SELF-TAUGHT EDUCATION UNIT

Wetland Functions And Values

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Introduction

Throughout the state of Virginia there is a variety of wetland types which range from tidal marshes and swamps near the coast, to nontidal wetlands found anywhere from the coastal plain to the mountains. Wetlands are found in topographic depressions or along rivers, lakes, and coastal waters. Wetlands, in general, are areas that are wet or have wet soils during some part of the growing season. Wetland soils are **hydric** meaning they have an abundance of moisture. Wetlands are further characterized by the vegetation that they support which is adapted to grow in wet conditions, which is referred to as **hydrophytic** vegetation. Wetland vegetation may include grasses, herbaceous plants (non-woody), shrubs, and trees. **Tidal wetlands** are found along the coastline where they are influenced by daily tidal fluctuations and include vegetated marshes and swamps or non-vegetated mud and sand flats (Figure 1). **Nontidal wetlands** are not influenced by tidal inundation and may include marshes, swamps, bogs, and low-lying areas along the margins of rivers, streams and lakes. They can also be found in isolated upland depressions or areas where the water table stays near the land surface (Figure 2). Nontidal and tidal wetlands share many of the same values and both are impor-tant in maintaining the health of the Chesapeake Bay and its living resources.

Wetlands were historically considered wastelands that harbored bothersome snakes and disease-carrying insects. They were considered useless for most farming or building because of the unstable, wet substrate. These lands were often drained or filled for farming, housing, and urban development. This view has changed significantly as the connection between wetlands, wildlife, water quality, and other ecological and economic values have been studied. Hunters, fishermen, trappers, and loggers have always benefited from the abundant supply of mammals, fish, waterfowl, and lumber harvested from wetlands.

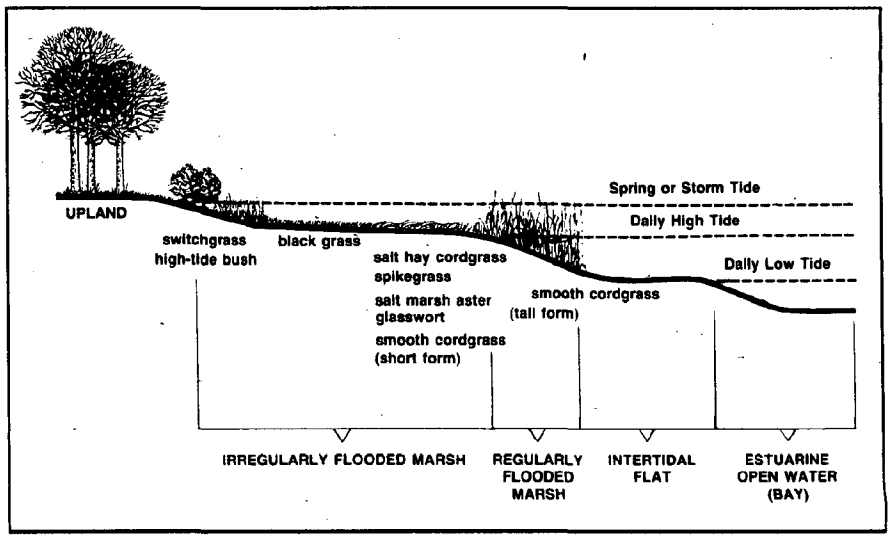

Figure 1. Cross-sectional diagram of a tidal salt marsh (adapted from Tiner, 1984).

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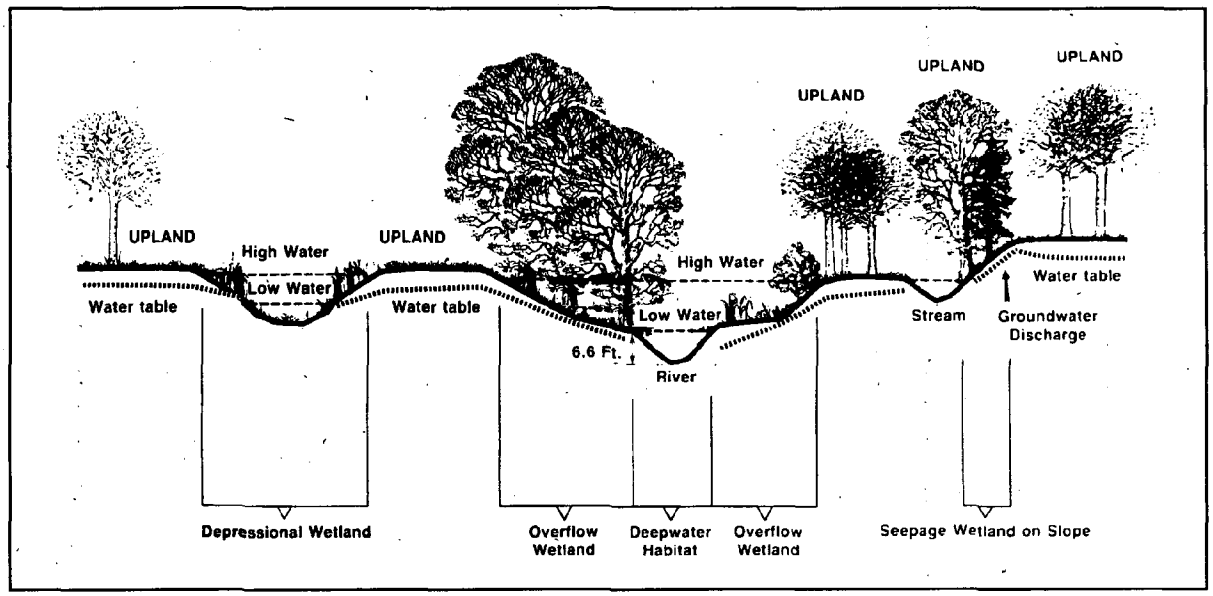
Figure 2. Schematic diagram showing wetlands, deepwater habitats, and uplands on landscape. Note differences in wetlands due to hydrology and topographic location (adapted from Tiner, 1984).



Wetland Functions and Values

Ecological processes are usually described by function, such as wildlife habitat support or primary productivity. **Function** is an ecological process that may not directly benefit humanity. The further classification of a function by its **value** connotes usefulness to humans. However, in general these terms may be used interchangeably because functions may be values. The location of the wetland, the human population pressures on it, or the extent of the wetland may indicate the value of a functional ecologic process (Mitsch and Gosselink, 1986). For example, wildlife habitat may be important to humans because it provides wildlife for hunting, or nature study. Location may give the wetland value also, for example; a wetland may be important for water quality if it is located downstream of a pollution source, there it has the greatest potential for filtering pollutants.

Wetlands provide many ecological and socio-economic benefits including: water quality improvement, aquatic productivity, fish and wildlife habitat, shoreline erosion control, stormwater treatment, flood protection, potable water supplies, economically valuable resources, and recreation. Wetlands are diverse and cover a wide range of habitats. Because they do not all provide the same values or functions, generally it is difficult to determine the functions a wetland provides without site specific analysis. Variables to consider in assessing the functional values of a wetland may include: wetland type, soil characteristics, hydrology, size, and surrounding upland land use. This report gives an overview of wetland functions and values.

Wetland Values to the Chesapeake Bay

In considering the values of wetlands, it is important to understand the coupling of wetlands with adjacent ecosystems, such as streams, rivers, lakes, bays, uplands, and floodplains. Of particular concern is the value Virginia's wetlands may play in improving or maintaining the Chesapeake Bay ecosystem. The entire Bay watershed should be considered in evaluating the

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Wetland Values

ENVIRONMENTAL QUALITY VALUES

Water Quality Improvement

- Pollutant removal (heavy metals, pathogens)
- Sediment trapping
- Nutrient uptake and recycling
- Oxygen production
- Wastewater treatment
- Stormwater treatment

Aquatic and Terrestrial Productivity

Fish and Wildlife Habitat

- Spawning and nesting sites
- Nursery areas for young
- Shelter from predators
- Foraging areas

SOCIO-ECONOMIC VALUES

- Shoreline Erosion Control
- Flood Protection
- Groundwater recharge and discharge
- Natural products (timber, fish, waterfowl)
- Recreation (boating, fishing, hunting)
- Aesthetics

cumulative function of wetlands. A **watershed** can be defined as all the area that drains by surface or subsurface flow into the water body being considered (Figure 3). The Chesapeake Bay watershed extends north through parts of New York State and west to the Appalachian mountains covering approximately 64,000 square miles (Chesapeake Bay Program, 1983)(Figure 3). Approximately 3% of the watershed is comprised of wetlands (Tiner, 1987). Any substance that is added to the land or water within this area has the potential to impact the water quality and ecology of the Bay system. For example, agricultural or lawn fertilizers applied in western Virginia or New York have the potential to impact the Bay either through surface flow or groundwater flow (Figure 4). Wetlands throughout this watershed have the potential to improve or maintain many ecological values in waters flowing toward the Bay, especially water quality.

Water Quality

Located at the interface between terrestrial and aquatic systems, wetlands often intercept pollutants and nutrients in upland runoff before they reach an adjacent waterway (Figure 5). Substances that can affect water quality include nutrients, dissolved gases, heavy metals, pesticides, pathogens, and industrial wastes. The nutrients of most importance in wetland and aquatic systems are nitrogen and phosphorous. In excessive quantities, they can cause nuisance algal blooms and subsequent low oxygen levels; however, they are essential for growth of wetland plants. Dissolved oxygen is produced by plants and is necessary for aquatic animals to survive. The processes occurring in wetland systems that impact water quality are plant uptake and cycling, filtering, sedimentation, reduction in shoreline erosion, soil adsorption, and soil microbial activity.

Nutrient Uptake and Cycling

As wetland plants grow they take up **inorganic forms** of nutrients (nitrogen, phosphorous) as they die they release **organic** or detrital forms (decaying plant material) of nutrients. The result is a valuable cycling and transformation of nutrients in the ecosystem. The transformation from inorganic to organic forms of nutrients reduces potential problems from excessive nutrient loadings, while providing organic forms of nutrients that are more useful to aquatic animals (Figure 6).

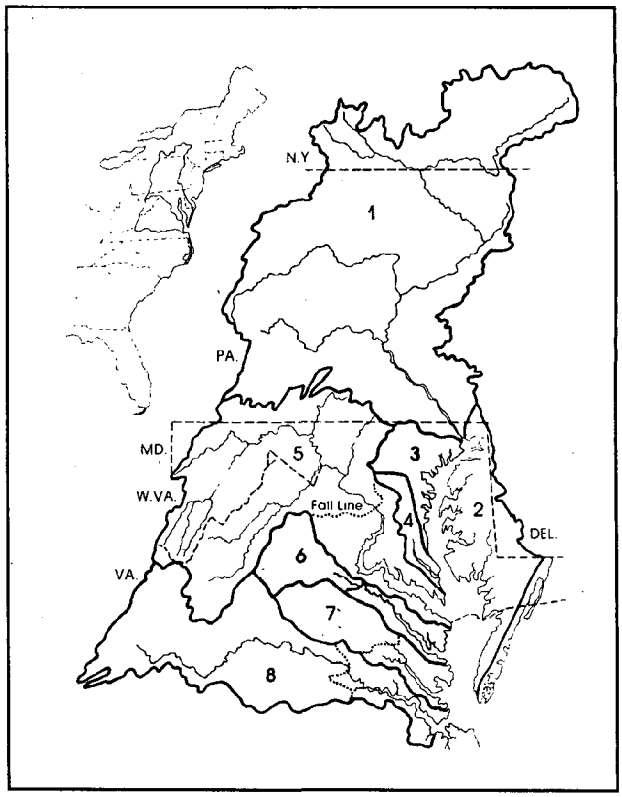

Figure 3. Chesapeake Bay watershed and major drainage basins (adapted from Chesapeake Bay Program, 1983).

The organic forms of nutrients provide the base of the detrital food web, which may support many commercially important fish, crabs, and shellfish (Elder, 1985). Detritus is consumed by many small invertebrates, juvenile fish, and oysters, which in turn are eaten by larger fish, birds, and crabs. This pattern of feeding is called a **food web** and is essential to the viability of the Chesapeake Bay and for providing fish for human consumption (Figure 7). Excessive nutrients may come from septic system leakage, sewage effluent, runoff from fertilized lawns and farms, and stormwater outflows. Uncontrolled inputs of nutrients may contribute to decreased water clarity by stimulating algal blooms. As the algae bloom dies and decomposes, it may also reduce the oxygen content in the water.

Some wetlands function as nutrient sinks in which the net output of nutrients is less than the net input. Most wetlands are at least seasonal sinks for nutrients, taking them up during the growing season. This wetland function can be very important in managing urban and agricultural runoff with high concentrations of nutrients which may degrade downstream water quality. The research of Cerco and Kuo (1979) concluded that a tidal marsh creek that received effluent from a poultry processing plant significantly reduced levels of nutrients and increased levels of dissolved oxygen. A review by Van der Valk et al. (1979) of 17 studies showed that freshwater wetlands trapped nutrients during the growing season. Even a slight increase in the amount of wetlands in an agricultural watershed reduced the amount of nitrogen leaving the watershed (Jones et al., 1976).

Plants may also take up heavy metals, and other chemical pollutants and incorporate them into their leaves, roots, and stems (Kadlec and Kadlec, 1979; Boto and Patrick, 1979). As the plant dies, the pollutants may be buried and removed from the system or returned to the water column. If the plant is consumed by an animal the pollutants may be passed up the food web.

Wetland Soil Processes

Wetland soils have been shown to be more important at removing nutrients from the overlying water than plant uptake. Sather et al. (1990) states that chemical adsorption or adhesion by detritus and chemical precipitation appear to remove more phosphorus than plant uptake. Bacteria at the water sediment interface remove significant amounts of nitrogen from the water column (Sather et al., 1990). Soil microbes such as bacteria are also important in degrading pesticides, resulting in reduced potential risk even if the soils are disturbed (Boto and Patrick, 1979).

Filtering and Sedimentation

Wetlands are sites of increased sedimentation, which improves water quality by reducing suspended solids and increases bank stabilization through the accumulation of sediment. Wetland vegetation and the associated root mass act to slow water flow, which results in settlement and deposition of suspended sediments, and the associated pollutants, and nutrients (Boto and Patrick, 1979). Riparian areas have been shown to retain 80 percent of sediment runoff from adjacent agricultural lands

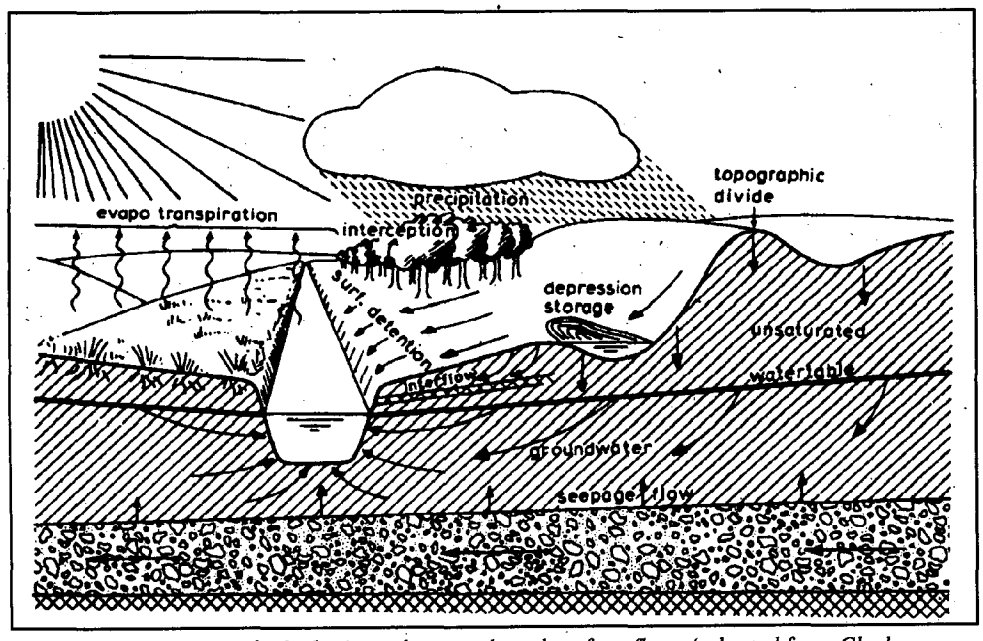

Figure 4. The riverine hydrologic cycle, note the subsurface flows (adapted from Clark, 1983).

(Richardson, 1989). Wetlands located in depressions may retain all the sediment entering them (Novitzki, 1979). Benefits are realized by increased water clarity and reduced siltation in downdrift oyster beds, fish spawning and nursery areas, seagrass beds, and navigation channels (Anderson et al., 1978).

As sediments are removed from the water column, so are attached nutrients, heavy metals, and other toxins. Mitsch et al. (1979) found that large amounts of phosphorous were deposited with river sediments during river flooding in a swamp. Most wetland sediments accumulate faster than they are removed. This accumulation rate allows the wetland to retain a significant portion of the nutrients and other pollutants buried in the soil (Sather et al., 1990). Heavy metals and other toxic substances attached to sediment particles will become immobile through burial in sediments until they become disturbed through dredging or lowering of the water table (Boto and Patrick, 1979).

Wastewater Treatment

Naturally occurring and artificially made wetlands have been utilized as an economically viable alternative in wastewater treatment. It has been shown that some wetlands are successful at reducing nutrients, heavy metals, and bacteria from sewage effluent and other waters (Grant and Patrick, 1970; Sloey et al., 1978; Kadlec and Kadlec, 1979). In Monterey, a town in western Virginia, a bulrush wetland was the most economical alternative for accomplishing secondary wastewater treatment. (Virginia Natural Resources Newsletter, 1989). Freshwater wetlands filter 60 - 90 percent of the suspended solids from wastewater addition studies (Richardson, 1989). Boyt et al. (1976) studied a hardwood swamp that had been receiving sewage effluent for 20 years and reported a 98 percent reduction in phosphorous and 90 percent reduction in nitrogen in the outflow waters. Coliform bacteria may also show significant reductions in sewage effluent after passing through a wetland (Spangler et al., 1976). Coliforms are an indicator of human fecal matter which may contain pathogens. Some wastewater heavy metals that are incorporated in plant tissue can be passed up the food web as organisms feed on the plant parts (Windom, 1976; Roman, 1981).

Stormwater Management

Stormwater runoff is becoming widely recognized as a significant contributor to water pollution problems. Stormwater runoff may contain many pollutants, among them are fuel and chemical spillage, lawn fertilizers and herbicides, vehicle drippings (oil, gas, antifreeze), sediment from erosion or construction activities, and sewage from failing systems. Urban areas are beginning to implement natural methods of reducing these pollutant loads, including vegetated drainage ways and detention basins with their associated wetland border. The Commonwealth's Best Management Practices (BMP) Manual for urban areas suggests using wetlands for natural biological treatment of stormwater (Virginia State Water Control Board, 1979b). Directing stormwater runoff through a wetland can be considered a filtering process analogous to running dirty water through a coffee filter. The filtering

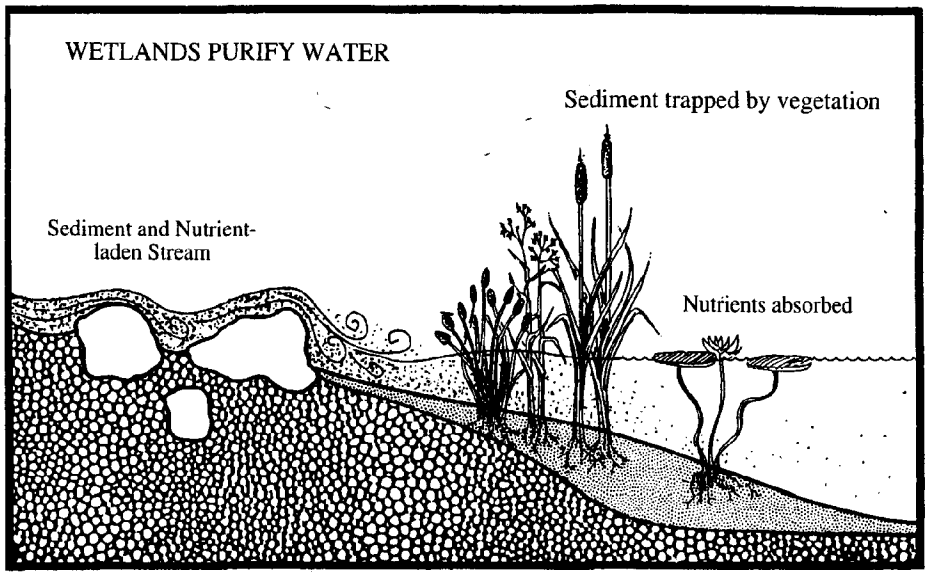

Figure 5. Wetlands help purify water by filtering out nutrients, wastes, and sediment from runoff and floods (adapted from Kusler, 1983).

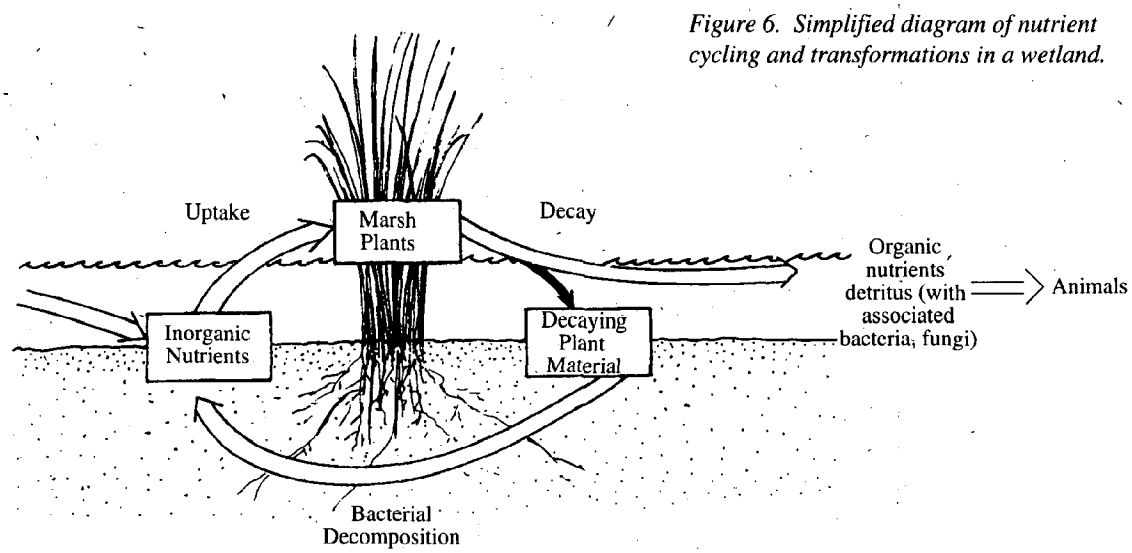

Figure 6. Simplified diagram of nutrient cycling and transformations in a wetland.

process is accompanied by complex biological and chemical reactions that occur in the wetland, resulting in significant reductions in total pollutants.

In summary, establishment or maintenance of wetland buffer zones may significantly improve water quality in the adjacent and downstream water bodies. Wetlands can improve water quality by five mechanisms: 1) plant nutrient uptake and cycling, 2) soil processes, 3) bacterial processes, 4) sedimentation, 5) reduction in shoreline erosion (discussed later).

Primary Production

Wetland productivity provides the source of many wetland functions, including nutrient recycling, fish and wildlife food and habitat, and food web support. All life is ultimately dependent on the photosynthetic production of plant material by **primary producers**. Photosynthetic production of plant tissue converts the sun's energy into a form which can be used by animals. In this process, nutrients and carbon dioxide are taken up and oxygen is released. Primary producers include grasses, shrubs, trees, macro-algae, and floating microscopic plants (phytoplankton). Wetland plants produce more plant material than some of our most productive cultivated farm fields (Figure 8)(Teal and Teal, 1969). Numerous wetland plant adaptations allow for maximum growth rates that are less common or impossible for terrestrial plants, which may be water or nutrient limited (Wetzel, 1989). Watersheds which drain wetland regions export more organic material than do watersheds that do not have wetlands (Mitsch and Gosselink, 1986).

Wetzel (1989) compared the productivity rates across a wetland gradient beginning on the uplands and moving into the open water. He reported that the photosynthetic production of organic matter was greatest in the wetland area. The upland forest and plants produced less than half the amount of organic matter that the wetland produced.

A portion of wetland production is directly consumed by animals such as mammals, birds, and insects. The most significant portion is consumed as detritus which is decaying plant material that is colonized by microorganisms (bacteria, protozoa, and fungi). The attached microbes increase the nutritional content of the plant material, resulting in a highly nutritious and readily available food source for many aquatic organisms including fish, crabs, shellfish, and zooplankton (microscopic animals). The fungi and bacteria in swamps produce vitamin B12, which is necessary for aquatic invertebrates and fish growth (Burkholder, 1956). Floodplain swamp forests are among the most productive ecosystems due to periodic flooding that supplies organic matter, water, nutrients, and clay (Bates, 1989).

Fish and Wildlife Habitat

Wetlands are used by a large variety of birds, fish, mammals, and invertebrates for food, shelter, and spawning and nesting sites. Among the most valued

food items in wetlands are plant leaves, detritus, tubers, seeds, snails, clams, worms, frogs, and insects. Approximately two-thirds of the fish and shellfish species that are harvested commercially are associated with wetlands (Mitsch and Gosselink, 1986). These species include: blue crab, oyster, clam, shrimp, striped bass, menhaden, bluefish, flounder, sea trout, spot, and croaker. Rozas and Hackney (1984) found 29 species of fish in a tidal marsh and suggested that shallow marsh areas are a preferred habitat because of reduced competition, slow currents, scarcity of predators and an abundant food supply.

In 1967-1968, 95% of Virginia's annual fish harvest was shown to be at least partially dependent on wetlands (Wass and Wright, 1969). Blue crabs use tidal marsh creeks as shelter from predators during molting (Hines et al., 1987). Juvenile blue crabs and 14 species of fish were more abundant on flooded salt marsh surfaces than in nonvegetated subtidal areas (Zimmerman and Minello, 1984a). Some species, such as mummichogs (minnows) and fiddler crabs, utilize wetlands throughout their lifespan. Other species, such as striped bass, spawn in waters adjacent to tidal freshwater marshes similar to those along the Pamunkey River (McGovern and Olney, 1988). Many coastal fish, including spot, menhaden, and mullet, use wetlands as nursery areas for their juvenile stage (Weinstein, 1979). The diet of menhaden has been shown to consist of 30% marsh derived detritus and 70% plankton (Deegan et al., 1990).

Mitsch and Gosselink (1986) reported that virtually all of the freshwater fish and shellfish are partially dependent on wetlands (Figure 9). Freshwater fish depend on wetlands for food, nursery grounds, and spawning. Almost all recreational freshwater fish spawn in the aquatic portions of wetlands, often spawning in marshes bordering lakes or in riparian forests during flooding (Peters et al., 1979, Mitsch and Gosselink, 1986). Common fish that utilize freshwater wetlands include pickerel, sunfish, bass, crappies, bullheads, carp, herring, white perch and American shad.

Several anadromous fish (those which migrate from saltwater to freshwater to spawn) spawn in wetlands of the freshwater portions of rivers. For example, the blueback herring spawns on the hardwood forest floor during flooding (Adams, 1970), and the American shad spawns in freshwater streams (Tiner, 1985). Striped bass migrate to fresh water areas to spawn al-

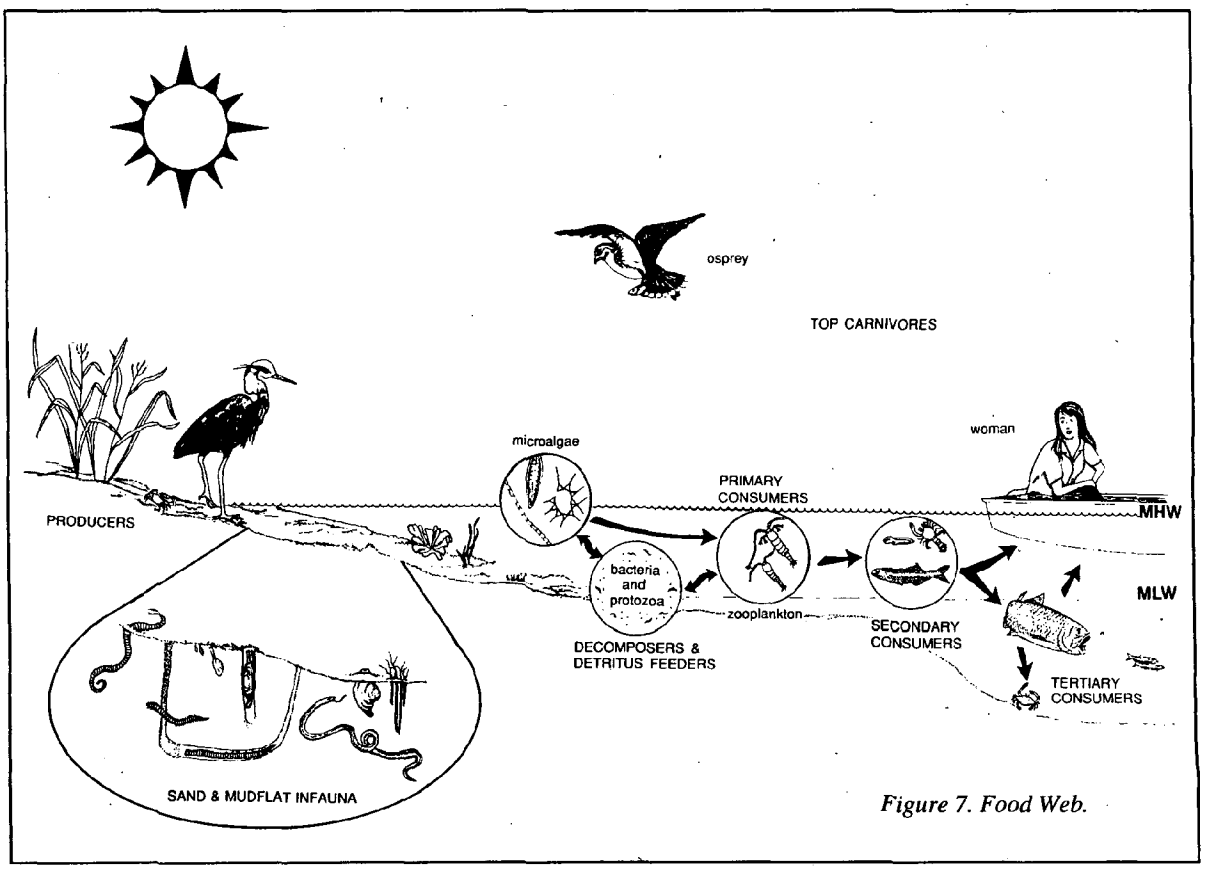

Figure 7. Food Web.

lowing the juveniles to utilize tidal fresh wetlands as nursery and feeding areas (Odum et. al. 1984). Bottomland hardwoods of the southeastern U.S. are important to fish that use them for spawning, feeding, and hiding (Sather et al., 1990). Estuarine and marine fish and crabs have been reported to migrate into freshwater wetlands for food, spawning, and nursery areas (Conner and Day, 1982).

Wetlands provide a critical habitat for many birds including waterfowl, migratory songbirds, and shorebirds. Some species may utilize wetlands year round while others use them seasonally for breeding, feeding, resting, or over-wintering. Wetland nesting birds include redwinged blackbirds, green herons, least bitterns, mallards, black ducks, wood ducks, and Virginia rails (Tiner, 1985). Migratory waterfowl are dependent on wetlands for feeding during their seasonal stopovers. Metzgar et al., (1973) estimated that the Bay's wintering population of waterfowl has been more than one million. Various shore and wading birds use wetlands as a food source and a location for nest sites. Atlantic coast salt marshes are used for nesting by birds such as laughing gulls, Forster's terns, clapper rails, willets, and marsh hawks (Tiner, 1984). Coastal wetlands are also used as foraging and nest sites for wading birds such as the herons and egrets (Tiner, 1984). Other birds utilizing nontidal wetlands may include towhees, chickadees, titmouses, warblers, tanagers, vireos, flycatchers, and sparrows (Tiner, 1985). Predacious birds such as hawks, bald eagles, ospreys, and owls also feed and nest in wetlands. Wetland seeds and tubers provide essential winter food for ducks and geese (Weller, 1979). Bottomland forested wetlands are primary wintering grounds for waterfowl, as well as important breeding areas for wood ducks, herons, egrets, and wild turkeys (Tiner, 1984).

Muskrats, beavers, rabbits, river otters, raccoons, mice, and white-tailed deer are among the furbearers utilizing wetlands. Muskrats may feed on plant parts including belowground tubers; they may also feed on invertebrates found in wetlands such as clams and mussels. Muskrat lodges are often made of tall robust plants such as big cordgrass and cattails. White-tailed deer depend on wetlands for winter shelter, food, cover and breeding (Tiner, 1985).

Another major component in wetland wildlife populations are the reptiles (turtles, snakes) and amphibians (frogs, salamanders). Almost all amphibians

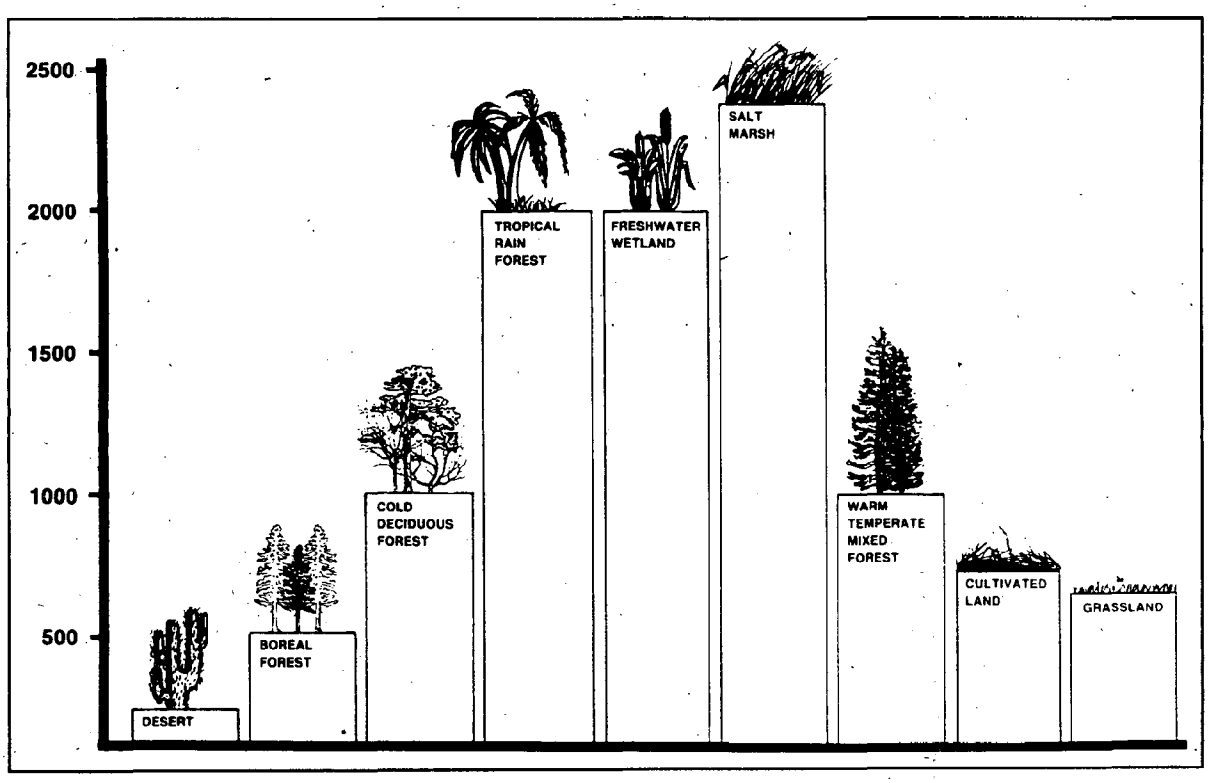

Figure 8. Net primary productivity of selected ecosystems (g/m^2/year) (adapted from Lieth, 1975 and Teal and Teal, 1969).

depend on wetlands for breeding. They lay eggs in water where their larvae develop and feed on algae as well as other foods (Weller, 1979). Frogs often found in wetlands include green, bull, and leopard frogs, and spring peepers (Tiner, 1985). Amphibians are numerous in some wetlands; 1,600 salamanders and 3,800 frogs and toads were found in a gum tree pond less than 100 feet wide in Georgia (Wharton, 1978). Amphibians are a prime food source for larger animals such as raccoons, herons, mink, bitterns, and fish (Weller, 1981). Turtles and snakes use freshwater wetlands for food and cover and move to drier land to deposit eggs. Turtles are most common in freshwater marshes and ponds, the most common being box, snapping, painted, pond, and mud turtles (Clark, 1979). Water snakes are the most abundant snake in wetlands, though cottonmouths, garter, and mud snakes are also found.

Wetlands are also important in maintaining species diversity which is critical to ecosystem balance. Diversity is a measure of the variety of species present in an ecosystem. High species diversity provides resilience to potentially catastrophic events such as disease or environmental disturbance. Of the nation's endangered and threatened species, 50 percent of the animals and 28 percent of the plants are dependent on wetlands for their survival (Niering, 1988). Preservation of wetland plants is also important for maintaining direct potential benefits in the fields of agriculture and medicine (Niering, 1988). As Ehrlich and Ehrlich (1981, in Niering, 1988) state:

> "The natural ecological systems of Earth, which supply these vital services, are analogous to the parts of an aeroplane that make it a suitable vehicle for human beings. But ecosystems are much more complex than wings or engines. Ecosystems, like well-made aeroplanes, tend to have redundant subsystems and other 'design' features that permit them to continue functioning after absorbing a certain amount of abuse. A dozen rivets, or a dozen species, might never be missed. On the other hand, a thirteenth rivet popped from a wing flap, or the extinction of a key species involved in the cycling of nitrogen, could lead to a serious accident."

For the survival of many fish and wildlife, it is critical to preserve not only the wetland habitat in which the species is most common, but also a portion of the adjacent areas. Maximum wildlife usage may be dependent on preservation of upland buffer areas adjacent to wetlands (Adamus, 1990). Certain species are dependent on adjacent upland or aquatic areas for some part of their life history such as breeding, feeding, protection, or raising young. For example, trees and shrubs along a wetland edge make valuable nesting sites, song perches, and cover for birds. The upland adjacent to a wetland may be favored by wildlife for feeding, denning, nesting, cover, roosting, or breeding (Porter, 1981). Upland buffers in urban areas may provide the necessary shield and concealment from human activities to allow for wildlife usage (Porter, 1981). The combination of the wetland and upland fringe provides an abundance of food close to good cover.

Shoreline Erosion Control

Wetlands located at the interface between upland and aquatic habitats have the potential to reduce upland erosion by reducing wave energy and current velocity. As water moves across the reduced slope of shallow waters and wetlands, the energy dissipates. As friction or drag from the bottom increases the erosive force declines. This action occurs in nonvegetated as well as vegetated wetlands. Wave height and current speed are reduced by nonvegetated wetlands, such as beaches and mudflats by causing waves to spread out as they pass over the flat (Theberge and Boesch, 1978). Vegetated wetlands can reduce shoreline erosion by several mechanisms. The complex root system binds and stabilizes the sediment; as a wave propagates through vegetation additional frictional drag reduces wave energy and current velocity (Dean, 1979). Wetland vegetation also increases deposition of sediment which helps build the shoreline channelward of the uplands. Wetlands reduce the final impact on the upland, thereby reducing erosion of upland areas.

As wave action and current speed are reduced by the wetland, sediments in the water settle to the bottom, resulting in improved water quality and the build-up of the marsh surface. Knutson et al., (1982) found that more than 50% of the energy associated with waves passing through a fringe marsh was dissipated within the first eight feet of the marsh. A planted salt marsh fringe may be an effective, inexpensive, and ecologically-preferred alternative to a bulkhead or a revetment (Hardaway et al., 1984).

Bulrushes and reed grass have been reported as the most successful herbaceous vegetation in freshwater wetlands in erosion abatement (Seibert, 1968; Kadlec and Wentz, 1974). Forested wetlands or buffer areas are also useful in minimizing erosion. Trees stabilize banks of streams and rivers with their deep penetrating roots (Siebert, 1968; Virginia State Water Control Board, 1979a). Shoreline erosion control with vegetation has its limitations depending on many factors such as: potential wave energies, current velocities, flood magnitude, vegetation type, soil type, and slope.

Flood Storage

Wetlands adjacent to watercourses slow surface water flow and may temporarily store flood waters. Wetlands are able to store or remove water through several mechanisms, which include: maximum water storage resulting from soil properties specific to wetlands, plant uptake and evapotranspiration, and open water surface evaporation (Carter et al., 1979). The predominantly organic soils of wetlands have better water retention capabilities than mineral soils (Novitzki, 1979). Plant evapotranspiration is the loss of water vapor by plant parts. Flood storage may be reduced when soils are already saturated or in winter when plant uptake is lower (Carter et al., 1979). The increased friction caused by contact with wetland vegetation and roughness of the ground reduce flood current velocities. These processes desynchronize peak flows by temporarily slowing and storing water, which results in a non-simultaneous, gradual release of peak waters, minimizing flow downstream (Figure 10) (Zacherle, 1984). This effect is particularly evident in riverine systems.

Estuarine wetlands adjacent to tidal rivers provide a temporary storage of flood water, but their storage effect may be either increased or reduced by the tidal stage during flooding (Carter et al., 1979). Boon (1975) demonstrated that the configuration of meandering marsh creeks and broad tidal flats can cause diversion and retention of peak tidal current flows. The ability of wetland vegetation to slow flood waters depends on the type and density of vegetation and the depth of the water (Carter et al., 1979).

Flood control has become increasingly important in urban areas where the rate and volume of stormwater runoff have increased with non-porous surfaces, such

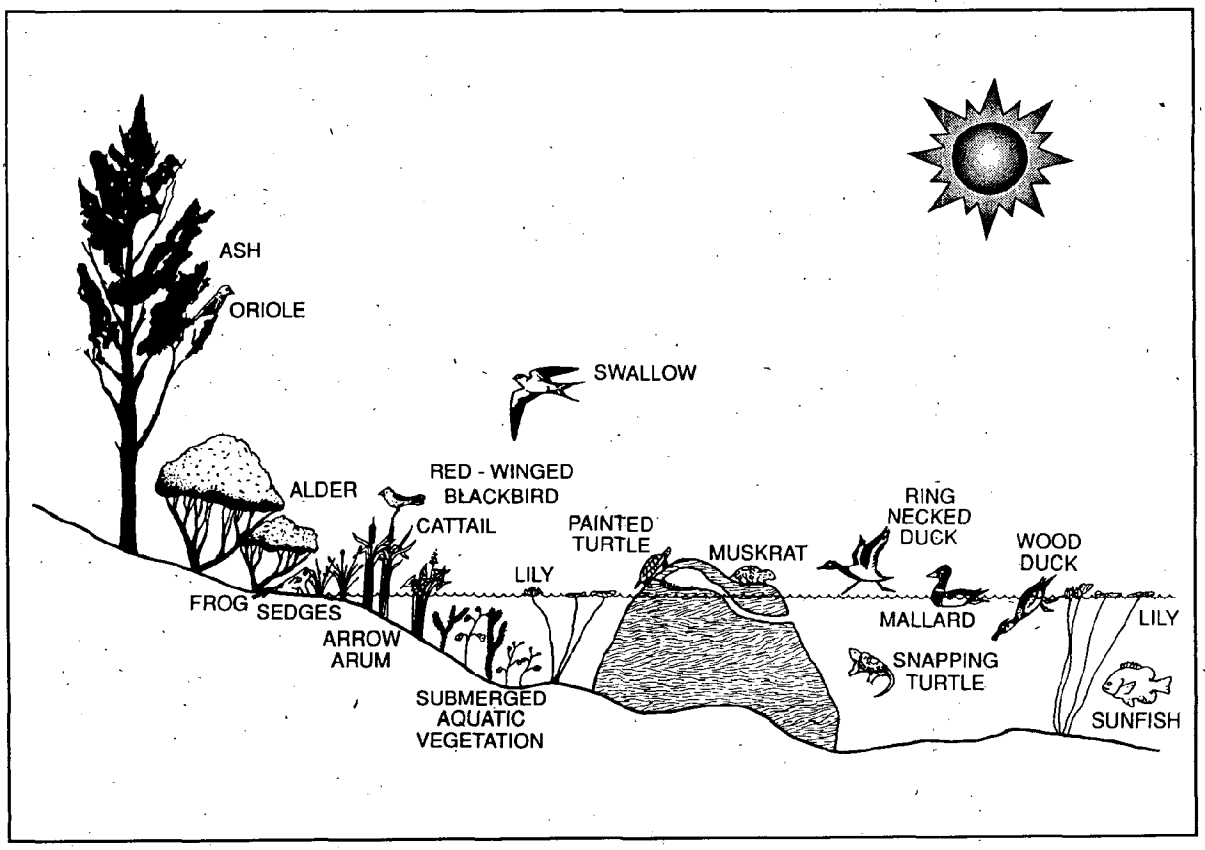

Figure 9. Simplified diagram of the plants and animals of a nontidal wetland and adjacent aquatic habitat.

as roads, parking lots, and buildings. The U.S. Army Corps of Engineers found that protection of natural wetland systems along the Charles River basin in Massachusetts was the most cost-effective solution to controlling flood waters (U.S. Army Corps, 1972; Carter et al., 1979). Mangrove swamps are so effective at reducing flood levels and buffering storm water damage that the Federal Flood Insurance program requires coastal communities to prohibit mangrove destruction if they wish to remain eligible for insurance (Tiner, 1984). Flood flows in watersheds with wetlands may be 80 percent lower than in basins without wetlands (Novitzki, 1979). Mitsch et al., (1979) observed floodwaters being slowly returned to the river from a swamp months after maximum runoff occurred. This action results in reduced flood water heights because water levels have subsided in the river channel as these floodwaters are slowly released (Figure 10).

Groundwater Discharge and Recharge

Some wetlands have been shown to be sites for groundwater recharge while most have been identified as areas of groundwater discharge. Groundwater recharge is the movement of water into a potential drinking water supply or aquifer. Wetlands located at sites of groundwater discharge occur where the groundwater table meets the surface of the land and discharges as springs or seeps. Most wetlands are discharge areas and may be used to supply drinking water. At least 60 municipalities in Massachusetts have public wells in or near wetlands (Motts and Heeley, 1973). In riverine wetlands, groundwater aquifers are recharged during floodplain inundation (Ward, 1989). Recharge potential varies according to wetland type, geographic location, season, soil type, water table location and precipitation (Tiner, 1984). Most estuarine intertidal wetlands are discharge rather than recharge areas (Carter et al., 1979). May (1989) observed that the freshwater wetlands on Hilton Head Island, South Carolina are important recharge reservoirs for the aquifer that supplies potable water. Wetlands have the potential to impact the quantity and quality of potable water supplies as recharge or discharge areas.

Economic and Recreational Values

The economic benefits of wetlands are realized in natural products, shoreline erosion control, stormwater treatment, flood protection, water supply, livestock grazing, and recreation. Natural products include timber, fish, shellfish, waterfowl, furbearers, peat, and wild rice. Wetland grasses are also used for livestock grazing or are harvested for hay. Recreational activities in wetlands include boating, swimming, fishing, hunting, and nature study. All of these activities and products derived from wetlands bring direct and indirect economic benefits to the adjacent communities.

Economic benefits from hunting and fishing are significant. Commercially important species such as striped bass, menhaden, bluefish, flounder, spot, blue crabs, oysters, and clams are partially dependent on coastal wetlands during some part of their life history.

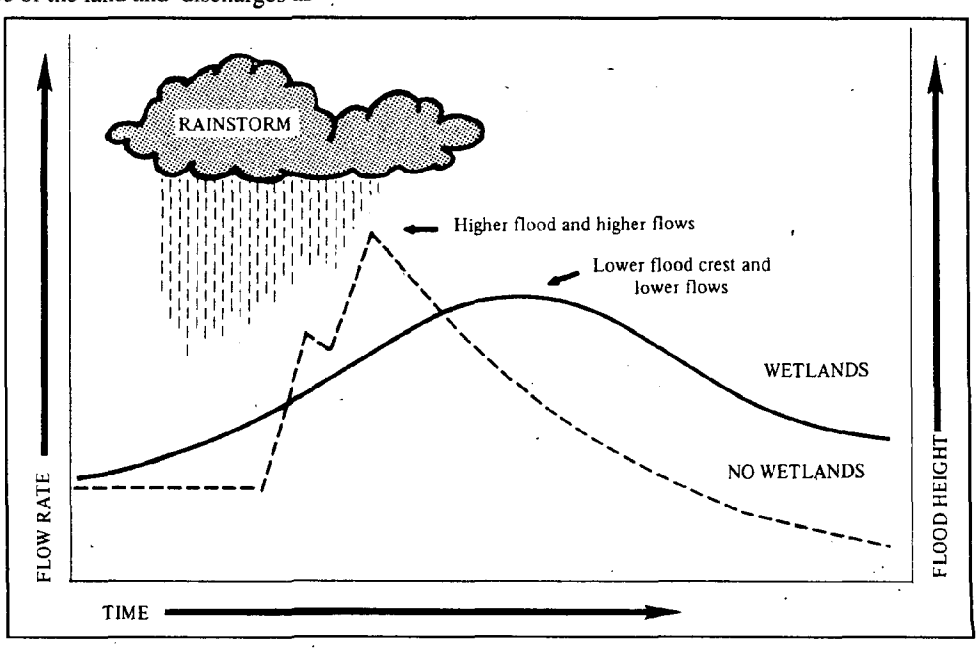

Figure 10. Wetland values in reducing flood crests and flow rates after rainstorms (adapted from Kusler, 1983).

In 1980 furs from muskrats yielded approximately $74 million; in 1980 5.3 million people spent $638 million on hunting waterfowl and other migratory birds; and in 1975 sport fishermen spent $13.1 billion to catch wetland dependent fishes in the U.S. (Burke et al., 1988). In 1980, 47 percent of Americans spent $10 billion observing and photographing waterfowl and other wetland birds (Burke et al., 1988).

The ability of wetlands to control flood waters reduces property damage from flooding, and reduces costs for flood control structures. Property damage from floods for 1975 in the U.S. was estimated to be $3.4 billion (U.S. Water Resources Council, 1978). Wetlands provide perpetual values, whereas economic benefits from wetland destruction are finite (Mitsch and Gosselink, 1986).

Wetland Losses

Human threats to wetlands include drainage, dredging, filling, construction of shoreline structures, groundwater withdrawal, and impoundments. Between 1956 and 1977, coastal and inland vegetated wetland loss in Virginia was approximately 63,000 acres (Tiner, 1987). Direct conversion of wetlands to cropland was the major cause of inland wetland loss (Figure 11). Wetland losses in the coastal area were dominated by urban development which accounted for 43 percent, and coastal waters (from impoundments) accounted for 36 percent (Tiner, 1987) (Figure 12).

Coastal wetlands are often lost where shoreline erosion control structures are built. The natural inland migration of wetlands is slowed or stopped where bulkheads or riprap are placed along shorelines for erosion control. As sea level rises wetlands in front of hardened shorelines will eventually be drowned because their natural inland migration has been stopped by the structure. Wave reflection from shoreline defense structures may accelerate erosion on adjacent or channelward wetlands unless there is a sediment source that can keep pace with the rise in sea level. Natural events that may cause wetland loss include rising sea level, natural succession, the hydrologic cycle, sedimentation, erosion, beaver dam construction, and fire (Tiner, 1984).

As wetlands are lost so are their associated benefits. The short term economic gains acquired through wetlands destruction are relatively easy to measure and therefore have received a great deal of emphasis in the past. However, the long term economic and environmental costs of wetland destruction may well outweigh the short term gains.

Regulation of Wetlands

In 1972 Virginia enacted a law with the intent to protect tidal wetlands while accommodating necessary economic development. The Virginia Marine Resources Commission (VMRC) was given the responsibility of lead state agency. Under the Act's local option alternative most localities have adopted the model ordinance and administer their programs through local wetlands boards and ordinances. Federal wetland regulation under the Clean Water Act is administered by the U.S. Army Corps of Engineers (COE) and overseen by the U.S. Environmental Protection Agency (EPA). The federal jurisdiction covers both tidal and nontidal wetlands. The Corps and the VMRC have developed a joint permit application that is used by the local, state, and the federal regulatory authorities to streamline the permit process. The VMRC has available a set of Wetland Guidelines which describe tidal

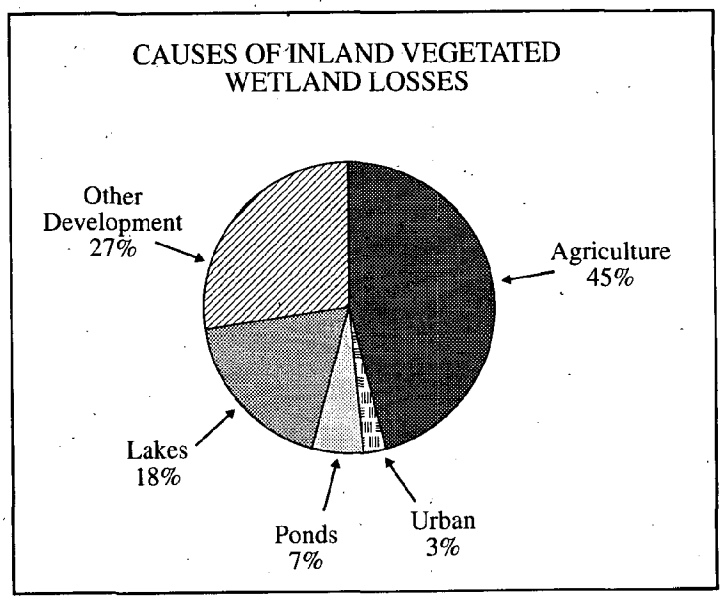

Figure 11. Direct conversion of wetlands to cropland in Virginia was the major cause of inland wetland loss, while other development (mainly channelization projects) and lake and pond construction were also major loss factors (Tiner, 1987).

wetland types, their values, and methods of coastal construction that minimize wetland impacts. These guidelines can be used to assist applicants when filling out the joint permit application. Other state and federal agencies that may comment on wetland applications during the joint permit review include: the U.S. Fish and Wildlife Service, National Marine Fisheries Service, Environmental Protection Agency, Council on the Environment, the State Department of Health, State Water Control Board, Shoreline Erosion Advisory Service, and Game and Inland Fisheries.

Presently Virginia does not have a state nontidal regulatory program. The Commonwealth's Chesapeake Bay Preservation Act includes nontidal wetlands that are connected by surface flow and are contiguous to tidal wetlands or tributary streams as part of Resource Protection Areas. These areas and an upland buffer bordering the wetland will be subject to land disturbance restrictions. The land management practices are implemented by local governments. The intent of the Act is to protect water quality in the Chesapeake Bay, through managing lands that have the potential to impact water quality in the Bay and its tributaries.

Concerned citizens can assist in wetland protection through various activities including: attending Wetlands Board public hearings; locating and monitoring wetlands in their area, supporting wetland legislation, informing neighbors and developers of the values of wetlands, and encouraging them to minimize their impact on wetlands. It is important for citizens to consider that any substances such as fertilizers, auto fluids, and pesticides that are distributed or disposed of within the Bay watershed (Figure 3) may potentially impact the waters of the Chesapeake Bay and drinking water supplies.

Economic development and wetland protection are not mutually exclusive. Many commercial activities and economic growth depend on the productivity and aesthetic values of the Chesapeake Bay. Without wetlands and their attendent values, expensive alternative methods would be required to prevent flooding, control erosion, improve water quality, and provide fish and wildlife habitat and recreational opportunities. Our wetlands resource, if properly managed, will provide these services far into the future. We risk much more than just the wetlands if we allow their loss in favor of short term economic gain.

"In the beginning, wetlands were considered valueless. Only when most of the native waterfowl vanished was it determined that wetlands might ensure the survival of many endangered plants and animals. Only after billions of dollars were spent on structural flood control that resulted in further flooding were wetlands recognized for reducing flood peaks. Only after additional billions were spent to purify streams was it realized wetlands naturally filter pollutants for free." (Illinois Institute of Natural Resources.)

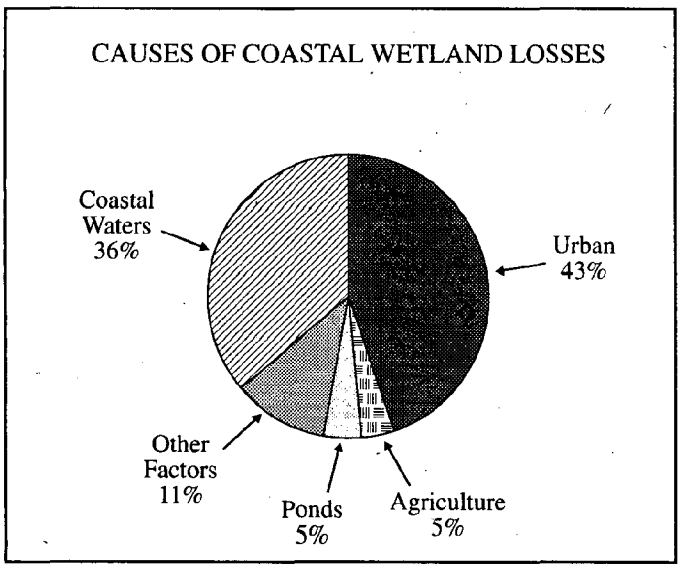

Figure 12. Urban development in Virginia had the biggest impact on coastal wetlands. Loss of coastal wetland to estuarine waters through impoundments, dredging projects, and sea level rise was also significant (Tiner, 1987).

Literature Cited

Adams, J.G. 1970. Clupeids in the Altamaha River, Georgia. Coastal Fisheries office, Georgia Game and Fish Commission, Contribution Series No. 20. Brunswick, GA.

Adamus, P. R., R. D. Smith, and T. Muir. 1990. manual for assessment of bottomland hardwood functions. EPA 600/3-90/053. Prepared by U.S. Army Engineer Waterways Experiment Station. Vicksburg, MS.

Anderson, G., J. Brokaw, T. Lassen, G. Mapp, and L. D. Theberge. 1978. In: E. L. Shea and N. B. Theberge, eds. Wetland Evaluation and Management in Virginia. SRAMSOE No. 211, Virginia Institute of Marine Science, Gloucester Point, Virginia. 116 pp.

Bates, R.D. 1989. Biomass and primary productivity on an early successional flood plain forest site. In: R.R. Sharitz and J.W. Gibbons (eds.) Freshwater wetlands and wildlife. Proceedings of a Symposium Held at Charleston, South Carolina, March 24-27, 1986. U.S. Department of Energy. Available from NTIS, Springfield, VA as DE90005384.

Bender, M.E. and D.L. Correll. 1974. The use of wetlands as nutrient removal systems. Chesapeake Research Consortium, No. 29, VIMS Contribution No. 624. Gloucester Point, VA. 12pp.

Boon, J.D. 1975. Tidal discharge asymmetry in a saltmarsh drainage system. Limnology and Ocean. 20(1):71-80.

Boto, K.G. and W.H. Patrick, Jr. 1979. Role of wetlands in the removal of suspended sediments. In: P.E. Greeson, J.R. Clark, and J.E. Clark (eds.) Wetland Functions and Values: The State of Our Understanding. Amer. Water Resources Assoc. pp. 479-489.

Boyt, F.L., S.E. Bayley, and J. Zoltek, Jr. 1976. Removal of Nutrients From Treated Municipal Wastewater by Wetland Vegetations. J. Water Poll. Cont. Fed. 49: 789-799.

Burke, D.G., E.J. Meyers, R.W. Tiner, Jr., and H. Groman. 1988. Protecting nontidal wetlands. American Planning Association. Washington D.C. 76 pp.

Burkholder, P.R. and L.M. 1956. Vitamin B12 in Suspended Solids and Marsh Muds Collected Along the Coast of Georgia, Limnol. & Oceanogr. 1 : 202-8.

Carter, V., M.S. Bedinger, R.P. Novitzki and W.O. Wilen. 1979. In: P.E. Greeson, J.R. Clark, and J.E. Clark (eds.). Wetland Functions and Values: The State of Our Understanding. Amer. Water Resources Assoc. pp. 334-376.

Cerco, C. F. and A. Y. Kuo. 1979. Water quality in a small tidal creek: Parker Creek, Virginia. SRASOE No. 231 Virginia Institute of Marine Science, Gloucester Point, Va. 112 pp.

Chesapeake Bay Program. 1983. Chesapeake Bay Program: Findings and Recommendations, U.S. Environmental Protection Agency, Philadelphia, PA. 48 pp.

Clark, J.E. 1979. Fresh water wetlands: habitats for aquatic invertebrates, amphibians, reptiles, and fish. In: P.E. Greeson, J.R. Clark, and J.E. Clark (eds.) Wetland Functions and Values: The State of Our Understanding. Amer. Water Resources Assoc. pp. 330-343.

Clark, J.R. 1983. Coastal Ecosystem Management, A technical manual for the conservation of coastal zone resources, Robert E. Krieger Publishing Company, Malabar, Florida.

Conner, W.H. and J.W. Day, Jr. 1982. The ecology of forested wetlands in the southeastern United States. In: B. Gopal, R.E. Turner, R.G. Wetzel, and D.F. Whigham (eds.) Wetlands Ecology and Management. National Institute of Ecology and International Scientific Publications. UNESCO, Paris and Dept. of Science and Technology, New Delhi. pp. 69-87.

Dean, R.G. 1979. Effects of vegetation on shoreline erosional processes. In: P.E. Greeson, J.R. Clark, and J.E. Clark (eds.) Wetland Functions and Values: The State of Our Understanding. Amer. Water Resources Assoc. pp. 415-426.

Deegan, L. A., B. J. Peterson, and R. Portier. 1990. Stable isotopes and cellulase activity as evidence for detritus as a food source for juvenile Gulf menhaden. Estuaries 13:14-19.

Ehrlich, P. and Ehrlich A. 1981. Extinction: the causes and consequences of the disappearance of species. Random House, New York. Quoted in Neiring, W.A. Endangered, threatened and rare wetland plants and animals of the continental United States.

Elder, J.F. 1985. Nitrogen and Phosphorus Speciation and Flux in a Large Florida River-Wetland System, Water Resources Research, 21: 724-732.

Grant, R. R., Jr. and R. Patrick. 1970. Tinicum Marsh as a water purifier. In: Two Studies of Tinicum Marsh. The Conservation Foundation. pp. 105-123.

Hardaway, C. S., G. R. Thomas, A. W. Azcherle, and B. K. Fowler. 1984. Vegetative erosion control project: Final report 1984. Virginia Institute of Marine Science, School of Marine Science, College of William and Mary, Gloucester Point, Virginia.

Hines, A. H., R. N. Lipcius and A. M. Haddon. 1987. Population dynamics and habitat partitioning by size, sex, and molt stage of blue crabs *Callinectes sapidus* in a subestuary of central Chesapeake Bay. Mar. Ecol. Prog. Ser. 36: 55-64.

Illinois Institute of Natural Resources, Illinois Wetlands, p. ix. Quoted in Zinn, J. A. and Copeland, C. 1982. Wetland Management. Congressional Research Service The Library of Congress, Washington D.C.

Jones, J.R., B.P. Borofka, and R.W. Bachmann. 1976. Factors Affecting Nutrient Loads in Some Iowa Streams. Water Research 10: 117-122.

Wetland Values and Functions
Exam Questions

1. What are the two major types of wetlands, based on water source, and how do they differ?

2. In general, what is a wetland? (soil, plants, moisture regime)

3. The Chesapeake Bay watershed receives ground and surface water from the following areas:
   a. all those areas adjacent to the tidal waters of the Bay
   b. lands in Maryland and Virginia that drain toward the Bay
   c. the 64,000 square mile area that extends north into New York and west to the Appalachian mountains

4. Name nine functions and/or values provided by wetlands:
   1.
   2.
   3.
   4.
   5.
   6.
   7.
   8.
   9.

5. Wetland plants may improve water quality through the following mechanisms. List two:
   1.
   2.

6. Give an example of a food web. List at least four organisms.

7. Nutrients are only removed by wetland plants, soils are ineffective in improving water quality.
   True or False

8. All wetlands provide all the functions listed in this education unit.
   True or False

9. Provided you do not live adjacent to a tidal waterway that flows into the Chesapeake Bay, you can fertilize your lawn and drain used moter oil in your backyard without impacting the Bay.
   True or False

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10. Wetlands can remove toxicants and other pollutants from the water column through plant uptake and increased sedimentation.

    True or False

11. Describe how wetlands improve water quality through filtering and sedimentation.

12. Why are wetlands being used as a viable alternative for wastewater treatment?

13. List three pollutants stormwater runoff may contain:

    1.
    2.
    3.

14. List two methods of reducing pollutant loads from stormwater runoff in urban or developing areas:

    1.
    2.

15. What are primary producers? Give 3 examples:

    1.
    2.
    3.

16. Wetlands are much more productive, in terms of amount of plant tissue produced, than our most productive agricultural fields.

    True or False

17. What is detritus and what is its value to an ecosystem?

18. List four commercially important species that are associated with wetlands:

    1.
    2.
    3.
    4.

19. List four reasons why marsh areas are a preferred habitat:

    1.
    2.
    3.
    4.

20. List four ways birds may use wetlands:
    1.
    2.
    3.
    4.

21. List five birds that may utilize wetlands:
    1.
    2.
    3.
    4.
    5.

22. List five mammals that may inhabit wetlands:
    1.
    2.
    3.
    4.
    5.

23. Why is species diversity important?

24. How do nonvegetated wetlands reduce shoreline erosion?

25. How do wetlands desynchronize peak flood flows?

    How do they reduce flood current velocities?

    How do they store and remove water? List three mechanisms:
    1.
    2.
    3.

26. Explain the curves in Figure 10 of the text.

27. Explain groundwater recharge and discharge and how wetlands may be associated with these.

28. List seven economic benefits of wetlands:
    1.
    2.
    3.
    4.
    5.
    6.
    7.

29. List four human threats to wetlands:
    1.
    2.
    3.
    4.

30. How do shoreline structures such as bulkheads and riprap impact wetlands?

31. What regulations does Virginia have in place to minimize loss of tidal wetlands?

32. What two lead federal agencies are involved in wetland regulation?
    1.
    2.

33. What are the Wetland Guidelines and where can they be found?

34. Describe how wetlands and economic growth can co-exist and compliment each other.

35. What can you as a citizen do to get more involved in wetland protection?

36. What is the most important or useful information you learned from this education unit?

Kadlec, J.A. and W.A. Wentz. 1974. State-of-the-art Survey and Evaluation of Marsh Plant Establishment Techniques: Induced and Natural. Vol. I: Report of Research, Contract Report D-74-9, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Kadlec, R.G. and J.A. Kadlec. 1979. Wetlands and water quality. In: P.E. Greeson, J.R. Clark, and J.E. Clark (eds.) Wetland Functions and Values: The State of Our Understanding. Amer. Water Resources Assoc. pp. 436-456.

Knutson, P. L., R. A. Brochu, W. N. Seelin, and M. Inskeep. 1982. Wave damping in *Spartina alterniflora* marshes. Wetlands 2: 87-104.

Kusler, J.A. 1983. Our National Wetland Heritage. A Protection Guidebook. Environmental Law Institute, Washington, D.C. 167 pp.

May, J.P. 1989. Groundwater recharge potential of freshwater wetlands on Hilton Head Island, South Carolina. In: R.R. Sharitz and J.W. Gibbons (eds.) Freshwater wetlands and wildlife. Proceedings of a symposium held at Charleston, South Carolina, March 24-27, 1986. U.S. Department of Energy. Available from NTIS, Springfield, VA as DE90005384.

McGovern, J. C. and J. E. Onley. 1988. Potential Predation by Fish and Invertebrates on Early Life History Stages of Striped Bass in the Pamunkey River, Virginia. Transactions of the American Fisheries Society 117:152-161.

Metzgar, R. G. 1973. Wetlands in Maryland. Maryland Dept. of State Planning, Baltimore, Md.

Mitsch, W.J., C.L. Dorge, and J.R. Wiemhoff. 1979. Ecosystem dynamics and a phosphorus budget of an alluvial cypress swamp in southern Illinois, Ecology 60: 1116-1124.

Mitsch, W.J. and J.G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold Co., New York, NY. 329 pp.

Motts, W.S. and R.W. Heeley. 1973. Wetlands and groundwater. In: J.S. Larson, ed. A Guide to Important Characteristics and Values of Freshwater Wetlands in the Northeast. University of Massachusetts, Water Resources Research Center. Pub. No. 31, pp. 5-8.

Niering, W.A. 1988. Endangered, threatened and rare wetland plants and animals of the continental United States. In: D.D. Hook and others, eds. The Ecology and Management of Wetlands, Vol. 1 Ecology of Wetlands. Timber Press, Portland, Oregon. p. 227-238.

Novitzki, R.P. 1979. Hydrologic characteristics of Wisconsin's wetlands and their influence on floods, stream flow, and sediment. In: P.E. Greeson, J.R. Clark, and J.E. Clark (eds.) Wetland Functions and Values: The State of Our Understanding. Amer. Water Resources Assoc. pp. 377-388.

Odum, W.E., T.J. Smith III, J.K. Hoover, and C.C. McIvor. 1984. The ecology of tidal freshwater marshes of the United States east coast: a community profile. U.S. Fish Wildl. Serv. FWS/OBS-83/17. 177 pp.

Odum, W.E. 1988. Nontidal freshwater wetlands in Virginia. Virginia Journal of Natural Resources Law 7: 421-434.

Peters, D.S., D.W. Ahrenholz, and T.R. Rice. 1979. Harvest and value of wetland associated fish and shellfish. In: P.E. Greeson, J.R. Clark, and J.E. Clark (eds.) Wetland Functions and Values: The State of Our Understanding. Amer. Water Resources Assoc. pp. 606-617.

Porter, B.W. 1981. The wetland edge as a community and its value to wildlife. In: Richardson, B. ed. Selected Proceedings of the Midwest Conference on Wetland Values and Management. Navarre, Minnesota: Freshwater Society; pp. 15-26.

Richardson, C.J. 1989. Freshwater wetlands: transformers, filters, or sinks? In: R.R. Sharitz and J.W. Gibbons (eds.) Freshwater wetlands and wildlife. Proceedings of a symposium held at Charleston, South Carolina, March 24-27, 1986. U.S. Department of Energy. Available from NTIS as DE90005384. pp. 25-46.

Roman, C.T. 1981. Detrital exchange processes of a Delaware salt marsh. Ph.D. dissertation, University of Delaware. 144 pp.

Rozas, L. P. and C. T. Hackney. 1984. Use of oligohaline marshes by fishes and macrofaunal crustaceans in North Carolina. Estuaries 7: 213-224.

Sather, J. H., R. D. Smith, and J. S. Larson. 1990. Natural values of wetlands. In: Wetlands and shallow continental water bodies, Vol. 1. Natural and human relationships, B. C. Patten (ed.). SPB Academic publishing. pp. 373-388.

Seibert, P. 1968. Importance of natural vegetation for the protection of the banks of streams, rivers, and canals. In: Nature and Environment Series (Vol. Freshwater). Council of Europe, pp. 35-67.

Sloey, W. E., F. L. Spangler, and C. W. Fetter, Jr. 1978. Management of freshwater wetlands for nutrient assimilation. In: R. E. Good, et al. Freshwater Wetlands. Ecological Processes and Management Potential. Academic Press, New York. pp. 321-340.

Spangler, F., W. Sloey, and C.W. Fetter. 1976. Experimental use of emergent vegetation for the biological treatment of municipal wastewater in Wiconsin. In: Biological Control of Water Pollution, J. Tourbier and R. Pierson, Jr. (eds.) Univ. Penn. Press, Philadelphia, Pennsylvania, pp. 161-172.

Sweeney, J. T. 1980. Measurement and analysis of tidal marsh fluxes of oxygen demanding materials. College of William and Mary, Virginia Institute of Marine Science Master's Thesis. 122 pp.

Teal, J. and M. 1969. Life and Death of a Salt Marsh. Boston. Little, Brown, and Co. 274 pp.

Theberge, L. and D. F. Boesch. 1978. Values and management strategies for nonvegetated tidal wetlands. Special Scientific Report No. 90, Virginia Institute of Marine Science, Gloucester Point, Virginia. 55 pp.

Tiner, R.W., Jr. 1984. Wetlands of the United States: Current Status and Recent Trends. Washington, D.C.: U.S. Fish and Wildlife Service.

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3 6668 14111863 0

Tiner, R.W., Jr. 1985. Wetlands of New Jersey. U.S. Fish and Wildlife Service, Washington D.C., pp. 117.

Tiner, R. W., Jr. 1987. Mid-Atlantic Wetlands a Disappearing Natural Treasure. Washington, D. C.: U.S. Fish and Wildlife Service.

U.S. Army Corps of Engineers. 1972. Charles River Watershed, Massachusetts. New England Division, U.S. Army Corps of Engrs., Waltham, Massachusetts, 65 pp.

U.S. Water Resources Council. 1978. The nation's water resources, 1975-2000. vol. 1. Washington, D.C.: U.S. Water Resources Council.

U. S. Water Resources Council. 1978. Estimated flood damages. Appendix B., Nationwide Analysis Report. Washington, D. C.

Van der Valk, A.G., C.B. Davis, J.L. Baker, and C.E. Beer. 1979. Natural freshwater wetlands as nitrogen and phosphorus traps for land runoff. In: P.E. Greeson, J.R. Clark, and J.E. Clark (eds.) Wetland Functions and Values: The State of Our Understanding, American Water Resources Assoc., Minneapolis, Minn., pp. 457-467.

Virginia Natural Resources Newsletter. 1989. Vol. 3.

Virginia State Water Control Board. 1979a. Best Management Practices Handbook, Agriculture. Planning Bulletin 316 pp.

Virginia State Water Control Board. 1979b. Best Management Practices Handbook, Urban. Planning Bulletin 321 pp.

Ward, J. V. 1989 Riverine-wetland interactions. In: R.R. Sharitz and J.W. Gibbons (eds.) Freshwater wetlands and wildlife. Proceedings of a symposium held at Charleston, South Carolina, March 24-27, 1986. U.S. Department of Energy. Available from NTIS as DE90005384. pp. 385-400.

Wass, M. L., and T. D. Wright. 1969. Coastal wetlands of Virginia. Special Report No. 10 in Applied Marine Science and Ocean Engineering, Virginia Institute of Marine Science, Gloucester Point, Virginia.

Weinstein, M. P. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. Fish. Bull. 77: 339-357.

Weller, M.W. 1981. Freshwater marshes. University of Minnesota Press, Minneapolis. 146 pp.

Weller, M.W. 1979. Wetland habitats. In: P.E. Greeson, J.R. Clark, and J.E. Clark (eds.) Wetland Functions and Values: The State of Our Understanding. Amer. Water Resources Assoc. pp. 210-234.

Wetzel, R.G. 1989. Wetland and littoral interfaces of lakes: productivity and nutrient regulation in the Lawrence Lake ecosystem. In: Proceedings of a Symposium Held at Charleston, South Carolina, March 24-27, 1986. U.S. Department of Energy. Available from NTIS, Springfield, VA as DE90005384. pp. 283-302.

Wharton, C.H. 1978. The Natural Environments of Georgia. Georgia Dept. of Nat. Res., Atlanta. 227 pp.

Windom, H.L. 1976. Geochemical interactions of heavy metals. In: Southeastern salt marsh environmentals, Ecol. Res. Ser. EPA-600/376-023, Washington, D.C. 36 pp.

Zacherle, A.W. 1984. A method for evaluating the long-term, cumulative impacts of tidal marsh alterations: the York River system- a case study. College of William and Mary, Virginia Institute of Marine Science Master's Thesis. 197 pp.

Zimmerman, R. J. and T. J. Minello. 1984. Densities of *Penaeus aztecus*, *Penaeus setiferus*, and other natant macrofauna in a Texas salt marsh. Estuaries 7: 421-433.