cavanaugh, J. A., et al., 1974, Distribution Models for Woody Species in a Southern Illinois Bottomland Forest, Assoc. Southeast Biol. Bull., Vol. 21(2), p. 46.

Chalmers, A. G., et al., 1976, Capacity a Spartina Salt Marsh to Assimilate Nitrogen from Secondarily Treated Sewage, Georgia Institute of Technology, Atlanta, Environmental Resources Center, Georgia University, Sapelo Island, NTIS Report No. PB-258 640/2ST.

Chitty, N. (Editor) and Davis, C. W., 1972, The Effects of the Discharge of Secondarily Treated Sewage Effluent into the Everglades Ecosystem, University of Miami, Special Bulletin No. 6, p. 134.

Christmas, J. Y., 1973, Cooperative Gulf of Mexico Estuarine Inventory and Study, Mississippi, Gulf Coast Research Laboratory, Ocean Springs, MS, NTIS Report No. COM-73-11269/0.

Clark, J. and J. Clark (Editors), 1979, Scientists Report, The National Symposium on Wetlands, Lake Buena Vista, FL, November 6-8, 1978, National Wetlands Technical Council.

Council on Environmental Quality, 6th Annual Report, 1975, Perspectives on the Environment: Coastal Zones.

Cowardin, L. M., et al., 1977, Classification of Wetlands and Deep-Water Habitats of the United States, U.S. Fish and Wildlife Service, Operational Draft Report.

Craig, N. J. and Day, J. W. Jr., 1977, Cumulative Impact Studies in the Louisiana Coastal Zone, Eutrophication, Land Loss, Louisiana State University, Baton Rouge, NTIS Report No. PB-273 157/8ST.

Craig, N. J. and Day, J. W. Jr., 1976, Barataria Basin: Eutrophication Case History, Louisiana State Planning Office, Baton Rouge, Coastal Resources Program, Louisiana State University, Baton Rouge, NTIS Report No. PB-265 278/2ST.

Crowder, J. P., 1974, Some Perspectives on the Status of Aquatic Wading Birds in South Florida, Bureau of Sport Fisheries and Wildlife, Atlanta, GA, Department of the Interior, Atlanta, GA, South Florida Environmental Project, NTIS Report No. PB-235 216/9ST.

Daiber, F. C., 1976, Tidal Marsh Bibliography, Selected Key Work Index, Delaware University, Newark, College of Marine Studies, NTIS Report No. PB-263 386/5ST.

Darnell, R. M., et al., 1976, Impacts of Construction Activities in Wetlands of the United States, Tereco Corp., College Station, TX, Environmental Research Laboratory, Corvallis, OR, NTIS Report No. PB-256 674/3ST.

Davis, P. B. and Humphrys, C. R., 1977, Ecological Effects of Highway Construction upon Michigan Woodlots and Wetlands, Michigan State University, East Lansing, Agricultural Experiment Station, NTIS Report No. PB-271 943/3ST.

Day, F. P. Jr., 1976, Ecosystem Studies in the Great Dismal Swamp U.S.A., a Preliminary Report, Virginia J. Sci., Vol. 27(2), p. 55.

Delaune, R. D., Patrick, W. H. Jr. and Grannon, J. M., 1976, Nutrient Transformations in Louisiana Salt Marsh Soils, Louisiana State University, Center for Wetlands, NTIS Report No. PB-266 991.

DeYoannes, A. M. and Farnham, R. S., 1969, Peat Bog Waste Stabilization, Minnesota State Department of Iron Range Resources and Rehabilitation, St. Paul, NTIS Report No. PB-215 324.

Dicks, B., 1975, The Effects of Refinery Effluents: The Case History of a Salt Marsh, Presented at Institute of Petroleum/Field Studies Council Meeting on Marine Ecology and Oil Pollution, Scotland, April 21-23, p. 227.

Dierberg, F. E. and Brezonik, P. L., 1978, The Effect of Secondary Sewage Effluent on the Surface Water and Groundwater Quality of Cypress Domes, pp. 178-270, In: Odum, H. T. and Ewel, K. C., Cypress Wetlands for Water Management, Recycling, and Conservation, 4th Annual Report NSF-RANN and The Rockefeller Foundation, Center for Wetlands, University of Florida, Gainesville.

Dinkins, C. E., 1972, Texas Seashore Boundary Law: The Effect of Natural and Artificial Modifications, Texas Law Institute of Coastal and Marine Resources, Houston, NTIS Report No. PB-222 136/4.

Dixon, K. R. and Kadlac, J. A., 1975, A Model for Predicting the Effects of Sewage Effluent on Wetland Ecosystems, Michigan University, Ann Arbor, Wetlands Ecosystem Research Group, NTIS Report No. PB-273 024/OST.

Dixon, K. R., 1974, A Model for Predicting the Effects of Sewage Effluention Wetland Ecosystems, Ph.D. Dissertation, University of Michigan.

Dolan, T. J., et al., 1978, The Clermont Project: Renovation of Treated Effluent by a Freshwater Marsh, p. 132-152, In: Drew, M. A. (Editor), Environmental Quality through Wetlands Utilization, Symposium on Freshwater Wetlands, Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin, Tallahassee, FL.

Drew, M. A., 1978, Environmental Quality through Wetlands Utilization, Symposium on Freshwater Wetlands, Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin, Tallahassee, FL.

Dunstan, W. M., Windom, H. L. and McIntire, G. L., 1975, The Role of "Spartina alterniflora" in the Flow of Pb, Cd, and Cu through the Salt Marsh Ecosystem, p. 250-256, In: Howell, F. G., Genty, J. T. and Smith, M. H. (Editors), Mineral Cycling in Southeastern Ecosystems, ERDA Symposium Series, COAF-740513.

Elkington, J. B., 1977, The Impact of Development Projects on Estuarine and Other Wetland Ecosystems, Env. Conservation, Vol. 4(2), p. 135.

Engler, R. M. and Patrick, W. H., 1974, Nitrate Removal from Floodwater Overlying Flooded Soils and Sediments, J. Env. Quality, Vol. 3(4), p. 409.

Estrada, M., et al., 1974, Concentration and Distribution of Chlorophyll in Fertilized Plots in a Massachusetts Salt Marsh, J. Exp. Marine Biol. Ecol., Vol. 14(1), p. 47.

Ewel, K. C. and Odum, H. T., 1978, Cypress Domes: Nature's Testing Treatment Filter, p. 35-60, In: Odum, H. T. and Ewel, K. C., Cypress Wetlands for Water Management, Recycling and Conservation, 4th Annual Report to NSF-RANN and The Rockefeller Foundation, Center for Wetlands, University of Florida, Gainesville.

Fetter, C. W., et al., 1978, Use of a Natural Marsh for Wastewater Polishing, Water Pollut. Control Fed., Vol. 52(2), p. 290.

Fetter, C. W., 1977, Attenuation of Wastewater Elutriated through Glacial Outwash, Groundwater 15 (in press).

Fetter, C. W., Sloey, W. E. and Spangler, F. L., 1976, Potential Replacement of Septic Tank Drain Fields by Artificial Marsh Wastewater Treatment Systems, Groundwater 14(6), p. 396-402.

Gardner, L. R., 1976, Exchange of Nutrients and Trace Metals between Marsh Sediments and Estuarine Waters - A Field Study, Clemson University, SC, Water Resources Research Institution, South Carolina University, Columbia, NTIS Report No. PB-261 492/3ST.

Ginn, T. M. and Fisher, F. M., 1974, Studies on the Distribution and Flux of Pesticides in Waterways Associated with a Ricefield-Marshland Ecosystem, Pesticides Monitoring J., Vol. 8(1), p. 23.

Good, R. E., Whigham, D. F. and Simpson, R. L., 1978, Freshwater Wetlands: Ecological Processes and Management Potential, Proc. Symposium Freshwater Marshes: Present Status, Future Needs, Febr 1977, Rutgers University, Academic Press, New York, p. 378.

Grant, R. R. Jr. and Patrick, R., 1970, Tinicum Marsh as a Water Purifier, p. 105-123, In: Two Studies of Tinicum Marsh; [illegible]rvation Foundation.

Greeson, P. E., Clark, J. and Clark J. (Editor), 1979, Wetland Functions and Values: The State of our Understanding, Proceedings of the Symposium sponsored by the American Water Resources Association, Minneapolis, MN.

Gunnison, D., 1978, Mineral Cycling in Salt Marsh-Estuarine Ecosystems; Ecosystem Structure, Function, and General Compartmental Model Describing Mineral Cycles, Army Engineer Waterways Experiment Station, Vicksburg, MS, NTIS Report No. AD-A052 737/4ST.

Hall, F. R., et al., 1972, The Influence of a New England Wetland on Water Quantity and Quality, Water Resources Research Center, New Hampshire University, Durham, NTIS Report No. PB-213 268/6ST.

Hansmann, E. and Zimmer, W., 1973, Man's Impact on the Eutrophication of a Lotic System, New Mexico University, Albuquerque Department of Mathematics and Statistics, NTIS Report No. AD-758 709.

Hartland-Rose, R. and Wright, P. B., 1975, Effects of Sewage Effluent on a Swampland Stream, In: International Association of Theoretical and Applied Limnology, Proceedings, Vol. 19, Parts 1-4 (Sladececk, V., Editor), Stuttgart, West Germany, p. 1575.

Heath, R. C., 1975, Hydrology of the Albemarle-Pamlico Region North Carolina, A Preliminary Report of the Impact of Agricultural Developments, Geological Survey, Raleigh, NC, Water Resources Division, North Carolina Department of Natural and Economic Resources, Raleigh, NTIS Report No. PB-243 642/6ST.

Heinle, D. R. and Flemer, D. A., 1976, Flows of Materials between Poorly Flooded Tidal Marshes and an Estuary, Marine Biology, Vol. 35(4), p. 359.

Helfgott, T., et al., 1973, Proceedings: Wetlands Conference, 1st Annual Conference held on June 20, 1973 at Storrs, CT, Connecticut University, Storrs, Institute of Water Resources, NTIS Report No. PB-232 430/9ST.

Hernande, J. W., 1975, Environmental Design for Istanbul Sewage Disposal, J. Environ. Eng. Div., ASCE, Vol. 101(NEE1), p. 175.

Hershner, C. and Moore, K., 1977, Effects of the Chesapeake Bay Oil Spill on Salt Marshes of the Lower Bay, Oil Spill Conference Proceedings, New Orleans, LA, March 8-10, p. 529.

Hertsgaard, T., 1975, Evaluation of Alternative Uses of Wetlands, North Dakota State University, Water Resources Research Institute, Report No. WI-221-035-76.

Hickok, E. A., et al., 1977, Urban Runoff Treatment Methods, Volume 1, Non-Structural Wetlands Treatment, Minnehaha Creek Watershed District, Wayzata, MN, NTIS Report No. PB-278 172/2ST.

Hickok, E. A., et al., 1976, Role of Wetlands in Storm Water Treatment, Water and Sewage Works, Vol. 123(11), p. 86.

Hoeppel, R. E., Nitrogen Transformations in Wetland Soils, Army Engineer Waterways Experiment Station, Vicksburg, MS, NTIS Report No. AD/A-000 610/6ST.

Horvath, G. J., 1973, The Influence of Big Cypress Land Development on the Distribution of Heavy Metals in Everglades Estuaries, Appendix, Florida State University, Tallahassee, Marine Laboratory, NTIS Report No. PB-231 941/6ST.

Hull, R. J., 1976, The Capacity of Salt Marsh Vegetation to Modify the Quality of Estuarine Waters, Rhode Island University, Kingston, Department of Plant and Soil Science, NTIS Report No. PB-261 997/1ST.

Jackson, H. W., 1972, Estuary Studies (161.3), Training Manual, Environmental Protection Agency, Cincinnati, OH, Office of Water Program Operations, NTIS Report No. PB-238 482/4ST.

Jeglum, J. K., 1975, Vegetation Habitat Changes Causes by Damming a Peatland Drainageway in Northern Ontario, Canada, Canadian Field-Nat., Vol. 89 (4), p. 400.

Jenks, B., et al., 1976, Coastal Zone Bibliography: Citations to Documents on Planning, Resources Management and Impact Assessment, Second Edition, California University, San Diego, Institute of Marine Resources, NTIS Report No. PB-259 647/6ST.

Jong, J. de., 1975, Bulrush and Reed Ponds: Purification of Sewage with the Aid of Ponds with Bulrushes or Reeds, Presented at International Conference on Biological Water Quality Improvement Alternatives, Philadelphia, PA.

Kadlec, J. A., 1976, Dissolved Nutrients in a Peatland near Houghton Lake, Michigan, p. 27-60, In: Tilton, et al.

Kadlec, J. A. and Wentz, W. A., 1974, State-of-the-Art Survey and Evaluation of Marsh Plant Establishment Techniques: Induced and Natural, Volume I, Report of Research, University of Michigan, Ann Arbor School of Natural Resources, NTIS Report No. AD-A012 834/8ST.

Kadlec, R. H. and Tilton, D. L., 1978, Wastewater Treatment via Wetland Irrigation: Nutrient Dynamics, p. 253-270, In: Drew, M. A. (Editor), Environmental Quality Through Wetlands Utilization, Symposium on Freshwater Wetlands, Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin, Tallahassee, FL.

Kadlec, R. H., 1976, Surface Hydrology of Peatlands, p. 3-24, In: Tilton, et al., (Editor), Freshwater Wetlands and Sewage Effluent Disposal..., Proceedings of a National Symposium held at the University of Michigan, NTIS Report No. PB-259 305.

Kadlec, R. H., et al., 1975, The Effects of Sewage Effluent on Wetland Ecosystems, University of Michigan, Ann Arbor, NTIS Report No. PB-249 192/6ST.

Kepczynski, K. and Ceynowa-Gieldon, M., 1972, Observations on the Vegetation of the Koronowo Reservoir, Stud. Soc. Sci. Torun. Sect. D., Vol. 9(4), p. 1.

Khalid, R. H., et al., 1977, Phosphorus Sorption Characteristics of Flooded Soils, Soil Science Society of American Journal, Vol. 41(2), p. 305.

Klopatek, J. M., 1978, Nutrient Dynamics of a Freshwater Riverine Marsh and the Role of Emergent Macrophytes, p. 195-216, In: Good, et al., Freshwater Wetlands: Ecological Processes and Management Potential, Academic Press.

Klopatek, J. M., 1977, Nutrient Dynamics of Freshwater Riverine Marshes and the Role of Emergent Macrophytes, Oak Ridge National Laboratory, TN, NTIS Report No. CONF-770248-1.

Kneip, T. J. and Hirshfield, H. I., 1975, Cadmium in an Aquatic Ecosystem: Distribution and Effects, New York University, Medical Center, New York Institute of Environmental Medicine, NTIS Report No. PB-242 180/8ST.

Kok, T., 1974, The Purification of Sewage from a Camping Site with the Aid of a Bulrush Pond, H_270(24) p. 536-544.

Kuenzler, E. J., et al., 1977, Water Quality of North Carolina Coastal Plain Streams and Effects of Channelization, North Carolina Water Resources Research Institute, Raleigh, NTIS Report No. PB-278 273/8ST.

Kuenzler, E. J., 1976, Seasonal Patterns of Dissolved Oxygen, Nutrients, and Metals in Natural and Channelized Swamp Streams, North Carolina University, Chapel Hill, Department of Environmental Sciences and Engineering, NTIS Report No. PB-268 979/2ST.

Kuenzler, E. J. and Marshall, H. L., 1973, Effects of Mosquito Control Ditching on Estuarine Ecosystems, North Carolina Water Resources Research Institute, Raleigh, NTIS Report No. PB-220 951/8.

LaRoe, E. T., 1974, Environmental Considerations for Water Management District 6 of Collier County, Conservation Foundation, Washington, D.C., NTIS Report No. PB-233 483/7ST.

Larson, J. S., 1976, Models for Evaluation of Freshwater Wetlands, Massachusetts University, Amherst, Water Resources Research Center, NTIS Report No. PB-253 950/OST.

Larson, J. S., et al., 1976, Models for Assessment of Freshwater Wetlands, University of Massachusetts Water Resources Research Center, Report No. 32.

Larson, J. S., 1973, A Guide to Important Characteristics and Values of Freshwater Wetlands in the Northeast, Massachusetts University, Amherst, Water Resources Research Center, NTIS Report No. PB-226 075/OST.

Lauff, G. H., 1967, Estuaries, Michigan State University, Hickory Corners, W. K. Kellogg Biological Station, American Association for the Advancement of Science, Washington, D.C., Report No. 83.

Lee, C. R., et al., 1978, Prediction of Heavy Metal Uptake by Marsh Plants Based on Chemical Extraction of Heavy Metals from Dredged Material, Army Engineer Waterways Experiment Station, Vicksburg, MS, NTIS Report No. AD-A054 129/2ST.

Lee, C. R., et al., 1976, Feasibility of the Functional Use of Vegetation to Filter, Dewater, and Remove Contaminants from Dredged Material, Army Engineer Waterways Experiment Station, Vicksburg, MS, NTIS Report No. AD-A028 336/6ST.

Lee, C. R., et al., 1976, A Hydroponic Study of Heavy Metal Uptake by Selected Marsh Plant Species, U.S. Army Waterways Experiment Station, Environmental Effects Laboratory, Tech., Report No. D-76-5.

Lee, F. G., Bentley, E. and Amundson, R., 1975, Effects of Marshes on Water Quality, p. 105-127, In: Hasler, A. D. (Editor), Coupling of Land and Water Systems, Springer-Verlag, NY.

Lee, J. J., 1977, Effects of Environmental Stress on the Community Structure and Productivity of Salt Marsh Epiphytic Communties, Progress Report, September 1, 1976 through August 31, 1977, City College, NY, NTIS Report No. COO-3254-34.

Lee, J. J., 1976, Effects of Environmental Stress on the Community Structure and Productivity of Salt Marsh Epiphytic Communities, Progress Report, September 1, 1975 through August 31, 1976, City College, NY, NTIS Report NO. COO-3254-32.

Lefor, M. W., et al., 1975, Proceedings of Wetlands Confernece on Delineation of Wetlands, 2nd Annual Conference held at Storrs, CT on January 9, 1974, Connecticut University, Storrs Institute of Water Resources, NTIS Report No. PB-252 753/9ST.

Lugo, A. E. and Snedaker, S. C., 1973, The Role of Mangrove Forest in South Florida, University of Florida, Gainesville, FL, NTIS Report No. PB-231 741.

Lynch, M. P., et al., 1976, An Assessment of Estuarine and Nearshore Marine Environments, Virginia Institute of Marine Science, Gloucester Point, NTIS Report No. PB-254 853/5ST.

MacDonald, K. B., 1976, The Natural Resources of Carpinteria Marsh, Their Status and Future, Report Number 13 on California Coastal Wetlands, California State Department of Fish and Game, Sacramento, NTIS Report No. PB-277 993/2ST.

MacDonald, K. B., 1976, The Natural Resources of Mugu Lagoon, Report Number 17 on California Coastal Wetlands, California State Department of Fish and Game, Sacramento, NTIS Report No. PB-277 997/3ST.

MacDonald, K. B., et al., 1971, Changes in the Ecology of a Southern California Wetland Removed from Tidal Action, In: 2nd National Coastal and Shallow Water Research Conference, Proceedings, U.S. Office of Naval Research, Geography Programs, Washington, D.C.

Mahrdt, C. R., et al., 1976, Natural Resources of Coastal Wetlands in Northern Santa Barbara County, Report Number 14 on California Coastal Wetlands, California State Department of Fish and Game, Sacramento, NTIS Report No. PB-277 994/0ST.

Marshall, D. E., 1970, Characteristics of Spartina Marsh which is Receiving Treated Municipal Sewage Wastes, p. 317-363, In: Odum, H. T. and Chestnut, A. F., Studies of Marine Estuaries Ecosystems Developing with Treated Sewage Wastes, Annual Report for 1969-1970 to National Science Foundation Grant No. GH-18.

Marshall, D. E., 1970, Characteristics of Spartina Marsh Receiving Treated Municipal Sewage Wastes, M.S. Thesis, University of North Carolina.

Mathis, J. H., 1973, Mangrove Decomposition, A Pathway for Heavy Metal Enrichment in Everglades Estuaries, Appendix III, Florida State University, Tallahassee, Marine Laboratory, NTIS Report No. PB-231 738/6ST.

Mattraw, H. C. Jr., 1973, Cation Exchange Capacity and Exchangeable Metals in Soils and Sediments of a South Florida Watershed, Florida State University, Tallahassee, Marine Laboratory, NTIS Report No. PB-233 526/3ST.

Mattson, C. P., et al., 1977, Hackensack Estuary Oil Spill: Cutting Oil-Soaked Marsh Grass as an Innovative Damage Control Technique, Oil Spill Conference Proceedings, New Orleans, LA, March 8-10, p. 243.

McCaffrey, R. J., 1977, Record of the Accumulation of Sediment and Trace Metals in a Connecticut U.S.A., Salt Marsh, Yale University, New Haven, Department of Geology and Geophysics, NTIS Report No. COO-3573-22.

McCaffrey, R. J. and Thomson, J., 1974, A Record of Trace Metal Fluxes to a Connecticut Salt Marsh, In: Trace Elements in Natural Waters, Turekign, K. K., Progress Report to AEC for Grant A T(11-1)3573, Report E, Yale University, New Haven, CT.

McPherson, B. F., et al., 1976, Nitrogen and Phosphorus Uptake in the Everglades Conservation Area, Florida, with Special Reference to the Effects of Backpumping Runoff, Geological Survey, Tallahassee, Water Resources Division, NTIS Report No. AD-A028 796/1ST.

Meo, M., et al., 1975, Overland Flow in the Louisiana Coastal Zone; the Potential for Land Treatment of Waste Water on Diked Dredge Spoil Disposal Sites in South Louisiana, Louisiana State University, Baton Rouge, Center for Wetlands Resources, NTIS Report No. PB-255 327/9ST.

Merrow, R. L. and Nickerson, N. H., 1975, Salinities of Ambient and Interstitial Waters of Some Massachusetts North Shore Salt Marshes, Massachusetts University, Amherst, NTIS Report No. PB-251 551/8ST.

Meyers, S. P., et al., 1973, The Impact of Oil on Marshland Microbial Ecosystems, Louisiana State University, Baton Rouge, Department of Food Science, NTIS Report No. COM-74-11013-22.

Millar, J. B., 1973, Vegetation Changes in Shallow Marsh Wetlands Under Improving Moisture Regime, Can. J. Bot., Vol. 51(8).

Misra, R., 1970, Save the Tropical Ecosystems, Intecol. Bull., No. 2, p. 29.

Mitsch, W. J., et al., 1977, Forested Wetlands for Water Resource Management in Southern Illinois, Illinois University, Urbana-Champaign, Water Resources Center, NTIS Report No. PB-276 659/OST.

National Science Foundation, 1977, Long-Term Ecological Measurements, Report of a Conference held at Woods Hole, MA on March 18, 1977, National Science Foundation, Washington, D.C., NTIS Report No. PB-271 896/3ST.

National Science Foundation, 1977, Putting Wetlands to Work, Washington, D.C., Research Applied to National Needs, NTIS Report No. PB-272 453/2ST.

Neafsey, J. A., 1974, Developing Criteria for the Evaluation of Wetlands, New York State Assembly Scientific Staff and New York State Sea Grant Program, Albany, p. 46.

Nedwell, B. D., 1975, Inorganic Nitrogen Metabolism in a Eutrophicated Tropical Mangrove Estuary, Water Research, Vol. 9(2), p. 221.

New York State Department of Environmental Conservation Catskill Study, 1976, Freshwater Wetlands in the Catskills, Report No. 10.

Niering, W. A., 1972, The Wetlands, Ecology Today, Vol. 2(3), p. 32-35.

Nixon, S. W. and Oviatt, C. A., 1973, Analysis of Local Variation in the Standing Crop of "Spartina alterniflora", Rhode Island University, Kingston, Graduate School of Oceanography, NTIS Report No. COM-74-10952/1.

Nixon, S. W. and Oviatt, C. A., 1973, Ecology of a New England Salt Marsh, Rhode Island University, Kingston, Graduate School of Oceanography, NTIS Report No. COM-74-1129/0.

Novitzki, R. P., 1978, Hydrology of the Nevin Wetland near Madison, Wisconsin, U.S. Geological Survey, Water Resources Investigation 78-48, in cooperation with the Wisconsin Department of Natural Resources.

Notohadiprawiro, T., 1976, Estuarine Water Chemistry as an Indicator of the Ecological Behavior of Tidal Swamps, International Symposium on the Ecology and Management of Some Tropical Shallow Water Communities.

O'Rear, C. W. Jr., 1975, The Effects of Stream Channelization on the Distribution of Nutrients and Metals, North Carolina Water Resources Research Institute, Raleigh, NTIS Report No. PB-246 193/7ST.

Odum, H. T. and Ewel, K. C., 1978, Cypress Wetlands for Water Management, Recycling and Conservation, University of Gainesville, Center for Wetlands, NTIS Report No. PB-282 159/3ST.

Odum, H. T., et al., 1976, Cypress Wetlands for Water Management, Recycling and Conservation, University of Florida, Gainesville, Center for Wetlands, NTIS Report No. PB-273 097/6ST.

Odum, W. E. and Hohannes, R. E., 1975, The Response of Mangroves to Man-Induced Environmental Stress, In: Elsevier Oceanography Series, No. 12--Tropical Marine Pollution (Wood, E., Ferguson, J. and Hohannes, R. E. - Editors), Elsevier Scientific Publishing Co., Amsterdam, Netherlands, New York, NY, p. 52.

Onvf, C. P., Teal, J. M. and Valiela, I., 1977, Interactions of Nutrients, Plant Growth, and Hersivory in a Mangrove Ecosystem, Ecology Vol. 58, p. 514-526.

Ornes, W. H. and Steward, K. K., 1975, Assessing a Marsh Environment for Wastewater Renovation, J. Water Poll. Control Fed., Vol. 47(7), p. 18.

Oviatt, C. A. and Nixon, S. W., 1973, Analysis of Local Variation in the Standing Crop of "Spartina alterniflora", Botanica Marina, Vol. 16(2), p. 103.

Park, G. R. and Schneider, G., 1974, Structure and Edaphic Factors of an Alder Swamp in Northern Michigan, U.S.A., Can. J. For. Res., Vol. 4(4), p. 499.

Patrick, W. H. Jr., 1977, Trace and Toxic Metal Uptake by Marsh Plants as Affected by Eh, pH, and Salinity, Louisiana State University, Baton Rouge, Center for Wetland Resources, NTIS Report No. AD-A050 914/1ST.

Patrick, W. H. Jr., et al., 1976, Nitrate Removal from Water at the Water-Mud Interface in Wetlands, Louisiana State University, Baton Rouge, Agricultural Experiment Station, NTIS Report No. PB-253 791/8ST.

Patrick, W. H. Jr. and Delaune, R. D., 1976, Nitrogen and Phosphorus Utilization by "S[artina alterniflora" in a Salt Marsh in Barataria Bay, Louisiana, Est. Coast. Mar. Sci., Vol. 4, p. 59-64.

Prentki, R. T., Gustafson, T. D. and Adams, M. S., 1978, Nutrient Movements in Lakeshore Marshes, p. 169-194, In: Good, et al., Freshwater Wetlands: Ecological Processes and Management Potential, Academic Press.

Pyne, R. D. G. and Wycoff, R. L., 1975, Urban Water Management and Coastal Wetland Protection in Collier County, Florida, Water Resource Bull. Vol. 11(3), p. 455.

Repert, R. T., et al., 1979, Wetland Values Concepts and Methods for Wetlands Evaluation, U.S. Army Corps of Engineers, Institute for Water Resources, Ft. Belvoir, VA.

Richardson, C. J., et al., 1975, Background Ecology and the Effects of Nutrient Additions on a Central Michigan Wetland, Michigan University, Ann Arbor, School of Natural Resources, NTIS Report No. PB-254 336/1ST.

Richardson, C. J., et al., 1976, Plant Growth, Nutrient Accumulation and Decomposition in a Central Michigan Peatland Used for Effluent Treatment, p. 77-117, In: Tilton, et al. (Editor), Freshwater Wetlands and Sewage Effluent Disposal Proceedings of a National Symposium held at the University of Michigan, NTIS Report No. PB-259 305.

Sather, J. H., 1976, Proceedings of the National Wetland Classification and Inventory Workshop, held at University of Maryland, College Park, MD, July 20-23, 1975, Fish and Wildlife Service, Washington, D.C., Office of Biological Services, NTIS Report No. PB-258 079/3ST.

Saville, T., 1966, A Study of Estuarine Pollution Problems on a Small Unpolluted Estuary and a Small Polluted Estuary in Florida, Florida University, Gainesville, Engineering Progress at the University of Florida, Vol. 20(8), p. 208.

Self, R. P., 1973, A Study of Sediment Transport and Erosion in the Fourchon Area of South Louisiana, Louisiana State University, Baton Rouge, Division of Engineering Research, NTIS Report No. N74-16056/5.

Sell, M. G. Jr., 1977, Modeling the Response of Mangrove Ecosystems to Herbicide Spraying, Hurricanes, Nutrients Enrichment and Economic Development, University of Florida, Ph.D. Dissertation.

Seidel, K., 1976, Macrophtes and Water Purification, In: Biological Control of Water Pollution, p. 109-122, J. Tourbier and R. Pierson (Editors).

Seidel, K., 1971, Macrophytes as Functional Elements in the Environment of Man, Hydrobiologia 122:121-130.

Seidel, K. and Kickuth, 1967, Biological Treatment of Phenol-Containing Wastewater with Bulrush (Sirps Lacustris L.), Wassersirtschaft, Wassertechnik. 17(6), p. 209-210.

Settlemyre, J. L. and Gardner, L. R., 1975, A Field Study of Chemical Budgets for a Small Tidal Creek - Charleston Harbor, South Carolina, p. 152-175, In: Church, T. M. (Editor), Marine Chemistry in the Coastal Environment, ACS Symposium Series, No. 18.

Settlemyre, J. L. and Gardner, L. R., 1975, Chemical and Sediment Budgets for a Small Tidal Creek - Charleston Harbor, South Carolina, Clemson University, South Carolina Water Resources Research Institute, NTIS Report No. PB-247 081/3ST.

Shabman, L. A., et al., 1979, The Economics of Wetlands Preservation in Virginia, Presented at the Northeastern Agricultural Economics Association, Newark, DE, Sea Grant Project Paper, VPI-56-79-01.

Shelter, S. G., 1970, The Suitland Bog, Atl. Natur., Vol. 25(2), p. 65.

Silberhorn, G. M., et al., 1974, Coastal Wetlands of Virginia: Guidelines for Activities Affecting Virginia Wetlands, Virginia Institute Marine Science Special Report in Applied Marine Science and Ocean Engineering 46.

Simpson, R. L., Whigham, D. F. and Walker, R., 1978, Seasonal Patterns of Nutrient Movement in a Freshwater Tide Marsh, p. 243-257, In: Good, et al., Freshwater Wetlands: Ecological Processes and Management Potential, Academic Press.

Skidaway Institute of Oceanography, 1974, Transport, Fate and Geochemical Interactions of Mercury, Cadmium and Other Inorganic Pollutants in the Coastal Littoral-Salt Marsh Environment of the Southeastern United States, Savannah, GA, NTIS Report No. PB-230 037/4ST.

Skidaway Institute of Oceanography, 1973, Fate and Geochemical Interactions of Mercury, Cadmium and Other Inorganic Pollutants in the Coastal Littoral-Salt Marsh Environment of the Southeastern United States, NTIS Report No. PB-227 035/3ST.

Sloey, W. E., et al., 1978, Management of Freshwater Wetlands for Nutrient Assimilation, In: Good, R. E., Whigham, D. F. and Simpson, R. L., Freshwater Wetlands: Ecological Processes and Management Potential, Academic Press, New York.

Small, M. M., 1976, Data Report: Marsh/Pond System, Brookhaven National Laboratory, Upton, NTIS Report No. BNL-50600.

Small, M. M., 1976, Freshwater from Sewage on Long Island, Brookhaven National Laboratory, Upton, NTIS Report No. BNL-21371.

Small, M. M., 1976, Marsh/Pond Sewage Treatment Plants, Brookhaven National Laboratory, Upton, NTIS Report No. BNL-21237.

Small, M. M., 1975, Meadow/Marsh Systems as Sewage Treatment Plants, Brookhaven National Laboratory, Upton, NTIS Report No. BNL-20757.

Smith, W. G. and Day, J. W., 1973, Enrichment of Marsh Habitats with Organic Wastes, Louisiana Water Resources Research Institute, Baton Rouge, NTIS Report No. PB-226 985/OST.

Smith, W. G., 1970, Spartina "Die-Back" in Louisiana Marshlands, Louisiana State University and Agricultural and Mechanical College, Coastal Studies Institute, Baton Rouge, Bull. No. 5, p. 89.

Smithsonian Institution, 1973, The Biological and Ecological Effects of Oil Pollution in Tropical Waters, An Annotated Bibliography, Washington, D.C., NTIS Report No. PB248 899/7ST.

Spangler, F. L., et al., 1977, Phosphorus Accumulation - Discharge Cycles in Marshes, Water Resource Bull., Vol. 13(6), p. 1191.

Spangler, F. L., et al., 1976, Wastewater Treatment by Natural and Artifical Marshes, Wisconsin University-Oshkosh, NTIS Report No. PB-259 992/6ST.

Stebbings, R. E., 1970, Recovery of Salt Marsh in Brittany 16 Months after Heavy Pollution by Oil, Environ. Pollut., Vol. 1(2), p. 163.

Steward, K. K. and Ornes, W. H., 1973, Assessing the Capability of the Everglades Marsh Environment for Renovating Wastewater, Agricultural Research Service, Fort Lauderdale, NTIS Report No. PB-231 652/9ST.

Sullivan, M. J. and Daiber, F. C., 1975, Light, Nitrogen and Phosphorus Limitation of Edaphic Algae in a Delaware Salt Marsh, J. Exp. Mar. Biol. Ecol., Vol. 18(1), p. 79.

Sullivan, M. J. and Daiber, F. C., 1974, Response of Production of Cord Grass, "Spartina alterniflora", to Inorganic Nitrogen and Phosphorus Fertilizer, Chesapeake Sci. 15: 121-123.

Sutherland, J. C., 1977, Investigation of the Feasibility of Tertiary Treatment of Municipal Wastewater Stabilization Pond Effluent Using River Wetlands in Michigan, Williams and Works, Grand Rapids, NTIS Report No. PB-275 283/OST.

Teal, J., Teal, M. and Valiela, I., 1973, The Salt Marsh as a Living Filter, Oceanus, Vol. XVII, Spring 1973, Woods Hole Oceanographic Institution, Woods Hole, MA.

Teal, J. and Teal, M., 1969, Life and Death of a Salt Marsh, Little, Brown, and Company, Boston, MA.

Tilton, D. L., et al., 1976, Freshwater Wetlands and Sewage Effluent Disposal, Proceedings of a National Symposium held at the University of Michigan, Ann Arbor on May 10-11, 1976, NTIS Report No. PB-259 305/1ST.

Tourbiber, J. and Pierson, R. W. Jr. (Editors), 1976, Biological Control of Water Pollution, University of Pennsylvania Press, Philadelphia, PA.

Toth, L., 1972, Reeds Control Eutrophication of Balaton Lake, Water Res. Vol. 6, p. 1533-1539.

Trattner, R. B. and Mattson, C. P., 1976, Nitrogen Budget Determination in the Hackensacke Meadowlands Estuary, J. Environmental Sci. Health Part A, Vol. 11(8-9), p. 549.

Tucker, D. L., et al., 1975, Use of Mathematical Models in the Palo Alto Marshland Rehabilitation Project, Presented at ASCE Symposium on Modeling Techniques, San Francisco, September 3-5, p. 140.

Turner, R. E., 1976, Geographic Variations in Salt Marsh Macrophyte Production: A Review, Contr. Marine Sci., Vol. 20, p. 47-68.

Turner, R. E., et al., 1976, Aspects of Land-Treated Waste Applications in Louisiana Wetlands, Louisiana State University, Baton Rouge, Department of Marine Science, NTIS Report No. PB-258 546/1ST.

University of Maryland, 1975, Assateague Ecological Studies, Part 1, Environmental Information, Maryland University, Solomons, NTIS Report No. PB-245 131/8ST.

United States Forest Service, 1977, Non-Point Water Quality Modeling in Wildland Management: A State-of-the-Art Assessment, Volume II, Appendixes, Forest Service, Washington, D.C., NTIS Report No. PB-272 949/9ST.

Uttormark, P. D., et al., 1974, Estimating Nutrient Loadings of Lakes from Non-Point Sources, Wisconsin University, Madison, Water Resources, Center, NTIS Report No. PB-238 355/2ST.

Valiela, I., et al., 1978, Nutrient and Particulate Fluxes in a Salt Marsh Ecosystem: Tidal Exchanges and Inputs by Precipitation and Groundwater, Limnol. Oceanogr., Vol. 23(4), p. 758-812.

Valiela, I., et al., 1976, Assimilation of Sewage by Wetlands, In: Estuarine Processes, Volume 1 - Uses, Stresses and Adaptation to the Estuary (Wiley, Martin - Editors), Academic Press, New York, p. 234.

Valiela, I., et al., 1975, Production and Dynamics of Salt Marsh Vegetation and the Effects of Experimental Treatment with Sewage Sludge, J. Applied Ecology, Vol. 12(3), p. 973.

Valiela, I., et al., 1973, Nutrient Retention Salt Marsh Plots Experimentally Fertilized with Sewage Sludge, Est. and Coastal Marine Sci., Vol. 1 (3), p. 261.

Vaughan, R. and Kimber, C., 1977, Maintenance Dredging Effects on Vegetation Adjacent to the Gulf Intracoastal Waterway - Cedar Lakes Section, Texas A&M University, College Station, NTIS Report No. PB-269 658/1ST.

Verry, E. W., 1975, Stream Flow Chemistry and Nutrient Yields from Upland-Peatland Watersheds in Minnesota, Ecology, Vol. 56, p. 1149-1157.

Vernberg, F. J., et al., 1977, The Dynamics of an Estuary as a Natural Ecosystem, South Carolina University, Columbia, NTIS Report No. PB-271 357/6ST.

Walsh, G. E., 1967, An Ecological Study of a Hawaiian Mangrove Swamp, p. 420-421, In: Lauff, G. H. (Editor), Estuaries, Publ., No. 83, A.A.A.S., Washington, D.C.

Waller, B. G., 1976, Analysis of Selected Benthic Communties in the Florida Everglades with Reference to their Physical and Chemical Environment, Geological Survey, Miami, FL, Water Resources Division, NTIS Report No. AD-A025 593/5ST.

Webster, B., 1975, Bulrushes being used in Artificial Marshes to Filter Water, New York Times, March 9, p. 47.

Westman, W. E., 1974, Risk to Mangroves in Sewage Proposal, Search, Vol. 5 (8), p. 368.

Westree, B., 1977, Biological Criteria for the Selection of Cleanup Techniques in Salt Marshes, Oil Spill Conference Proceedings, New Orleans, LA, March 8-10, p. 231.

Whelan, T. III, et al., 1976, Long-Term Chemical Effects of Petroleum in South Louisiana Wetlands, I. Organic Carbon in Sediments and Waters, Louisiana State University, Baton Rouge, NTIS Report No. PB-265 443/2ST.

Whigham, D. F. and Simpson, R. L., 1976, The Potential Use of Freshwater Tidal Marshes in the Management of Water Quality in the Delaware River, In: Tourbier, J. and Pierson, R. W. (Editors), Biological Control of Water Pollution, University of Pennsylvania Press, p. 197.

Windom, H. L., 1976, Geochemical Interactions of Heavy Metals in Southeastern Salt Marsh Environments, Skidway Institute of Oceanography, Savannah, GA, NTIS Report No. PB-252 250/6ST.

Windom, H. L., 1973, Mercury Distribution in Estuarine-Nearshore Environment, Skidaway Institute of Oceanography, Savannah, GA, NTIS Report No. PB-224 512/4ST.

Woodwell, G. M., 1977, Recycling Sewage through Plan Communities, American Scientist, Vol. 65(5), p. 556.

Woodwell, G. M., et al., 1974, Experimental Eutrophication of Terrestrial and Aquatic Ecosystems First Annual Report of the Upland Recharge Project, Brookhaven National Laboratory, NTIS Report No. BNL-50420.

GROUNDWATER RECHARGE

Adams, R. D., et al., 1976, Barataria Basin: Geologic Processes and Framework, Louisiana State University, Baton Rouge, Center for Wetlands Resources, NTIS Report No. PB-262 997/OST.

Allen, E. A., 1977, Petrology and Stratigraphy of Holocene Coastal-Marsh Deposits Along the Western Shore of Delaware Bay, Delaware University, Newark, College of Marine Studies, NTIS Report No. PB-278 893/3ST.

Anderson, M. W. and Ross, B. E., 1975, A Hydrologic Study of a Small Suburban Watershed, NTIS Report No. PB-249 744.

Andrews, C. B. and Anderson, M. P., 1978, Impact of a Power Plant on the Groundwater System of a Wetland, Groundwater, Vol. 16(2), p. 105.

April, R. H., et al., 1975, Factors Influencing Flow within the Fresh-, Salt-Groundwater Transition Zone Beneath Coastal Salt Marshes, Amer. Geophys. Union, Vol. 56(6), p. 358.

Baffa, J. J., 1975, Artificial Groundwater Recharge and Wastewater Reclamation, J. Amer. Water Works Assoc., Vol. 67(9), p. 471.

Bay, R. R., 1967, Groundwater and Vegetation in Two Peat Bogs in Northern Minnesota, Ecology, Vol. 48(2), p. 308-310.

Bay, R. R., 1967, Interpretation of Fundamental Hydrologic Relationships of Forested Bogs in Northern Minnesota, University of Minnesota, Ph.D. Dissertation.

Beeftink, W. G., et al., 1977, Analysis of Estuarine Soil Gradients in the Scheldt Estuary, Hydrobiologia, Vol. 52(1), p. 93.

Beeftink, W. G., et al., 1977, Salt Marshes of the Southwestern Netherlands with Special Reference to the Scheldt Estuary, Hydrobiologia, Vol. 52 (1), p. 93.

Belskaya, M. A., 1968, Changes in the Physical Properties of Peat-Bog Forest Soils Due to Drainage, National Science Foundation, Report No. SFCSI-Agr(TT-67-51314), Washington, D.C.

Black, R. F., 1973, Wetland Geology, In: Helfgott, T., et al., Proceeding: Wetlands Conference first held on June 20, 1973 at Storrs, CT, Connecticut University, Storr, Institute of Water Resources, NTIS Report No. PB-232 430/9ST, p. 42.

Bloom, A. L., 1967, Coastal Geomorphology of Connecticut, Cornell University, Department of Geological Sciences, Ithaca, Final Report, p. 79.

Boelter, D. H. and Verry, E. S., 1978, Peatland and Water in the Northern Lake States, North Central Forest Experiment Station, St. Paul, MN, NTIS Report No. PB-278 310/8ST.

Boyt, F. L., et al., 1977, Removal of Nutrients from Treated Municipal Waste Water by Wetland Vegetation, J. Water Poll. Control Fed., Vol. 49(5), p. 789-799.

Burke, W., 1975, Effect of Drainage on the Hydrology of Blanket Bog, J. Agric. Res., Vol. 14(2), p. 145.

Callaham, J. T., 1964, The Yield of Sedimentary Aquifer of the Coastal Plain: Southeast River Basins, Geol. Survey Water Supply, Paper 1669-W, U.S. Government Printing Office.

Cheng, R. T-S., 1975, Finite Element Modeling of Flow through Porous Media, State University of New York, Buffalo, NTIS Report No. PB-243 750/7ST.

Childs, E. C., 1940, The use of Soil Moisture Characteristics in Soil Studies, Soil Science, Vol. 50, p. 239-252.

Christmas, J. Y., 1973, Cooperative Gulf of Mexico Estuarine Inventory and Study, Mississippi, Gulf Coast Research Laboratory, Ocean Springs, MS, NTIS Report No. COM-73-11269/0.

Clark, J. and J. Clark (Editors), 1979, Scientists Report, The National Symposium on Wetlands, Lake Buena Vista, FL, November 6-8, 1978, National Wetlands Technical Council.

Cowardin, L. M., et al., 1977, Classification of Wetlands and Deep-Water Habitats of the United States, U.S. Fish and Wildlife Service, Operational Draft Report.

Cronin, L. E. (Editor), 1973, Estuarine Research, Volume 2: Geology and Engineering, Academic Press, New York, p. 587.

Crowder, J. P., 1974, The Effects of Drainage and Associated Development in the Big Cypress Swamp, Department of the Interior, Atlanta, GA, South Florida Environmental Project, NTIS Report No. PB-231 612/3ST.

Daiber, F. C., 1976, Tidal Marsh Bibliography, Selected Key Work Index, Delaware University, Newark, College of Marine Studies, NTIS Report No. PB-263 386/5ST.

Darnell, R. M., et al., 1976, Impacts of Construction Activities in Wetlands of the United States, Tereco Corp., College Station, TX, Environmental Research Laboratory, Corvallis, OR, NTIS Report No. PB-256 674/3ST.

DeSmedt, F. A. Van Der Beken and Demaree, G., 1977, Peat Bog Waste Stabilization, Minnesota State Department of Iron Range Resources and Rehabilitation, St. Paul, NTIS Report No. PB-215 324.

Dierberg, F. E. and Brezonik, P. L., 1978, The Effect of Secondary Sewage Effluent on the Surface Water and Groundwater Quality of Cypress Domes, p. 178-270, in Odum, H. T. and Ewel, K. C., Cypress Wetlands for Water Management, Recycling, and Conservation, 4th Annual Report NSF-RANN and The Rockefeller Foundation, Center for Wetlands, University of Florida, Gainesville.

Dinkins, C. E., 1972, Texas Seashore Boundary Law: The Effect of Natural and Artificial Modifications, Texas Law Institute of Coastal and Marine Resources, Houston, NTIS Report No. PB-222 136/4.

Elkington, J. B., 1977, The Impact of Development Projects on Estuarine and Other Wetland Ecosystems, Env. Conservation, Vol. 4(2), p. 135.

Fetter, C. W., 1977, Attenuation of Wastewater Elutriated through Glacial Outwash, Groundwater 15 (in press).

Fetter, C. W., Sloey, W. E. and Spangler, F. L., 1976, Potential Replacement of Septic Tank Drain Fields by Artificial Marsh Wastewater Treatment Systems, Groundwater 14(6), p. 396-402.

Greeson, P. E., Clark, J. and Clark J. (Editor), 1979, Wetland Functions and Values: The State of our Understanding, Proceedings of the Symposium sponsored by the American Water Resources Association, Minneapolis, MN.

Heeley, R. W., 1973, Hydrogeology of Wetlands in Massachusetts, University, Amherst, Department of Geology, Office of Water Research and Technology, Washington, D.C., NTIS Report No. PB-236 945/2SL.

Helfgott, T., et al., 1973, Proceedings: Wetlands Conference, 1st Annual Conference held on June 20, 1973 at Storrs, CT, Connecticut University, Storrs, Institute of Water Resources, NTIS Report No. PB-232 430/9ST.

Hickok, E. A., et al., 1977, Urban Runoff Treatment Methods, Volume 1, Non-Structural Wetlands Treatment, Minnehaha Creek Watershed District, Wayzata, MN, NTIS Report No. PB-278 172/2ST.

Holzer, T. L., 1973, Inland Wetlands and Groundwater in Eastern Connecticut, In: Halfgolt, T., et al., Proceedings: Wetlands Conference first held on June 20, 1973 at Storrs, CT, Connecticut University, Storrs, Institute of Water Resources, NTIS Report No. PB-232 430/9ST, p. 66.

Huber, W. C., et al., 1976, Environmental Resources Management Studies of the Kissimmee River Basin, University of Florida, Gainesville, Department of Environmental Engineering Sciences, NTIS Report No. PB-269 330/7ST.

Ivanov, K. E., et al., 1972, The Hydrology of Marshlands, Department of Agriculture, Washington, D.C., NTIS Report No. TT-71-50091.

Ivitskii, A. I., 1968, Evaporation from Bogs, Depending on Climate, Drainage and Cultivation, National Science Foundation, Washington, D.C., Foreign Currency Science Information Program, NTIS Report No. TT-67-51385.

Ivitskii, A. I., 1967, Study of Water Yield by Peat, National Science Foundation, Washington, D.C., Special Foreign Currency Science Information Program, NTIS Report No. TT-67-51333.

Jenks, B., et al., 1976, Coastal Zone Bibliography: Citations to Documents on Planning, Resources Management and Impact Assessment, Second Edition, California University, San Diego, Institute of Marine Resources, NTIS Report No. PB-259 647/6ST.

Knochenmus, D. D. and Hughes, G. H., 1976, Hydrology of Lake County, Florida, Geological Survey, Tallahassee, FL, Water Resources Division, NTIS Report No. PB-257 755/7ST.

Kopanev, I. D., 1959, Air Temperature and Humidity Over a Drainage Bog, Weather Bureau, Washington, D.C., CFSTI Report No. AD-660 991.

Kovacevic, P., 1973, Soils of the Koprivnica District, Department of Agriculture, Washington, D.C., NTIS Report No. TT-71-56092.

Kraft, J. C., 1971, A Guide to the Geology of Delaware's Coastal Environments, Delaware University, Newark, College of Marine Studies, NTIS Report No. AD-736 036.

Larson, J. S., 1976, Models for Evaluation of Freshwater Wetlands, Massachusetts University, Amherst, Water Resources Research Center, NTIS Report No. PB-253 950/0ST.

Larson, J. S., et al., 1976, Models for Assessment of Freshwater Wetlands, University of Massachusetts Water Resources Research Center, Report No. 32.

Larson, J. S., 1973, A Guide to Important Characteristics and Values of Freshwater Wetlands in the Northeast, Massachusetts University, Amherst, Water Resources Research Center, NTIS Report No. PB-226 075/0ST.

Lefor, M. W., et al., 1975, Proceedings of Wetlands Confernece on Delineation of Wetlands, 2nd Annual Conference held at Storrs, CT on January 9, 1974, Connecticut University, Storrs Institute of Water Resources, NTIS Report No. PB-252 753/9ST.

Lichtler, W. F. and Walker, P. N., 1974, Hydrology of the Dismal Swamp, Virginia-North Carolina, U.S. Geological Survey, Open-File Report, p. 50.

Lindberg, S. E. and Harriss, R. C., 1973, Mechanisms Controlling Pore Water Salinities in a Salt Marsh, Limnology and Oceanography, Vol. 18(5), p. 788.

Lugo, A. E. and Snedaker, S. C., 1973, The Role of Mangrove Forest in South Florida, University of Florida, Gainesville, FL, NTIS Report No. PB-231 741.

McLeese, R. L. and Whitesid, E. P., 1977, Ecological Effects of Highway Construction Upon Michigan Woodlots and Wetlands, Soil Relationships, J. Env. Quality, Vol. 6(4), p. 467.

Mitsch, W. J., et al., 1977, Forested Wetlands for Water Resource Management in Southern Illinois, Illinois University, Urbana-Champaign, Water Resources Center, NTIS Report No. PB-276 659/0ST.

Mulica, W. S., 1977, Wetlands and Municipal Groundwater Resource Protection, Abstracts of Papers of the American Chemical Society, Vol. 173, p. 38.

National Science Foundation, 1977, Long-Term Ecological Measurements, Report of a Conference held at Woods Hole, MA on March 18, 1977, National Science Foundation, Washington, D.C., NTIS Report No. PB-271 896/3ST.

Neafsey, J. A., 1974, Developing Criteria for the Evaluation of Wetlands, New York State Assembly Scientific Staff and New York State Sea Grant Program, Albany, p. 46.

New York State Department of Environmental Conservation Catskill Study, 1976, Freshwater Wetlands in the Catskills, Report No. 10.

Niering, W. A., 1972, The Wetlands, Ecology Today, Vol. 2(3), p. 32-35.

Nivikov, S. M., 1976, Calculation of Daily Groundwater Levels in Swamps Using Meterological Data, Department of Agriculture, Washington, D.C., NTIS Report No. PB-257 548/8ST.

Novitzki, R. P., 1978, Hydrology of the Nevin Wetland near Madison, Wisconsin, U.S. Geological Survey, Water Resources Investigation 78-48, in cooperation with the Wisconsin Department of Natural Resources.

O'Brien, A., 1977, Hydrology of Two Small Wetland Basins in Eastern Massachusetts, Water Resources Bull., Vol. 13(2), p. 325.

Odum, H. T. and Ewel, K. C., 1978, Cypress Wetlands for Water Management, Recycling and Conservation, University of Gainesville, Center for Wetlands, NTIS Report No. PB-282 159/3ST.

Odum, H. T., et al., 1976, Cypress Wetlands for Water Management, Recycling and Conservation, University of Florida, Gainesville, Center for Wetlands, NTIS Report No. PB-273 097/6ST.

Orkruszko, H., 1967, Hydrological Factors as a Basis for Classification of Peat Bogs, National Science Foundation, Washington, D.C., SFSTI Report No. TT-66-57022.

Orr, H. K., 1975, Watershed Management in the Black Hills: The Status of Our Knowledge, U.S. Forestry Service Research Paper RM-141.

Palmer, H. D., 1977, Shoreline Erosion in Upper Chesapeake Bay: Role of Groundwater, Shore and Beach, Vol. 41(2), p. 18-22.

Paulson, O. L. Jr., et al., 1977, Hydrologic and Biologic Characteristics of Natural Channels in Coastal Marsh of Mississippi, University of Southern Mississippi, Hattiesburg, Department of Geology, NTIS Report No. PB-273 813/6ST.

Repert, R. T., et al., 1979, Wetland Values Concepts and Methods for Wetlands Evaluation, U.S. Army Corps of Engineers, Institute for Water Resources, Ft. Belvoir, VA.

Romanov, V. V., 1968, Hydrophysics of Bogs, National Science Foundation, Washington, D.C., CFSTI Report No. TT-65-51289.

Rykiel, E. J. Jr., 1977, Toward Simulation and Systems Analysis of Nutrient Cycling in the Okefenokee Swamp, Georgia, Georgia Institute of Technology, Atlanta, Environmental Resources Center, NTIS Report No. PB-264 045/6ST.

Sander, J. E., 1976, Electric Analog Approach to Bog Hydrology, Groundwater, Vol. 14(1), p. 30.

Sander, J. E., 1971, Bog-Watershed Relationships Utilizing Electric Analog Modeling, Michigan State University, Ph.D. Dissertation.

Sather, J. H., 1976, Proceedings of the National Wetland Classification and Inventory Workshop, held at University of Maryland, College Park, MD, July 20-23, 1975, Fish and Wildlife Service, Washington, D.C., Office of Biological Services, NTIS Report No. PB-258 079/3ST.

Silberhorn, G. M., et al., 1974, Coastal Wetlands of Virginia: Guidelines for Activities Affecting Virginia Wetlands, Virginia Institute Marine Science Special Report in Applied Marine Science and Ocean Engineering 46.

Singe, P. B., 1974, Studies on Drainage of Ditched Tidal Marshes, Rutgers University, Ph.D. Dissertation.

Stankevich, V. S. and Rubin, P. R., 1968, Drainage and Reclamation of Bogs and Bogged Areas, National Science Foundation, Washington, D.C., CFSTI Report No. TT-67-51298.

Taylor, J. W., 1955, Ditch, Tile, and Levee: The Significance of Wetlands and Their Drainage to the W bash Lowlands of Indiana, Indiana University, Ph.D. Dissertation.

Terrell, R. E., et al., 1977, Estimating and Predicting Changes in Wetland Water Levels, Presented at Sensing of Environmental Pollutants 4th Joint Conference, New Orleans, November 6-11, p. 167.

Vecchioli, J., Gill, H. E. and Lang, S. M., 1962, Hydrologic Role of the Great Swamp and Other Marshland in Upper Passaic River Basin, American Water Works Association Journal, Vol. 54, p. 697-701.

Vorobev, P. K., 1974, Study of the Physical Characteristics of the Active Horizon of Undrained Bogs, Forest Service, Washington, D.C., NTIS Report No. TT-71-51010.

Walker, P. H., 1972, Seasonal and Stratigraphic Controls in Coastal Floodplain Soils, Aust. J. Soil Res., Vol. 10(2), p. 127.

Wharton, C. H., et al., 1977, Southern Swamps, Nature Conservancy News, Vol. 27(3), p. 4.

Wharton, C. H., et al., 1977, Forested Wetlands of Florida, Their Management and Use, Florida University, Gainesville, NTIS Report No. PB-282 215/3ST.

Young, C. E., et al., 1972, Hydrologic Model of Wetland Forest, J. Soil Water Conservation, Vol. 27(3), p. 122.

STORM AND FLOOD WATER STORAGE

Anderson, M. W. and Ross, B. E., 1975, A Hydrologic Study of a Small Suburban Watershed, NTIS Report No. PB-249 744.

Bay, R. R., 1967, Interpretation of Fundamental Hydrologic Relationships of Forested Bogs in Northern Minnesota, University of Minnesota, Ph.D. Dissertation.

Boelter, D. H. and Verry, E. S., 1978, Peatland and Water in the Northern Lake States, North Central Forest Experiment Station, St. Paul, MN, NTIS Report No. PB-278 310/8ST.

Boelter, D. H. and Close, G. E., 1974, Pipelines in Forested Wetlands, J. For., Vol. 72(9), p. 561.

Bradley, E. H. Jr. and Armstrong, J. M., 1972, A Description and Analysis of Coastal Zone and Shoreland Management Programs in the United States, University of Michigan, Technical Report No. 20.

Braeke, F. H., 1978, Swamp Drainage in Norwegian Forestry Influence on Water Balance and Flood Danger, Tidsskr Skogbruk, Vol. 78(2), p. 227.

Briscoe, C. B., 1957, Diameter Growth and Effects of Flooding on Certain Bottomland Forest Trees, Duke University, Ph.D. Dissertation.

Brown, R. J., 1978, Salt Marshes, Volume 1, National Technical Information Service, Springfield, VA, NTIS Report No. PS-78 0533/6ST.

Brown, R. J., 1978, Salt Marshes, Volume 2, National Technical Information Service, Springfield, VA, NTIS Report No. PS-78 0533.

Bulavko, A. G., 1971, Hydrology of Marshes and Marsh-Ridded Lands, Nature and Resources, Vol. 7(1), p. 12.

Burke, W., 1975, Effect of Drainage on the Hydrology of Blanket Bog, J. Agric. Res., Vol. 14(2), p. 145.

Byrne, P., et al., 1976, Barataria Basin: Hydrologic and Climatologic Processes, Louisiana State University, Baton Rouge, Center for Wetlands Resources, NTIS Report No. PB-265 271/7ST.

Cavanaugh, J. A., et al., 1974, Distribution Models for Woody Species in a Southern Illinois Bottomland Forest, Assoc. Southeast Biol. Bull., Vol. 21(2), p. 46.

Chabreck, R. H. and Palmisano, A. W., 1973, The Effects of Hurricane Camille on the Marshes of the Mississippi River Delta, Ecology, Vol. 54(5), p. 1118.

Choate, J. S., 1972, Stream Channeling in Wetlands in Minnesota Watershed, J. Wildlife Mgmnt, Vol. 36(3), p. 940.

Christmas, J. Y., 1973, Cooperative Gulf of Mexico Estuarine Inventory and Study, Mississippi, Gulf Coast Research Laboratory, Ocean Springs, MS, NTIS Report No. COM-73-11269/0.

Clark, J. and J. Clark (Editors), 1979, Scientists Report, The National Symposium on Wetlands, Lake Buena Vista, FL, November 6-8, 1978, National Wetlands Technical Council.

Cowardin, L. M., et al., 1977, Classification of Wetlands and Deep-Water Habitats of the United States, U.S. Fish and Wildlife Service, Operational Draft Report.

Craig, N. J. and Day, J. W. Jr., 1977, Cumulative Impact Studies in the Louisiana Coastal Zone, Eutrophication, Land Loss, Louisiana State University, Baton Rouge, NTIS Report No. PB-273 157/8ST.

Crowder, J. P., 1974, The Effects of Drainage and Associated Development in the Big Cypress Swamp, Department of the Interior, Atlanta, GA, South Florida Environmental Project, NTIS Report No. PB-231 612/3ST.

Daiber, F. C., 1976, Tidal Marsh Bibliography, Selected Key Work Index, Delaware University, Newark, College of Marine Studies, NTIS Report No. PB-263 386/5ST.

Darnell, R. M., et al., 1976, Impacts of Construction Activities in Wetlands of the United States, Tereco Corp., College Station, TX, Environmental Research Laboratory, Corvallis, OR, NTIS Report No. PB-256 674/3ST.

Dawes, G. M., et al., 1973, Local Management of Wetlands Environmental Considerations, Virginia Institute, Marine Science 35.

DeSmedt, F. A. Van Der Beken and Demaree, G., 1977, Peat Bog Waste Stabilization, Minnesota State Department of Iron Range Resources and Rehabilitation, St. Paul, NTIS Report No. PB-215 324.

Dinkins, C. E., 1972, Texas Seashore Boundary Law: The Effect of Natural and Artificial Modifications, Texas Law Institute of Coastal and Marine Resources, Houston, NTIS Report No. PB-222 136/4.

Doiron, L. N. and Whitehurst, C. A., 1974, Geomorphic Processes Active in the Southwestern Louisiana Canal, Lafourche Parish, Louisiana, Louisiana State University, Baton Rouge, Division of Engineering Research, NTIS Report No. N75-15128/2ST.

Dzekster, E. S., 1968, Experiment in Draining a Bog by Widely Spaced Deep Canals, National Science Foundation, Washington, D.C., Special Foreign Currency Science Information Program, NTIS Report No. TT-67-513126.

Elkington, J. B., 1977, The Impact of Development Projects on Estuarine and Other Wetland Ecosystems, Env. Conservation, Vol. 4(2), p. 135.

Federal Wetlands Aid Flood Control, 1971, Minnesota Out-of-Doors, Vol. 16 (8), p. 9.

Fillenham, L. F. and Jack, W. L., 1975, Evaluation of Flood Prevention Schemes for the Middle Level, Cambridgeshire, J. Inst. Water Eng. Sci., Vol. 29(6), p. 297.

Gagliana, S. M., et al., 1975, Environment Base and Management Study - Atchafalaya Basin, Louisiana, Louisiana State University, Baton Rouge, Center for Wetlands Resources, NTIS Report No. PB-259 948/8ST.

Greeson, P. E., Clark, J. and Clark J. (Editor), 1979, Wetland Functions and Values: The State of our Understanding, Proceedings of the Symposium sponsored by the American Water Resources Association, Minneapolis, MN.

Gosselink, J. G. and Turner, R. E., 1978, The Role of Hydrology in Freshwater Wetland Ecosystems, In: Good, R. E., Whigham, D. F. and Simpson, R. L. (Editors), Freshwater Wetlands: Ecological Processes and Management Potential, Academic Press, New York, p. 378.

Harvey, E. J. and Skelton, J., 1978, Relationship Between Hydrology and Bottomland Vegetation in Ozark Mountains of Missouri, J. Res. U.S. Geological Survey, Vol. 6(3), p. 299.

Heath, R. C., 1975, Hydrology of the Albemarle-Pamlico Region North Carolina, A Preliminary Report of the Impact of Agricultural Developments, Geological Survey, Raleigh, NC, Water Resources Division, North Carolina Department of Natural and Economic Resources, Raleigh, NTIS Report No. PB-243 642/6ST.

Helfgott, T., et al., 1973, Proceedings: Wetlands Conference, 1st Annual Conference held on June 20, 1973 at Storrs, CT, Connecticut University, Storrs, Institute of Water Resources, NTIS Report No. PB-232 430/9ST.

Hertsgaard, T., 1975, Evaluation of Alternative Uses of Wetlands, North Dakota State University, Water Resources Research Institute, Report No. WI-221-035-76.

Hewlett, J. D., 1972, An Analysis of Forest Water Problems in Georgia, Georgia Forest Research Council, NTIS Report No PB-239 350.

Holzer, T. L., 1973, Inland Wetlands and Groundwater in Eastern Connecticut, In: Halfgolt, T., et al., Proceedings: Wetlands Conference first held on June 20, 1973 at Storrs, CT, Connecticut University, Storrs, Institute of Water Resources, NTIS Report No. PB-232 430/9ST, p. 66.

Howells, D. H., 1970, Proceedings Workshop on Stream Channelization and Wetland Drainage, held at Quail Roost Conference Center, Rougemont, NC on November 18, 1970, North Carolina Water Resources Research Institute, Raleigh, NTIS Report No. PB-197 673.

Huber, W. C., et al., 1976, Environmental Resources Management Studies of the Kissimmee River Basin, University of Florida, Gainesville, Department of Environmental Engineering Sciences, NTIS Report No. PB-269 330/7ST.

Ivanov, K. E., et al., 1972, The Hydrology of Marshlands, Department of Agriculture, Washington, D.C., NTIS Report No. TT-71-50091.

Ivitskii, A. I., 1968, Evaporation from Bogs, Depending on Climate, Drainage and Cultivation, National Science Foundation, Washington, D.C., Foreign Currency Science Information Program, NTIS Report No. TT-67-51385.

Ivitskii, A. I., 1968, Maximum and Optimum Norms of Bog Drainage, National Science Foundation, Washington, D.C., Special Foreign Currency Science Information Program, NTIS Report No. TT-67-51317.

Jackson, H. W., 1972, Estuary Studies (161.3), Training Manual, Environmental Protection Agency, Cincinnati, OH, Office of Water Program Operations, NTIS Report No. PB-238 482/4ST.

Jeglum, J. K., 1975, Vegetation Habitat Changes Causes by Damming a Peatland Drainageway in Northern Ontario, Canada, Canadian Field-Nat., Vol. 89 (4), p. 400.

Jenks, B., et al., 1976, Coastal Zone Bibliography: Citations to Documents on Planning, Resources Management and Impact Assessment, Second Edition, California University, San Diego, Institute of Marine Resources, NTIS Report No. PB-259 647/6ST.

Kadlec, R. H., 1976, Surface Hydrology of Peatlands, p. 3-24, In: Tilton, et al., (Editor), Freshwater Wetlands and Sewage Effluent Disposal..., Proceedings of a National Symposium held at the University of Michigan, NTIS Report No. PB-259 305.

Knochenmus, D. D. and Hughes, G. H., 1976, Hydrology of Lake County, Florida, Geological Survey, Tallahassee, FL, Water Resources Division, NTIS Report No. PB-257 755/7ST.

Knollenberg, R., 1964, The Distribution of String Bogs in Central Canada in Relation to Climate, Wisconsin University, Madison, Report No. AD-608 150

Kopanev, I. D., 1959, Air Temperature and Humidity Over a Drainage Bog, Weather Bureau, Washington, D.C., CFSTI Report No. AD-660 991.

Larson, J. S., 1976, Models for Evaluation of Freshwater Wetlands, Massachusetts University, Amherst, Water Resources Research Center, NTIS Report No. PB-253 950/OST.

Larson, J. S., et al., 1976, Models for Assessment of Freshwater Wetlands, University of Massachusetts Water Resources Research Center, Report No. 32.

Larson, J. S., 1973, A Guide to Important Characteristics and Values of Freshwater Wetlands in the Northeast, Massachusetts University, Amherst, Water Resources Research Center, NTIS Report No. PB-226 075/OST.

LaSalle, R. N. and Knight, K. L., 1973, The Effects of Ditching on the Mosquito Populations in Some Sections of "Juncus" Salt Marsh in Carteret County, North Carolina, North Carolina Water Resources Research Institute, Raleigh, NTIS Report No. PB-221 589/5ST.

Lauff, G. H., 1967, Estuaries, Michigan State University, Hickory Corners, W. K. Kellogg Biological Station, American Association for the Advancement of Science, Washington, D.C., Report No. 83.

Lefor, M. W., et al., 1975, Proceedings of Wetlands Confernece on Delineation of Wetlands, 2nd Annual Conference held at Storrs, CT on January 9, 1974, Connecticut University, Storrs Institute of Water Resources, NTIS Report No. PB-252 753/9ST.

Lichtler, W. F. and Walker, P. N., 1974, Hydrology of the Dismal Swamp, Virginia-North Carolina, U.S. Geological Survey, Open-File Report, p. 50.

Lugo, A. E. and Snedaker, S. C., 1973, The Role of Mangrove Forest in South Florida, University of Florida, Gainesville, FL, NTIS Report No. PB-231 741.

Maki, T. E., et al., 1975, Effects of Stream Channelization on Bottomland and Swamp Forest Ecosystems, North Carolina State University, Raleigh, School of Forest Resources, NTIS Report No. PB-269 021/2ST.

Male, A. J. and Farnsorth, M. C., 1975, Second Thoughts on Swamp Drainage, New Zealand, J. Agric., Vol. 130(3), p. 17.

Massachusetts Water Resources Commission, 1971, Neponset River Basin Flood Plain and Wetland Enroachment Study, Massachusetts Waster Resources Commission, Boston, p. 59.

McIntire, W. G., et al., 1975, A Rationale for Determining Louisiana's Coastal Zone, Louisiana State University, Baton Rouge, Center for Wetlands Resources, NTIS Report No. PB-255 328/7ST.

McLeese, R. L. and Whitesid, E. P., 1977, Ecological Effects of Highway Construction Upon Michigan Woodlots and Wetlands, Soil Relationships, J. Env. Quality, Vol. 6(4), p. 467.

Millar, J. B., 1973, Vegetation Changes in Shallow Marsh Wetlands Under Improving Moisture Regime, Can. J. Bot., Vol. 51(8).

Miller, B. J. and Goodwin, R. F., 1975, Legal and Economic Strategies for Shorelines Management - Workshop Proceedings, Washington University, Seattle, Division of Marine Resources, NTIS Report No. PB-256 186/8ST.

National Science Foundation, 1977, Long-Term Ecological Measurements, Report of a Conference held at Woods Hole, MA on March 18, 1977, National Science Foundation, Washington, D.C., NTIS Report No. PB-271 896/3ST.

National Science Foundation, 1977, Putting Wetlands to Work, Washington, D.C., Research Applied to National Needs, NTIS Report No. PB-272 453/2ST.

Neafsey, J. A., 1974, Developing Criteria for the Evaluation of Wetlands, New York State Assembly Scientific Staff and New York State Sea Grant Program, Albany, p. 46.

New York State Department of Environmental Conservation Catskill Study, 1976, Freshwater Wetlands in the Catskills, Report No. 10.

Niering, W. A., 1972, The Wetlands, Ecology Today, Vol. 2(3), p. 32-35.

Novitzki, R. P., 1978, Hydrology of the Nevin Wetland near Madison, Wisconsin, U.S. Geological Survey, Water Resources Investigation 78-48, in cooperation with the Wisconsin Department of Natural Resources.

O'Brien, A., 1977, Hydrology of Two Small Wetland Basins in Eastern Massachusetts, Water Resources Bull., Vol. 13(2), p. 325.

Orkruszko, H., 1967, Hydrological Factors as a Basis for Classification of Peat Bogs, National Science Foundation, Washington, D.C., SFSTI Report No. TT-66-57022.

Orr, H. K., 1975, Watershed Management in the Black Hills: The Status of Our Knowledge, U.S. Forestry Service Research Paper RM-141.

Park, W. M. and Batie, S., 1978, Alternative Management Strategies for Virginia's Coastal Wetlands: A Program of Study, Department of Agricultural Economics, VPI, Blacksburg, VA.

Parker, F., et al., 1976, Ecological Determinants of Coastal Area Management, Volume I: An Overview, North Carolina State University, Raleigh, NTIS Report No. PB-257 247/7ST.

Parker, G. R., 1970, The Structure of a Swamp Community in Northern Michigan and Its Reaction to Partial Drainage, Michigan State University, Ph.D. Dissertation.

Paulson, O. L. Jr., et al., 1977, Hydrologic and Biologic Characteristics of Natural Channels in Coastal Marsh of Mississippi, University of Southern Mississippi, Hattiesburg, Department of Geology, NTIS Report No. PB-273 813/6ST.

Pestrong, R., 1969, Tidal Flat Sedimentation at Cooley Landing, Southwestern San Francisco Bay, Stanford University, CFSTI Report No. AD-702 059.

Pestrong, R., 1965, The Development of Drainage Patterns on Tidal Marshes, Stanford University, School of Earth Sciences, Standford University Publications, Geological Sciences, Volume 10(2).

Pyne, R. D. G. and Wycoff, R. L., 1975, Urban Water Management and Coastal Wetland Protection in Collier County, Florida, Water Resource Bull. Vol. 11(3), p. 455.

Repert, R. T., et al., 1979, Wetland Values Concepts and Methods for Wetlands Evaluation, U.S. Army Corps of Engineers, Institute for Water Resources, Ft. Belvoir, VA.

Roberts, O. L. Jr., 1974, Cypress Land and Floodway: Environmental Change and the Development of Land Utilization in the Atchafalaya Basin, Louisiana, University of Tennessee, Ph.D. Dissertation.

Romanov, V. V., 1968, Hydrophysics of Bogs, National Science Foundation, Washington, D.C., CFSTI Report No. TT-65-51289.

Sander, J. E., 1976, Electric Analog Approach to Bog Hydrology, Groundwater, Vol. 14(1), p. 30.

Sather, J. H., 1976, Proceedings of the National Wetland Classification and Inventory Workshop, held at University of Maryland, College Park, MD, July 20-23, 1975, Fish and Wildlife Service, Washington, D.C., Office of Biological Services, NTIS Report No. PB-258 079/3ST.

Shabman, L. A. and Batie, S. S., 1979, Estimating the Economic Value of Coastal Wetlands: Conceptual Issues and Research Needs, VPI, Sea Grant Paper VPI-SG-79-08, Blacksburg, VA.

Shabman, L. A. and Batie, S. S., 1979, Estimating the Economic Value of Coastal Wetlands: Conceptual Issues and Research, International Estuarine Research Conference, Jeckyll Island, GA, October 7-12.

Silberhorn, G. M., et al., 1974, Coastal Wetlands of Virginia: Guidelines for Activities Affecting Virginia Wetlands, Virginia Institute Marine Science Special Report in Applied Marine Science and Ocean Engineering 46.

Singe, P. B., 1974, Studies on Drainage of Ditched Tidal Marshes, Rutgers University, Ph.D. Dissertation.

Stankevich, V. S. and Rubin, P. R., 1968, Drainage and Reclamation of Bogs and Bogged Areas, National Science Foundation, Washington, D.C., CFSTI Report No. TT-67-51298.

Taylor, J. W., 1955, Ditch, Tile, and Levee: The Significance of Wetlands and Their Drainage to the Wabash Lowlands of Indiana, Indiana University, Ph. D. Dissertation.

Terrell, R. E., et al., 1977, Estimating and Predicting Changes in Wetland Water Levels, Presented at Sensing of Environmental Pollutants 4th Joint Conference, New Orleans, November 6-11, p. 167.

Teskey, R. O. and Hinckley, T. M., 1977, Impact of Water Level Changes on Woody Riparian and Wetland Communities, Volume I: Plant and Soil Responses, Missouri University, Columbia, School of Forestry, Fisheries and Wildlife, NTIS Report No. PB-276 036/1ST.

Teskey, R. O. and Hinckley, T. M., 1977, Impact of Water Level Changes on Woody Riparian and Wetland Communities, Volume II: The Southern Forest Region, Missouri University, Columbia, School of Forestry, Fisheries and Wildlife, NTIS Report No. PB-276 037/9ST.

Teskey, R. O. and Hinckley, T. M., 1977, Impact of Water Level Changes on Woody Riparian and Wetland Communities, Volume III: The Central Forest Region, Missouri University, Columbia, School of Forestry, Fisheries and Wildlife, NTIS Report No. PB-276 038/7ST.

Tri-State Regional Planning Commission, 1975, The Tri-State Coastal Zone Management Perspectives, Tri-State Regional Planning Commission, New York, NTIS Report No. PB-245 658/0ST.

Tucker, D. L., et al., 1975, Use of Mathematical Models in the Palo Alto Marshland Rehabilitation Project, Presented at ASCE Symposium on Modeling Techniques, San Francisco, September 3-5, p. 140.

Vecchioli, J., Gill, H. E. and Lang, S. M., 1962, Hydrologic Role of the Great Swamp and Other Marshland in Upper Passaic River Basin, American Water Works Association Journal, Vol. 54, p. 697-701.

Vomperski, S. E., 1977, Biological Foundations of Forest Drainage Efficiency, Conservation Service, Washington, D.C., NTIS Report No. PB-273 902-T/ST.

Vorobev, P. K., 1974, Study of the Physical Characteristics of the Active Horizon of Undrained Bogs, Forest Service, Washington, D.C., NTIS Report No. TT-71-51010.

Walker, P. H., 1972, Seasonal and Stratigraphic Controls in Coastal Floodplain Soils, Aust. J. Soil Res., Vol. 10(2), p. 127.

Wharton, C. H., et al., 1977, Southern Swamps, Nature Conservancy News, Vol. 27(3), p. 4.

Wharton, C. H., et al., 1977, Forested Wetlands of Florida, Their Management and Use, Florida University, Gainesville, NTIS Report No. PB-282 215/3ST.

Winner, M. D. Jr. and Simmons, C. E., 1977, Hydrology of the Creeping Swamp Watershed, North Carolina, with Reference to Potential Effects of Stream Channelization, Geological Survey, Raleigh, NC, NTIS Report No. PB-270 926/9ST.

Young, C. E., et al., 1972, Hydrologic Model of Wetland Forest, J. Soil Water Conservation, Vol. 27(3), p. 122.

SHORELINE PROTECTION

American Water Resources Association, 1976, The Future of Chesapeake Bay, Washington, D.C., NTIS Report No. PB-263 457/4ST.

Armstrong, J. M. and Bruck, D. R., 1977, An Investment Decision Model for Shoreland Protection and Management, Coastal Zone Management J., Vol. 3 (3), p. 237.

Bahr, L. M. and Hebrard, J. J., Barataria Basin: Biological Characterization, Louisiana State University, Baton Rouge, Center for Wetlands Resources, NTIS Report No. PB-263 807/OST.

Baker, S., 1975, Coastal Development and Areas of Environmental Concern, Proceedings held at East Carolina University, Greensville, NC on March 5, 1975, North Carolina State University, Raleigh, NTIS Report No. PB-247 358/5ST.

Bartberger, C. E., 1976, Sediment Sources and Sedimentation Rates, Chincoteague Bay, Maryland and Virginia, J. Sed. Petrology, Vol. 46(20), p. 326.

Bellis, V., et al., 1975, Estuarine Shoreline Erosion in the Albemarle-Pamlico Region of North Carolina, East Carolina University, Greensville, NTIS Report No. PB-257 257/6ST.

Bird, E. C., 1971, Mangroves as Land Builders, Victorian Nat., Vol. 88(7), p. 189-197.

Bird, E. C. F. and Barson, M. M., 1975, Shoreline Changes in Westernport Bay, R. Soc. Victoria Proc., Vol. 87(1&2), p. 15.

Bloom, A. L., 1967, Coastal Geomorphology of Connecticut, Cornell University, Department of Geological Sciences, Ithaca, Final Report, p. 79.

Boon, J. D. III, 1975, Tidal Discharge Asymmetry in a Salt Marsh Drainage System, Limnology and Oceanography, Vol. 20(1), p. 71.

Bradley, E. H. Jr. and Armstrong, J. M., 1972, A Description and Analysis of Coastal Zone and Shoreland Management Programs in the United States, University of Michigan, Technical Report No. 20.

Brown, R. J., 1978, Salt Marshes, Volume 1, National Technical Information Service, Springfield, VA, NTIS Report No. PS-78 0533/6ST.

Brown, R. J., 1978, Salt Marshes, Volume 2, National Technical Information Service, Springfield, VA, NTIS Report No. PS-78 0533.

Camfield, F. E., 1977, Wind-Wave Propagation Over Flooded, Vegetated Land, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Technical Paper No. 77-12.

Carlton, J. M., 1974, Land-Building and Stabilization by Mangroves, Env. Conservation, Vol. 1(4), p. 285.

Choate, J. S., 1972, Stream Channeling in Wetlands in Minnesota Watershed, J. Wildlife Mgmnt, Vol. 36(3), p. 940.

Christmas, J. Y., 1973, Cooperative Gulf of Mexico Estuarine Inventory and Study, Mississippi, Gulf Coast Research Laboratory, Ocean Springs, MS, NTIS Report No. COM-73-11269/0.

Clark, J. and J. Clark (Editors), 1979, Scientists Report, The National Symposium on Wetlands, Lake Buena Vista, FL, November 6-8, 1978, National Wetlands Technical Council.

Coleman, J. M., 1966, Recent Coastal Sedimentation: Central Louisiana Coast, Louisiana State University, Baton Rouge Coastal Studies Institute, Report No. AD-653 092.

Council on Environmental Quality, 6th Annual Report, 1975, Perspectives on the Environment: Coastal Zones.

Coventry, R. J. and Jennings, J. N., 1973, Structure and Texture of a Gravelly Barrier Island in the Fitzroy Estuary, Western Australia, and the Role of Mangroves in the Shore Dynamics, Aust. Marine Geol. Vol. 15 (3), p. 145.

Cowardin, L. M., et al., 1977, Classification of Wetlands and Deep-Water Habitats of the United States, U.S. Fish and Wildlife Service, Operational Draft Report.

Craig, N. J. and Day, J. W. Jr., 1976, Barataria Basin: Eutrophication Case History, Louisiana State Planning Office, Baton Rouge, Coastal Resources Program, Louisiana State University, Baton Rouge, NTIS Report No. PB-265 278/2ST.

Dahl, B. E., et al., 1975, Construction and Stabilization of Coastal Foredunes with Vegetation: Padre Island, Texas, Gulf Universities Research Consortium, Houston, TX, NTIS Report No. AD-A018 065/3ST.

Daiber, F. C., 1976, Tidal Marsh Bibliography, Selected Key Work Index, Delaware University, Newark, College of Marine Studies, NTIS Report No. PB-263 386/5ST.

Darnell, R. M., et al., 1976, Impacts of Construction Activities in Wetlands of the United States, Tereco Corp., College Station, TX, Environmental Research Laboratory, Corvallis, OR, NTIS Report No. PB-256 674/3ST.

Department of the Interior, 1974, The Biological Impact of Residential Real Estate Development in the South Florida Coastal Wetlands, South Florida Environmental Project, Atlanta, GA, NTIS Report No. PB-231 672/7ST.

Dinkins, C. E., 1972, Texas Seashore Boundary Law: The Effect of Natural and Artificial Modifications, Texas Law Institute of Coastal and Marine Resources, Houston, NTIS Report No. PB-222 136/4.

Dodd, J. D. and Webb, J. W., 1975, Establishment of Vegetation for Shoreline Stabilization in Galveston Bay, Texas A&M University, College Station, Department of Range Science and Coastal Engineering Research Center, Fort Belvoir, VA, NTIS Report No. AD-A012 839/7ST.

Doiron, L. N. and Whitehurst, C. A., 1974, Geomorphic Processes Active in the Southwestern Louisiana Canal, Lafourche Parish, Louisiana, Louisiana State University, Baton Rouge, Division of Engineering Research, NTIS Report No. N75-1512B/2ST.

Eberhart, R. C., 1975, Chesapeake Bay Research and Management Shoreline Data Bank, IEEE Conference on Engineering in the Ocean Environment and Marine Technology Soc., 11th Annual Meeting, Proceedings of, San Diego, CA, September 22-25, p. 423.

Elkington, J. B., 1977, The Impact of Development Projects on Estuarine and Other Wetland Ecosystems, Env. Conservation, Vol. 4(2), p. 135.

Fosberg, F. R., 1971, Mangroves Versus Tidal Waves, Biological Conservation, Vol. 4(1).

Garbish, E. W. Jr., 1977, Marsh Development for Shore Erosion Control, In: Great Lakes Vegetation Workshop Proceedings, Great Lakes Basin Commission and U.S. Department of Agriculture, p. 77.

Garbisch, E. W. Jr., 1977, Recent and Planned Marsh Establishment Work throughout the Contiguous United States - A Survey and Basic Guidelines, Environmental Concern Inc., St. Michaels, MD, NTIS Report No. AD-A041 464/9ST.

Garbisch, E. W. Jr., et al., 1975, Salt Marsh Establishment and Development, Environmental Concern Inc., St. Michaels, MD, Coastal Engineering Research Center, Fort Belvoir, VA, NTIS Report No. AD-A014 136/6ST.

Giannio, S. P. and Wang, H., 1974, Engineering Considerations for Marinas in Tidal Marshes, Delaware University, Newark, College of Marine Studies, NTIS Report No. COM-75-10105/5ST.

Greeson, P. E., Clark, J. and Clark J. (Editor), 1979, Wetland Functions and Values: The State of our Understanding, Proceedings of the Symposium sponsored by the American Water Resources Association, Minneapolis, MN.

Gosselink, J. G. and Turner, R. E., 1978, The Role of Hydrology in Freshwater Wetland Ecosystems, In: Good, R. E., Whigham, D. F. and Simpson, R. L. - Editors), Freshwater Wetlands: Ecological Processes and Management Potential, Academic Press, New York, p. 378.

Greensmith, J. T. and Tucker, E. V., 1965, Salt Marsh Erosion in Essex, Nature, Vol. 206(4984), p. 606.

Hails, J. R. and Hoyt, J. H., 1967, Pleistocene Shoreline Sediments in Coastal Georgia-Deposition and Modification, Science, Vol. 155(3769), p. 1541.

Hall, F. R., et al., 1972, The Influence of a New England Wetland on Water Quantity and Quality, Water Resources Research Center, New Hampshire University, Durham, NTIS Report No. PB-213 268/6ST.

Hall, V. L. and Ludwig, J. D., 1975, Evaluation of Potential Use of Vegetation for Erosion Abatement Along the Great Lakes Shoreline, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Miscellaneous Paper No. 7-75.

Heath, R. C., 1975, Hydrology of the Albemarle-Pamlico Region North Carolina, A Preliminary Report of the Impact of Agricultural Developments, Geological Survey, Raleigh, NC, Water Resources Division, North Carolina Department of Natural and Economic Resources, Raleigh, NTIS Report No. PB-243 642/6ST.

Helfgott, T., et al., 1973, Proceedings: Wetlands Conference, 1st Annual Conference held on June 20, 1973 at Storrs, CT, Connecticut University, Storrs, Institute of Water Resources, NTIS Report No. PB-232 430/9ST.

Hertsgaard, T., 1975, Evaluation of Alternative Uses of Wetlands, North Dakota State University, Water Resources Research Institute, Report No. WI-221-035-76.

Jenks, B., et al., 1976, Coastal Zone Bibliography: Citations to Documents on Planning, Resources Management and Impact Assessment, Second Edition, California University, San Diego, Institute of Marine Resources, NTIS Report No. PB-259 647/6ST.

Knutson, P. L., 1977, Planting Guidelines for Marsh Development and Bank Stabilization, Coastal Engineering Research Center, Fort Belvoir, VA, NTIS Report No. AD-A046 547/6ST.

Kraft, J. C. and Caulk, R. L., 1972, The Evolution of Lewes Harbor, Delaware University, Newark, College of Marine Studies, NTIS Report No. AD-753 860.

Larson, J. S., 1976, Models for Evaluation of Freshwater Wetlands, Massachusetts University, Amherst, Water Resources Research Center, NTIS Report No. PB-253 950/0ST.

Larson, J. S., et al., 1976, Models for Assessment of Freshwater Wetlands, University of Massachusetts Water Resources Research Center, Report No. 32.

Larson, J. S., 1973, A Guide to Important Characteristics and Values of Freshwater Wetlands in the Northeast, Massachusetts University, Amherst, Water Resources Research Center, NTIS Report No. PB-226 075/0ST.

Lauff, G. H., 1967, Estuaries, Michigan State University, Hickory Corners, W. K. Kellogg Biological Station, American Association for the Advancement of Science, Washington, D.C., Report No. 83.

Lefor, M. W., et al., 1975, Proceedings of Wetlands Confernece on Delineation of Wetlands, 2nd Annual Conference held at Storrs, CT on January 9, 1974, Connecticut University, Storrs Institute of Water Resources, NTIS Report No. PB-252 753/9ST.

McIntire, W. G., et al., 1975, A Rationale for Determining Louisiana's Coastal Zone, Louisiana State University, Baton Rouge, Center for Wetlands Resources, NTIS Report No. PB-255 328/7ST.

Miller, B. J. and Goodwin, R. F., 1975, Legal and Economic Strategies for Shorelines Management - Workshop Proceedings, Washington University, Seattle, Division of Marine Resources, NTIS Report No. PB-256 186/8ST.

National Science Foundation, 1977, Long-Term Ecological Measurements, Report of a Conference held at Woods Hole, MA on March 18, 1977, National Science Foundation, Washington, D.C., NTIS Report No. PB-271 896/3ST.

Neafsey, J. A., 1974, Developing Criteria for the Evaluation of Wetlands, New York State Assembly Scientific Staff and New York State Sea Grant Program, Albany, p. 46.

Novitzki, R. P., 1978, Hydrology of the Nevin Wetland near Madison, Wisconsin, U.S. Geological Survey, Water Resources Investigation 78-48, in cooperation with the Wisconsin Department of Natural Resources.

Oertel, G. F. and Harding, J. L., Wassaw Island Erosion Study, Part III: Sand Stabilization on the Dunes, Beach and Shoreface of a Historically Eroding Barrier Island, Georgia Marine Science Center, Savannah, NTIS Report No. PB-267 028/9ST.

Orr, H. K., 1975, Watershed Management in the Black Hills: The Status of Our Knowledge, U.S. Forestry Service Research Paper RM-141.

Parker, F., et al., 1976, Ecological Determinants of Coastal Area Management, Volume I: An Overview, North Carolina State University, Raleigh, NTIS Report No. PB-257 247/7ST.

Pestrong, R., 1969, Tidal Flat Sedimentation at Cooley Landing, Southwestern San Francisco Bay, Stanford University, CFSTI Report No. AD-702 059.

Pyne, R. D. G. and Wycoff, R. L., 1975, Urban Water Management and Coastal Wetland Protection in Collier County, Florida, Water Resource Bull. Vol. II(3), p. 455.

Quisenberry, D. L., et al., 1977, The Role of Vegetation in Stabilization of the Great Lakes Shoreline, Great Lakes Vegetation Workshop Proceedings.

Ranwell, D. W., 1975, Management of Salt-Marsh and Coastal-Dune Vegetation, Coastal Ecol. Res. Stn., Inst. of Terr. Ecol., Norwich, England, Int. Estuarine Resources Conference, 2nd: Estuarine Resources, Vol. 2, Academic Press, New York, p. 471.

Redfield, A. C., 1972, Development of a New England Salt Marsh, Ecological Monographys, Vol. 42(2), p. 201.

Repert, R. T., et al., 1979, Wetland Values Concepts and Methods for Wetlands Evaluation, U.S. Army Corps of Engineers, Institute for Water Resources, Ft. Belvoir, VA.

Rhode Island Statewide Planning Program, 1972, Protection and Control of the Salt Water Shore Area, Providence, NTIS Report No. PB-212 886/6ST.

Rogers, J., et al., 1976, Maryland Uplands Natural Areas Study, Volume I: Eastern Shore, Maryland Department of Natural Resources, Annapolis, Coastal Zone Management Program, NTIS Report No. PB-263 025/9ST.

Rogers, J., et al., 1976, Maryland Uplands Natural Areas Study, Volume II: Eastern Shore - Field Notebook, Maryland Department of Natural Resources, Annapolis, Coastal Zone Management Program, NTIS Report No. PB-263 026/7ST.

Salisbury, E. J., 1973, Conservational Importance of Pioneer Vegetation of Exposed Muds, Biol. Conserv., Vol. 5(4), p. 310.

Sather, J. H., 1976, Proceedings of the National Wetland Classification and Inventory Workshop, held at University of Maryland, College Park, MD, July 20-23, 1975, Fish and Wildlife Service, Washington, D.C., Office of Biological Services, NTIS Report No. PB-258 079/3ST.

Savage, R. P. and Woodhouse, W. W. Jr., 1968, Creation and Stabilization of Coastal Barrier Dunes, Army Coastal Engineering Research Center, Washington, D.C., Proceedings of the 11th Conference on Coastal Engineering, London, England.

Savage, T., 1972, Florida Mangroves as Shoreline Stabilizers, Florida Department of Resource, Marine Research Laboratory, Professional Paper Series No. 19.

Self, R. P., 1973, A Study of Sediment Transport and Erosion in the Fourchon Area of South Louisiana, Louisiana State University, Baton Rouge, Division of Engineering Research, NTIS Report No. N74-16056/5.

Sell, M. G. Jr., 1977, Modeling the Response of Mangrove Ecosystems to Herbicide Spraying, Hurricanes, Nutrients Enrichment and Economic Development, University of Florida, Ph.D. Dissertation.

Shabman, L. A. and Batie, S. S., 1979, Estimating the Economic Value of Coastal Wetlands: Conceptual Issues and Research Needs, VPI, Sea Grant Paper VPI-SG-79-08, Blacksburg, VA.

Shabman, L. A. and Batie, S. S., 1979, Estimating the Economic Value of Coastal Wetlands: Conceptual Issues and Research, International Estuarine Research Conference, Jeckyll Island, GA, October 7-12.

Silberhorn, G. M., et al., 1974, Coastal Wetlands of Virginia: Guidelines for Activities Affecting Virginia Wetlands, Virginia Institute Marine Science Special Report in Applied Marine Science and Ocean Engineering 46.

Steers, J. A., 1969, The Sea Coast, The Sea Coast, Collins, London, p. 292.

Steers, J. A., 1969, Coasts and Beaches, Coasts and Beaches, Oliver & Boyd, Endinburgh.

Teas, H. J., 1977, Ecology and Restoration of Mangrove Shorelines in Florida, Env. Conservation, Vol. 4(1), p. 51.

Thom, B. G., 1967, Mangrove Ecology and Deltaic Geomorphology: Tabasco, Mexico, Louisiana State University, Baton Rouge, Coastal Studies Institute, J. Ecol., Vol. 55, p. 301-343.

Thom, B. G., et al., 1975, Mangrove Ecology and Deltaic-Estuarine Geomorphology: Cambridge Gulf - Ord River, Western Austrialia, Louisiana State University, Baton Rouge, Coastal Studies Institute, J. Ecol. Vol. 63, p. 203-232, NTIS Report No. AD-A015 161/3ST.

Trent, W. L., et al., 1972, Waterfront Housing Developments: Their Effects on the Ecology of a Texas Estuarine Area, National Marine Fisheries Service, Galveston, Biological Laboratory, NTIS Report No. COM-73-10851.

Tri-State Regional Planning Commission, 1975, The Tri-State Coastal Zone Management Perspectives, Tri-State Regional Planning Commission, New York, NTIS Report No. PB-245 658/0ST.

Wanless, H. R. and Rine, J. M., 1976, Timing Character and Preservability of Sedimentation Events in Low Energy Coastal Environments Southwest Florida, Am. Assoc. Pet. Geol. Bull., Vol. 60(4), p. 731.

Wayne, C. J., 1976, The Effects of Sea and Marsh Grasses on Wave Energy, Unpublished paper dated March 1976.

Weil, C. B., 1977, Sediments, Structural Framework, and Evolution of Delaware Bay: A Transgressive Estuarine Delta, Delaware University, Newark, College of Marine Studies, NTIS Report No. PB-271 074/7ST.

Wentz, W. A., et al. 1974, State-of-the-Art Survey and Evaluation of Marsh Plant Establishment Techniques: Induced and Natural, Volume II, Michigan University, Ann Arbor School of Natural Resources, NTIS Report No. AD-A012 837/1ST.

Whitehurst, C. A. and Self, R. P., 1974, Sediment Transport and Erosion in the Fourchon Area of Lafourche Parish, Louisiana State University, Baton Rouge, NTIS Report No. N74-26911/9.

Woodhouse, W. W. Jr., et al., 1976, Propagation and Use of "Spartina alterniflora" for Shoreline Eros[illegible] Abatement, North Carolina State University, Raleigh, NTIS Report No. AD-A030 423/8ST.

Woodhouse, W. W. Jr., et al., 1976, Ten Years of Development of Man-Initiated Coastal Barrier Dunes in North Carolina, North Carolina State University, Raleigh, NTIS Report No. PB-273 113/1ST.

Woodhouse, W. W. Jr., 1974, Stabilizing Coastal Dunes, North Carolina State University, Raleigh, NTIS Report No. COM-75-10493/5ST.

Woodhouse, W. W. Jr., et al., 1974, Propagation of "Spartina alterniflora for Substrate Stabilization and Salt Marsh Development, North Carolina State University, Raleigh, NTIS Report No. AD/A-002 005 2ST.

END

FILMED

2-85

DTIC