Effectiveness of Shoreland Zoning Standards to Meet Statutory Objectives:

A Literature Review with Policy Implications

Dams, Floodplain & Shoreland Section
Bureau of Watershed Managment

Prepared by Thomas W. Bernthal
Edited by Julia R. Barrett

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A Study by the Wisconsin Department of Natural Resources
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This study is a companion to the **Shoreland Management Program Assessment** (PUBL-508-97) and focuses on program policy implications from the scientific and planning literature. The **Shoreland Management Program Assessment** incorporates the findings of this literature review within a broad assessment of the program's effectiveness in light of current waterfront development patterns and trends, issues of administrative effectiveness, and program history. It concludes with a listing of policy issues and options relative to NR 115, the administrative rule for the shoreland program, and possible initiatives to meet the challenge of preserving the natural amenities and wildlife habitat values along developed shorelands.

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TABLE OF CONTENTS

INTRODUCTION

Wisconsin's shoreland zoning standards contained in NR 115 were originally developed in the late 1960s based on a combination of the best available scientific information, best professional judgement, and the feasibility of implementation at the time. The standards for lot width minimums (65 feet for sewered lots, 100 feet for unsewered lots), lot size minimums (10,000 square feet for sewered lots, 20,000 square feet for unsewered lots), restrictions on vegetative cutting within 35 feet of the water's edge, and the 75-foot building setback combine to create a buffer that is intended to minimize pollution of, and disturbances to, aquatic resources and allow for the preservation of the natural beauty of our lakes, rivers, and streams. The literature search has focused on the effectiveness of this buffer in accomplishing these objectives. In evaluating the literature on riparian (synonomous with shoreland - the interface of land and water bodies) buffer zones for various purposes, it must be noted that buffer effectiveness depends on site-specific conditions and on the functions the buffer is asked to perform. It is also important to note that the review evaluates the standards as written, assuming adequate implementation. Program implementation effectiveness is discussed in a companion document, Shoreland Management Program Assessment.

Although shoreland zoning standards are designed to achieve multiple objectives, the following presentation discusses objectives for water quality, ecological functions (aquatic and riparian habitat protection), and aesthetic quality separately. The implications on the overall effectiveness and role of current shoreland zoning standards are then summarized, and suggestions are offered for new policy initiatives. The reader should keep in mind that somewhat arbitrary distinctions were made to organize inherently interrelated subjects. For instance, stream bank stability is discussed in the ecological function section rather than the water quality section because it appears to relate more to stream dynamics and habitat quality than delivery of pollutants from outside the stream channel. Of course, it makes no difference to the fish whether we describe their loss of a spawning bed as a water quality issue or a habitat issue.

1. SHORELAND ZONING AND WATER QUALITY PROTECTION

Water quality, especially water clarity, is a major factor in public enjoyment of lakes and streams. For instance, water clarity is strongly related to the price people are willing to pay for lakefront property. In a five-year study of 900 shorefront properties on 34 lakes in Maine, declining water clarity was shown to reduce lakefront property values and could increase the tax burden of offshore properties (Michael et al. 1996). A 1 meter (roughly 3-foot) difference in average minimum water clarity was associated with property value declines of up to 22%.

1.1 Cumulative Impacts to Water Quality from Shoreland Development

1.1.1 Lakes

Studies of the water quality impacts of lakeshore development point to the importance of reducing the cumulative impact of lakeshore development, both in terms of the impacts to habitat and in terms of phosphorus loading. A study in Maine (Dennis 1986) of paired watersheds of similar size and physical characteristics compared an undeveloped, forested watershed to an adjacent watershed with 40% forest and a subdivision developed with 1-acre lots. The more developed watershed showed an increase of 720% in phosphorus export, the main nutrient of concern in lakes because of its role in the eutrophication process described below.

When shoreland vegetation is disturbed or removed by human activities, aquatic plants and animals will be affected by elevated sediment, nutrient, and toxicant loads. A recent study modeling land use pattern and topography in the Lake Mendota watershed found that increases in phosphorous loading were strongest with conversions of undisturbed riparian (shoreland) areas to either urban or agriculture uses (Soranno, et al 1996). Toxic materials, such as pesticides, herbicides, and heavy metals, can cause acute mortality of aquatic life. Most commonly, however, they cause chronic effects by affecting reproduction and degrading habitat.

1.1.1.1 Eutrophication in Deep Lakes

Excess nutrient input from the watershed stimulates the growth of aquatic plants, but stimulates algal growth even more, and can created nuisance algal blooms, which consume large amounts of oxygen when they die and decompose. This process is called eutrophication. In lakes deep enough to stratify into distinct layers of water of different temperature and density, loss of oxygen in the hypolimnion (the cold bottom layer of water) triggers further water quality degradation. In a healthy deep-lake ecosystem, the colder oxygenated waters of the hypolimnion protect water quality by acting as a trap for nutrients, especially phosphorus contained in bottom sediments, the nutrient of greatest concern because it has the greatest effect on algal growth. Over the course of a summer, however, an overfertilized lake can lose all oxygen in the deepest water, with the result that chemical changes result in further release of phosphorus from lake-bottom sediments. The complete loss of oxygen (anoxia) occurs in the deepest water first and extends upward. As more of the hypolimnetic layer becomes anoxic, fish that depend on cold oxygenated water cannot survive when forced into shallower, warmer depths. In the fall, when falling temperatures and wind action allow the lake waters to mix again, phosphorus from bottom sediments is released throughout the lake, causing further water quality problems.

1.1.1.2 Eutrophication in Shallow Lakes

In shallow lakes, the water is mixed throughout the year and nutrients are therefore constantly available, fostering naturally abundant emergent and submergent aquatic plant growth that provides excellent food and habitat for microscopic animal life and diverse aquatic insect life, as well as for the fish, waterfowl, amphibians, and other wildlife that thrive in these sometimes marsh-like ecosystems. These lakes are especially sensitive to excessive sediment delivery and problems with exotic fish species such as carp. As a shallow lake receives excessive fertilization from nutrients in the shoreland area and from inflowing streams, algal growth is increased and water clarity declines, favoring bottom-feeding carp over sight-feeding fish such as northern pike. As carp feed, they stir up soft bottom sediments and uproot beneficial aquatic plants which further accelerates the decline of game fish species. The trigger for this vicious cycle is the excessive delivery of sediments and nutrients into the lake from the surrounding watershed.

1.1.1.3. Studies of Cumulative Water Quality Impacts

One technique to measure the relative eutrophication of a lake is to measure the rate at which water in the hypolimnion of a lake basin loses oxygen and the volume of anoxic water in the hypolimnion. Water quality problems associated with eutrophication are indicated by a greater relative volume of anoxic water in the hypolimnion. A study on a single forested, hourglass-shaped lake in northern Wisconsin, with two distinct basins of sharply differing levels of development, found that the more developed basin had a larger volume of anoxic water than the lesser developed basin, the opposite of what the physical conditions in these two basins would predict (Ganske 1990). A 20-year study of a Michigan lake with three distinct basins used similar oxygen deficit methodology to track the rate of eutrophication at ten year intervals. The most developed basin was found to be the most eutrophic (greatest oxygen deficit) over time, and a lesser developed basin had a consistently lower oxygen deficit, while one basin showed wide anomalous fluctuations (Lind and Davalos-Lind 1993). Two basins showed an increasing rate in eutrophication during the time period of the study (1971 to 1991). By extrapolating their data backward and comparing with a measure of eutrophication in 1922, the authors approximate that the rate of eutrophication began increasing in about 1950, coincident with an increase in summer home construction during the postwar economic boom.

These two studies are insightful because they were able to control for some of the many variables, besides the level of shoreland development, that also influence water quality in lakes, by looking at separate basins of the same lake. Even in these studies however, some physical factors such as the shape, size, and orientation of the basin interact with level of shoreland development to determine water quality.

Modelling studies of sediment and nutrient delivery to two different lakes in northern Wisconsin also show increases of from 200% to 700% in phosphorus loading as lots are cleared and developed (J. Panuska, Wisconsin Department of Natural Resources, to P. Sorge, internal memorandum Nov. 16, 1994; E&S Environmental Chemistry, Inc. 1992). Dillon, et al. (1995) found that phosphorus delivery from on-site sewage disposal systems associated with shoreline development accounted for a significant portion of the observed total phosphorus level in four Ontario lakes. On two of the lakes with thinner soils all total phosphorus transported into and out of septic systems reached the lakes. About one-third of the total phosphorus from septic systems reached the third lake, which had a thicker layer of till/soil, while the fourth lake was undeveloped. Weber (1994) found significantly greater nitrogen and phosphorus concentrations in the seepage water, sediment, and plant tissues in the near-shore waters of Legend Lake, along shorelands with septic systems where groundwater flowed toward the lake, compared to groundwater outflow sites and sites with no septic system.

The amount of phosphorus loading can be reduced by best management practices directed to minimize soil compaction and control erosion and sediment delivery during construction. However, it is clear from these studies that more densely settled shorelands can contribute greater phosphorus loading.

Paleolimnological studies offer the opportunity to look at a historical record that documents the response of a lake to land-use changes in its watershed. This technique involves taking sediment cores from the lake, dating core layers, and examining the chemical and fossil record preserved in the cores. A sharp increase in the sedimentation rate soon after European settlement and clearing for agriculture, logging, or town establishment in the watershed has been thoroughly documented throughout Wisconsin (E&S Environmental Chemistry, Inc. 1992, Garrison 1993, Garrison and Hurley 1993). Although each lake has a unique history, these studies all show increasing water quality degradation related to increased phosphorus loading, starting in the 1960s and 1970s, and continuing to the present, apparently related to increasing levels of lakeshore development.

The record for Lake Ripley, a highly developed lake in a watershed that is shifting from agricultural to residential land use, showed a slight decrease in phosphorus in the 1960s when land was beginning to be taken out of agriculture for homesite development, but since the mid-1970s, phosphorus loading has increased even though the rate of erosion in the watershed has decreased (Garrison 1993). The author concludes that lakeshore homes are now the largest source of nutrient loading to the lake. The record for Lac La Belle, shows that lake productivity (excessive productivity is an indication of eutrophication) dropped for a time after sewer installation in 1980, but has begun to increase again in recent years, with recent phosphorus concentrations at levels similar to those just prior to sewer installation (P. Garrison, Wisconsin Department of Natural Resources, letter to L. Conley, Sept. 6, 1995). This suggests that providing sewer service to lake subdivisions, while providing major water quality benefits, does not control all the important sources of phosphorus to a lake. The benefits of sewer service may be offset by increases in phosphorus loading and habitat degradation due to increased residential density.

By way of contrast, deep sediment in Little Bearskin Lake, a lightly developed lake in Oneida County with 12% residential development, has not shown an increase in phosphorus concentration in the last century (Garrison and Winkelman 1995). Although phosphorus loading has likely increased, phosphorus appears to be taken up by aquatic plants along the shoreline. This has resulted in a less diverse but more dense aquatic plant community with increased density of coontail, which is becoming a nuisance to lake homeowners at some sites.

Differences between cores from two nearby lakes demonstrate the importance of lake and watershed characteristics in determining how a particular lake's water quality is affected by land-use changes. Garrison (in press) compared the cores of Long Lake, a deep 1,050-acre stratified drainage lake, to nearby Round Lake, a 215-acre softwater shallow seepage lake that does not stratify. Long Lake water quality began to decline in the 1880s in response to added sediment and nutrients delivered to the lake by inflowing streams, caused by erosion from logging in the watershed. Round Lake was not as affected by the initial land clearing, because its lack of inflowing streams meant that it did not receive as large a nutrient load. However, water quality has declined in recent years, evidenced by a profound change in the algal community. The increased nutrient loading is most likely the result of cottage development around the shoreline. Today, Round Lake suffers from algal blooms during years of high rainfall while Long Lake does not.

This comparative study has some important implications for lake planning because it lends support to the notion that smaller, shallower seepage lakes are likely to receive a larger portion of their nutrient inputs from the immediate shoreland, while drainage lakes receive a larger portion of their inputs from the larger watershed (Shaw et al. 1994). This implies that shoreland zoning along lakeshores, as a water quality tool, may be more effective in buffering seepage lakes. However, any measure that can reduce phosphorous loading to any lake type will contribute to water quality. Buffers along streams, along with other best management practices, are essential to control nutrient inputs to drainage lakes and impoundments, especially in agricultural watersheds.

1.1.2 Streams

Fine sediment eroded from riparian areas delivers perhaps the most widespread and pervasive impact of shoreline development, particularly from agricultural practices and construction of roads and buildings (Waters 1995). Agriculture may also contribute excessive animal wastes and nutrients, leading to problems with low dissolved oxygen concentrations, high ammonia concentrations, and accelerated eutrophication. Mason et al. (1991) documented these effects on smallmouth bass in four southwestern Wisconsin streams. Even relatively low levels of sediment delivery can gradually degrade stream bed habitat, resulting in disruption of food webs and reductions in fish reproductive success. The effect is insidious because it is often unspectacular and goes unnoticed from one year to the next.

Excess sediment delivered to streams gradually fills in rocky bottom habitat and buries benthic (bottom-dwelling) invertebrates, resulting in reduction in numbers or loss of some species. This reduces the amount of food available for upper-level predators such as minnows and game fish species. Richards et al. (1993) found that sediment eroding from clay soils had a greater negative effect on stream invertebrates than sediments from sandy soils. Declines in invertebrates reduce the amount of food available for upper-level predators such as fish, amphibians, and reptiles. Further, when sediments settle over coarser stream bed substrates they cover essential spawning grounds or eggs, or prevent emergence of recently hatched fry. In a study of Missouri streams, Rabeni and Smale (1995) found that excessive stream sediment significantly decreased species number and abundance. They also found that the types of fish most sensitive to increased siltation were those that feed on algae or benthic invertebrates, or those that spawn exclusively on gravel or cobble substrates.

Many studies have shown that urban development is associated with declines of pollution-sensitive invertebrate groups such as mayflies, stoneflies, and caddisflies and a pronounced increase in pollution-tolerant groups, such as midges and oligochaetes (e.g., Jones and Clark 1987, Lenat and Crawford 1994). Research over the past 15 years shows a strong correlation between the amount of impervious surface in a watershed and the health of the receiving stream (Arnold and Gibbons 1996). Stream water quality and habitat begin to degrade as watersheds become more densely developed (Schueler 1994a, Masterson and Bannerman 1994). Hicks (1995) has also found shifts to pollution-tolerant invertebrate communities and degraded habitat in freshwater wetlands in urbanizing watersheds. Richards et al. (1993) indicated that sediment eroding from clay soil types had a greater effect on stream macroinvertebrates than sediments eroding from sandy soil types.

1.1.3 Water Quality Protection Functions Provided by NR 115

Shoreland standards in NR 115 addressing water quality impacts are primarily focused on reducing sediment and pollutant delivery from overland flow runoff in the immediate shoreland. The requirement to establish shoreland-wetland zoning districts provides an important means to preserve the water quality (as well as habitat and natural beauty) functions of wetlands by restricting the uses of wetlands to those which are not expected to significantly affect wetland functions. Water quality in lakes and streams is intended to be protected through providing a 35-foot-wide buffer zone landward of the ordinary high-water mark, in which trees and shrubs may not be clear-cut. The 35-foot zone is expected to provide a buffer of undisturbed shoreland vegetation that can trap sediments and remove nutrients and toxicants from runoff by providing a physical barrier that slows surface flow rate, traps sediment, and removes nutrients and toxicants by chemical transformation or plant uptake. The 75-foot structure setback improves the ability of the 35-foot buffer to perform by decreasing soil disturbance and erosion from construction activities and reducing the amount of impervious area within 75 feet of the water's edge. This reduces the volume of runoff and amount of sediments, nutrients, and toxicants reaching the 35-foot buffer. In addition, standards controlling the intensity of development through minimum lot sizes and widths affect the continuity and overall amount of shoreline left as undisturbed buffer area.

Though not specifically included in NR 115, many counties have adopted the erosion control requirements contained in the Model Shoreland Zoning Ordinance. A special exception permit is required for filling and grading on steeper slopes.

1.3 Shoreland Zoning Effectiveness for Water Quality Protection

1.3.1 Trapping and Retention of Sediments, Nutrients, and Toxicants from Runoff Water

Shoreland vegetation and other erosion control and best management practices can reduce the amount of sediments, nutrients, and toxicants, reducing their effects on aquatic animals. The efficiency of sediment removal from runoff depends upon the length and slope of vegetated area, the runoff depth relative to vegetation height, and vegetation characteristics. The efficiency also depends on sediment particle size, surface roughness, and runoff characteristics. Generally, small undisturbed shoreland widths remove small amounts of sediment. However, the relationship between shoreland width and percentage of sediment removed is nonlinear. Disproportionately large shoreland widths are required for incrementally greater sediment removal. The rate of sediment deposition in vegetation is constant over a range of lower slopes, but after a critical slope is reached, trapping efficiency declines.

Denser and taller vegetation in the shoreland area is more efficient in removing sediment. There is a inverse relationship between sediment particle size, surface roughness, and runoff depth and the vegetation height, shoreland width, and shoreland slope required to remove a given percentage of sediment. When vegetation is disturbed or flow depth is too high, the effectiveness of vegetation in removing sediment declines. During extreme flows, vegetation loses its function completely. Because most nutrients and toxicants in surface runoff from agricultural and urban watersheds are attached to sediment particles, vegetation in the shoreland area removes nutrients and toxicants from runoff both through filtering water and through plant uptake.

In some controlled situations relatively small buffer strips can be effective in removing sediment. Quantitative laboratory and field studies in an agricultural setting have shown that a 30-foot vegetated filter strip removed more than 90% nitrate-nitrogen (NO_3-N) and phosphate (PO_4-P) (Madison et al. 1992) and 84% of suspended solids (Dillaha et al. 1989). A study of an agricultural buffer in Iowa found that 70% sediment removal occurred in the first 10 feet of a bromegrass filter strip next to a 12% clean tilled slope, and 85% sediment removal occurred in the first 30 feet (Robinson et al. 1996). A critical aspect of this study is that care was taken to minimize concentration of overland flow before runoff water reached the filter strip.

The buffer created by the existing standards appears to fall within the middle range of what the literature recommends for adequate buffering for sediment trapping and nutrient retention (Welsch 1991, Comerford et al. 1992, Desbonnet et al. 1995). Pollutant removal increases with increasing buffer width, but after 70% to 80% removal is obtained, much greater widths are needed to gain the next increment of removal (Desbonnet et al. 1995).

Because of the wide range of conditions that have been evaluated for a number of different pollutants, a wide range of pollutant removal efficiencies have been reported for different buffer widths. Desbonnet et al. (1995) provide a summary of average buffer width and pollutant removal efficiency reported for various pollutants. The numbers reported should not be taken as absolutes but demonstrate the exponential increase in width needed to attain high removal efficiencies. Based on the average of reported buffer widths and pollutant removal efficiencies, the 35-foot buffer can be expected to achieve about 60% removal of total suspended solids, nitrogen, and phosphorus. For sediment, 70% removal is obtained at 7 meters (roughly 25 feet),[1] while 80% removal is generally reached at 25 meters (80 feet). Seventy percent removal of total suspended solids is reported at 20 meters (65 feet) and 80% removal is generally reached at 60 meters (200 feet). Seventy percent removal of total nitrogen is reported at 23 meters (75 feet) and 80% removal at 60 meters (200 feet). Nitrate-nitrogen is primarily removed through the denitrification process and is affected by soil moisture more than buffer width, with saturated wetland soils being the most effective. For total phosphorus, 70% removal is reported at 35 meters (115 feet), but 80% removal is reported at a much larger distance, 85 meters (275 feet).

From these ranges, it can be concluded that the 35-foot buffer requirement can accomplish significant pollutant removal, but in general a wider buffer would be prudent to build in an adequate safety factor, to recognize the lack of control over field conditions, especially in achieving the removal of nitrogen and phosphorus. These reported ranges also indicate that the point of diminishing returns in relation to increasing buffer width is reached at around 100 feet. In any given situation, buffer effectiveness could be quite different than the ranges reported here.

1.3.2 The Role of Wetlands in Lake and Stream Water Quality

Preserving wetlands maintains an essential water quality buffering agent for associated lakes and streams. The water quality function of a wetland is closely tied to its position in the landscape and on the wetland type (Brinson 1993, Beilfuss and Siebert 1996). Wetlands that have organic soils, saturated soil or shallow water depths, and longer retention times experience the predominantly anaerobic (oxygen-free) conditions needed for nutrient transformation. In addition, those that have dense vegetation and are located between upland pollutant sources and lakes and rivers, offer the greatest amount of sediment and nutrient retention. These types of wetlands, such as sedge meadows, fresh wet meadows, wooded swamps, and shallow marshes, have both the opportunity and advantageous soil conditions to facilitate the processes of denitrification, sulfate reduction, and transformation of nutrients to more soluble forms for plant uptake. Wetlands can permanently remove metals and organic compounds if they remain adsorbed to sediments and the sediments eventually become buried below the root uptake zone of wetland plants (Elder 1987).

However, if bottom sediments are stirred up and subsequently flushed downstream, the wetland can become a source for downstream pollution. Wetlands can also be a seasonal source for organic nutrients released by plants when they die off in the fall and the dead litter is flushed downstream in the fall and early spring, while acting as a nutrient sink during the growing season (Van der Valk et al. 1979). Wetlands play an important role in natural ecosystem functioning by providing an organic input to lake and stream detrital-based food webs, a process discussed in the next section on the ecological functions of shoreland vegetation.

Wetlands in river floodplains provide opportunities for flood storage, with associated sediment

[1] Throughout this report distances reported in meters (and greater than 2 meters) will be converted to the nearest 5 feet. This is done to avoid the impression of greater precision than is justified.

deposition as flood waters recede, while wetlands in closed basins serve as sites for permanent sediment deposition. Riverine wetlands along headwater streams are often found in areas of groundwater discharge and play a very important role in maintaining baseflow in these streams (Beilfuss and Siebert 1996). Lake-fringe wetlands and wetlands located near lakes are particularly important in protecting lake water quality. In a study of 33 lake watersheds in the seven counties surrounding Minneapolis, Detenbeck et al. (1993) documented higher water quality where wetlands were concentrated near the lake of interest.

While the size of an individual wetland plays a role in its ability to perform water quality functions, landscape position, surrounding land use, and wetland type are also very important factors (Simon et al. 1987, Beilfuss and Siebert 1996). Cumulatively, wetlands smaller than 2 acres can perform important water quality functions in shoreland areas, especially in watersheds with small amounts of wetlands left. Johnston et al. (1990) showed that small wetland losses would have a small effect on floodflow in watersheds with 10-50% wetlands, but a large effect on floodflow in watersheds with less than 10%. Oberts (1981) showed that sediment- and nutrient-loading rates per unit area from watersheds with less than 10% wetlands were as much as 100 times greater than the loading rate of watersheds with more than 10% wetlands. Hey and Wickencamp (1996) documented the combined impact of increasing impervious area and wetland loss on alteration in stream hydrology for nine watersheds in southeastern Wisconsin. They found extreme fluctuations in stream flows in watersheds with less than 10% wetlands and more than 8% impervious surface. Extreme fluctuations result in greater flooding risk, poorer water quality, and poorer fish habitat. These studies indicate that, given the cumulative impact of wetland loss, especially in urbanizing areas, the current size cutoff in most zoning ordinances (either 5 acres or 2 acres) is too large.

A strong note of caution must be stated in regard to the relationship between the sediment and nutrient retention function and other functions and human values of wetlands. In watersheds where planners are grappling with stormwater treatment issues, routing stormwater to a wetland can appear to be an attractive solution that utilizes the sediment and nutrient retention function of wetlands, while avoiding the need to dedicate developable land to stormwater treatment facilities. However, wetlands do not have an unlimited capacity to store peak flows of stormwater and retain sediments and nutrients without themselves developing eutrophic conditions that degrade their own water quality, habitat functions, and aesthetic and recreational values. Algal blooms, duckweed blooms, monotypic stands of cattails, giant reed grass (phragmites), and reed canary grass are all possible symptoms that a wetland is being overloaded with nutrients (Beilfuss and Siebert 1996). Given the potential for wetland degradation, plans for routing stormwater to a natural wetland, or modifying a natural wetland to increase its storage capacity and/or water quality functions should be closely scrutinized, with a presumption in favor of upland stormwater treatment. Where site conditions are favorable, constructing an artificial wetland in an upland area is a potential strategy for stormwater treatment (Schueler 1992).

1.3.3 Construction Site Erosion and Sediment Delivery Control

Sediment delivery from construction site erosion can be a major source of nonpoint pollution. Construction sites without adequate erosion and sediment control practices have very high rates of soil loss, from 30 to 200 tons/acre/year, 10 to 20 times that of cropland (Wisconsin Land Conservation Board 1984). The Southeastern Wisconsin Regional Planning Commission estimated that runoff from urban and suburban construction sites contributed 35% of the sediment and 28% of the phosphorus entering the inland lakes and streams in its seven-county planning area (Jackson et al. 1981). Given the soil disturbance and runoff conditions that develop on construction sites, the buffer provided by shoreland zoning is not adequate to prevent serious sediment delivery to lakes, streams, and wetlands. However, sediment delivery from construction sites can be controlled through proper erosion and sediment control practices, and more effective erosion control materials are being developed. Langford and Coleman (1996) have shown biodegradable erosion control mats to be from 89% to 97% effective on sandy loam soils, while product testing results reported by Godrey and McFalls (1992) indicate that sediment control efficiency on clay soils is generally about half that obtainable on sandy soils.

The degree to which sediment control is achieved on construction sites is dependent on the knowledge and care taken by the builder to utilize the best techniques available, though on steep slopes the chances of achieving good sediment control are reduced. The requirement for a special exception permit for filling and grading on steeper slopes can allow counties the opportunity for an increased level of scrutiny on projects where the risk of sediment delivery is greatest. The success of this approach lies in the ability of county staff to educate themselves and the contractors they work with on the best erosion and sediment control methods, and to maintain adequate inspection of construction sites in the shoreland.

1.3.4 Landowner Practices

Landowner practices, in terms of construction activities and yard-care practices, will greatly affect the ability of the shoreline buffer to trap and retain sediments, nutrients, and toxicants. On average, the typical lakeshore or streamshore home setting can be expected to have a smaller contributing area and considerably less soil disturbance than the agricultural or logging activities which most of the buffer research has evaluated. However, research studies typically assume an unbroken buffer, and the current shoreland standards allow for a clear-cut area along the shoreline. If this area is highly disturbed and runoff flow begins to be channelized through it, sediment trapping and nutrient retention functions will be lost. Other site circumstances that can reduce the effectiveness of the 35-foot shoreline buffer for runoff pollution control are erodible and fine-grained soils, steep slopes, construction disturbance, large impervious surfaces or compacted soils, and heavy use of fertilizers and pesticides.

A modeling study of phosphorus loading to a forested lake in Wisconsin illustrates the interaction of site conditions and types of development on water quality impacts (J. Panuska, Wisconsin Department of Natural Resources, to P. Sorge, internal memorandum, Nov. 4, 1994). Given a 1940s style development with a small 700-square-foot house set back 150 feet from the lake with a 35-foot-wide undisturbed buffer and a 20-foot-wide grass path from the house to the lake, phosphorus loading did not increase compared to undeveloped shoreland. However, under a 1990s style development scenario, with a large 3,350-square-foot house set back 80 feet from the lake and the lot entirely converted to lawn, phosphorus loading increased 700% compared to undeveloped shoreland.

A study of pollutants in urban stormwater runoff undertaken in Wisconsin showed that lawns and driveways contribute large phosphorus loads, accounting for more than 75% of the contaminant load from residential areas during significant runoff events. The study concluded that a decrease in the amount of fertilizers applied to lawns would decrease the amount of phosphorus coming from residential land uses (Bannerman et al. 1993). Since phosphorus is the primary nutrient of concern in lakes, these results indicate there is good reason to be concerned about fertilized lawns in close proximity to waterways. The data on streets are applicable to shoreland areas where there is dense first tier development and/or second tier development requiring an expansion of the street network and associated storm sewers.

1.3.5 On-Site Sewage Systems

Although the literature indicates water pollution from on-site sewage disposal systems is a valid concern (e.g., Weber 1994, Dillon et al. 1995), these systems are currently regulated by the Department of Commerce, under Comm 83, Wis. Adm. Code. This administrative code is in the process of being revised but currently contains a 50-foot setback from the ordinary high-water mark and other locational standards based on suitable soil conditions. This study does not attempt to address these issues, except from the perspective of addressing the cumulative impacts of shoreline development.

1.3.6 Summary on Water Quality Protection

Because the impacts to water quality from shoreland development operate on a cumulative level, controlling the density of development is an essential aspect of meeting the statutory water quality goal. The issue of cumulative impacts also arises in connection with protecting aquatic habitat and natural beauty and is discussed in Section 4, Cumulative Impacts Considerations.

Generally, a smaller buffer width is adequate in areas with dense vegetation, undisturbed soils, low shoreland slope, and a relatively low intensity of human activities, such as park land or a low density of residences. Larger buffers are necessary for streams with steep shoreland slopes and more intense land use in the watershed, such as extensive paved areas or feedlots. Site-specific conditions vary too greatly to make a definitive conclusion on the effectiveness of the 35-foot cutting restriction and the 75-foot structure setback, but these standards can be expected to provide at least moderate sediment trapping and nutrient and toxicant retention in situations in which slopes are not extreme, runoff volume is moderate, and the soil outside the buffer is not severely disturbed. The buffer cannot be expected to provide adequate sediment control during construction if proper erosion and sediment control techniques are not practiced. Natural wetlands provide an effective water quality buffering function but can themselves be overloaded.

Vegetated shoreland buffers alone cannot be expected to adequately protect stream ecosystems in urbanizing areas because the duration and frequency of any given flood discharge in urban streams can be 2-5 times higher than in rural streams (Hollis 1975). In addition, storm sewers bypass the buffer and deliver polluted runoff directly into the stream. Such drastic changes in flood duration and frequency and the bypass of storm sewers require additional nonpoint source pollution best management practices.

1.4 Policy Implications for Water Quality Protection

There are three basic strategies that have been used by government agencies in formulating buffer regulations (Palfrey and Bradley 1982, Xiang 1993). The first one is to define a minimum buffer width for the entire area under consideration. The second strategy begins with a minimum acceptable buffer width and extends it based on slope, soil, and land-cover conditions. The third strategy does not use minimum buffer width but determines buffer width entirely based on physical conditions. The current shoreland zoning standards use the first strategy. This strategy is easy to enforce, does not require regulatory personnel with specialized knowledge, and entails smaller expenditures of time and money to administer. The shortcoming associated with this strategy is that a mandatory constant buffer width cannot take into account regional differences in physical, ecological, and socio-economic conditions and may put aquatic resources in risk under some circumstances.

The ideal buffer width would be determined by considering site-specific conditions and could be adjusted to adequately protect valuable and vulnerable resources such as trout streams. The GIS model developed by Xiang (1993) offers a scientifically justifiable and generally applicable method for variable buffer width delineation, providing a valuable tool in pursuing this strategy. However, given the investment in data-gathering and GIS technology required, it is highly unlikely this strategy could be implemented statewide at this time.

The literature indicates that the current standards are appropriate as **minimums** for control of sediment and nutrient delivery, but larger buffers would be more effective up to a point. Beyond around 100 feet the effectiveness of a buffer in sediment trapping and nutrient retention appears to reach a point of diminishing returns. This indicates that communities wishing to accomplish greater control of sediment and nutrients in runoff could do so through wider buffers and structure setbacks. Landowner education initiatives are needed to inform new owners along shorelines of the water quality benefits of proper erosion control during construction and of leaving natural shoreline vegetation in place, instead of establishing a manicured lawn on the entire lot.

The provisions for setback averaging and continuance of nonconforming structures and uses greatly reduce the ability to maintain an adequate buffer for runoff control. Around heavily developed lakes and streams, initiatives should be continued and intensified to encourage landowners to reestablish natural shoreland vegetation in areas where lawns extend to the water's edge, control the timing and amount of fertilizer and pesticide use, and minimize runoff through various other best management practices.

Wetlands smaller than 2 acres play important roles in maintaining water quality and providing flood storage, both individually and cumulatively, especially when located in floodplains. Because of their importance to water quality, small wetlands should be zoned as shoreland-wetlands as they are delineated in the field. Any size limitation should be based on the feasibility of field delineation, rather than a notion that functions are insignificant below a certain size.

Policy makers and planners need to identify the correct tools to address a particular water quality problem situation. Stormwater impacts have a great influence on water quality in urbanizing areas with storm sewer inputs. In these areas current shoreland zoning standards alone are inadequate to protect water quality and must be supplemented with adequate standards for stormwater treatment. Shoreland standards that limit the amount of impervious surface per lot could be an important first step in addressing stormwater issues.

In larger watersheds, inputs from streams running through agricultural land greatly influence water quality. In these watersheds, agricultural best management practices reducing soil loss and excessive nutrient inputs, and buffers along agricultural streams, are needed in addition to shoreland zoning standards. Forested watersheds present the fewest water quality impacts, but buffer standards are critical in protecting water quality as these watersheds are logged or developed. The current shoreland vegetative cutting standard allows the clear-cutting to the water's edge of 30 feet in any 100 feet of shoreline. This standard is not appropriate for forestry practices since there is no need to access the water. Voluntary Forestry Best Management Practices for Water Quality have recently been developed (Wisconsin Department of Natural Resources 1995) and are currently under evaluation.

In small seepage lakes, shoreland zoning standards can play a large role in protecting water quality, because the shoreland zone accounts for a larger proportion of the nutrient delivery to the lake. A useful measure for planning purposes is the ratio of drainage basin area:lake area, with a smaller ratio indicating that lakeshore buffer standards will be relatively more important to lake water quality.

Another useful measure for lake planning is the shoreline development index, which is a measure of the shape of the lake shoreline (Cole 1983). This term originated in limnology, but has been adapted by planners in several lake classification methods as a simple, common sense way to identify lakes subject to greater development and recreational user pressure and described as "crowding potential" (Minnesota Department of Natural Resources 1976) or "shoreline development factor" (Lontz and Andrews 1981). One way to measure this is by the ratio of shoreline length:water surface area. Other factors being equal, irregular-shaped lakes, with a greater length of shoreline per acre of water, will be subject to a greater amount of development per acre of water, and therefore can be expected to receive a larger total nutrient input from the shoreland area than circular-shaped lakes of the same size.

2. SHORELAND ZONING AND THE ECOLOGICAL FUNCTIONS OF SHORELAND BUFFER AREAS

Ecologically, the shoreland, or riparian zone, is a living bridge between interdependent aquatic and terrestrial worlds. Shallow near-shore waters, known as the littoral zone in lakes, are the most biologically productive part of lake ecosystems. Stream, lake, and wetland ecosystems are inextricably linked to adjacent uplands through both structural habitat and food chain connections between the aquatic system and the riparian area. The role of habitat in the maintenance of healthy fish and aquatic life is as important as the role of water quality. Riparian zones have unique physical and biological conditions that allow them to host a great variety of wildlife. The shoreland buffer is intended to protect the habitat of both species that are totally aquatic, such as fish; and those that rely on the unique habitat found in riparian areas, such as waterfowl, fish-eating birds, amphibians and reptiles, and mammals.

2.1 Aquatic Habitat Functions and Impacts

There are many different types of habitat found in a shoreland buffer and many different ways in which the shoreland buffer affects aquatic systems. Along larger rivers, wetland complexes such as floodplain forests are found with many associated backwater sloughs and ponds that host a wide variety of habitats for amphibians, reptiles, birds, mammals, and fish. Smaller rivers and streams with narrower floodplains flow through a wide variety of vegetative communities, from large upland forests to large wetland complexes composed of meadow, shrub, and forest communities. In agricultural landscapes, riparian corridors along streams may be fairly narrow or nonexistent. Smaller river-edge wet meadows (sometimes referred to as backswamps) lie in the floodplain. Similarly, lakeshore topography varies from steep cliffs and slopes, to gently sloping uplands, to flat wetlands, and vegetation displays varying combinations of forest, shrub, or herbaceous cover. The enormous variety of habitat types created by the combination of topography, soil, and vegetation along shorelines leads to a wide variety of ways in which habitat functions are performed along different shorelines. The following discussion is focused on the functions of riparian and wetland buffers and ecological processes which shoreland zoning standards affect.

2.1.1 Stream Systems

2.1.1.1 Stream Systems and Shoreland Vegetation

The role of stream habitat in the maintenance of healthy fish communities in streams is fairly well understood, and habitat assessment methodologies for streams have been developed based on pool and riffle morphology, bottom substrate, bank stability, and other factors (Ball 1982, Simonson et al. 1994). The following discussion describes the role of the riparian buffer in the ecology of streams and the impacts of disturbance to the vegetation of the stream corridor.

2.1.1.2 Providing Food and Habitat Diversity for Aquatic Life

Fallen leaves, twigs, and other shoreland vegetation constitute an essential external food source for aquatic organisms. Once in the stream, organic material (or detritus) will begin to be colonized by decay microorganisms or will be reduced to smaller particles by certain invertebrates, which shred the organic matter and digest the microorganisms growing on it. Finer organic particles are then utilized by other invertebrates. At the top of this detrital food web are fish predators, thus fish and other aquatic predators are in large part dependent on shoreland vegetation to supply organic material to headwater streams.

Small headwater streams have been shown to be heavily dependent upon the input of organic material from the surrounding terrestrial system (e.g., Swanson et al. 1982, Gurtz et al. 1988). As stream size increases, the relative proportion of direct terrestrial inputs of organic matter decreases and internal (e.g., algal and aquatic plant) production and imports from upstream become more important (Cummins 1975, Vannote et al. 1980). Headwater streams are important spawning and nursery grounds for commercial and sport fish species which spend their adult life in lakes and large rivers. In these headwater areas most energy utilized by fish is directly or indirectly terrestrial in origin. Removal of shoreland vegetation not only affects aquatic communities in the headwaters but also affects fish populations downstream in large rivers and lakes.

Dead or diseased, and occasionally healthy, trees along the shoreline can be undermined by stream currents and ice action and eventually topple into the water during storms. The fallen branches, trunks, and roots of moderate-to-large size, referred to as coarse woody debris, play several important roles in stream (and lake) ecosystems.

Many studies have shown that woody debris traps smaller organic particles and forms debris accumulations that regulate downstream transport and decomposition rates of organic material (e.g., Naiman and Sedell 1979, Bilby and Likens 1980). Woody debris provides stable substrates for aquatic organisms, such as bacteria, fungi, and invertebrates, that decompose organic material and form major components of food webs in stream ecosystems. Studies indicate that production of invertebrates on wood is particularly important in habitats with unstable bottom substrates (e.g., Nilsen and Larimore 1973, Benke et al. 1984, Angermeier and Karr 1984).

Woody debris and overhanging grassy or woody vegetation from the shoreland area also provide cover for fish and other aquatic organisms. The importance of woody debris in influencing stream depth, current, and substrate characteristics through its interaction with hydraulic processes is well documented (Zimmerman et al. 1967, Beschta 1979, Gurtz et al. 1988). Large pieces of woody debris can constrict the stream channel, thereby increasing the erosion potential of flowing water and enhancing pool formation. Woody debris is thought to be more important in determining the channel shape of low-gradient, fine-substrate streams than high-gradient, coarse-substrate streams because flow constrictions derived from woody debris can promote particle-sorting and scour, thereby increasing depth, current, and substrate diversity (Angermeier and Karr 1984). Partially undercut tree roots provide cover for fish. The differing physical conditions created by these processes promote the habitat diversity that is characteristic of streams with high-quality fish habitat.

In comparing a natural stream with a stream from which riparian vegetation was removed for cultivation, Schlosser (1982) found that vegetation removal resulted in significant changes in macroinvertebrate and fish communities. Karr and Schlosser (1978) also reported that removal of near-stream vegetation in upstream areas resulted in significant reduction in invertebrate and fish production because of reduction of terrestrial energy inputs.

Several studies have shown that removal of riparian vegetation during timber harvest stimulated aquatic algal production in forested headwater streams (e.g., Hansmann and Phinney 1973, Murphy et al. 1981). Such an effect is obvious only in small headwater streams where there is little if any canopy opening and less than 1% of total solar radiation reaches the streams (Gregory et al. 1987). Saturation of photosynthesis in benthic algal communities in streams occurs at approximately 20% of full sunlight. For most nonforested streams, the percentages of sunlight reaching streams range from 30% to 100% of full sunlight (Gregory et al. 1987). Therefore, the positive effect of removal of riparian vegetation that sometimes occurs in forested streams is not expected in other types of streams.

In Wisconsin, Hunt (1979, 1985, 1988) found that removal of the shrub layer along three small, heavily shaded trout streams flowing through alder thickets improved trout habitat and resulted in increased population and biomass of wild brook trout (two streams) and wild brown trout (one stream) during the first four years after treatment, compared to untreated reaches. A follow-up assessment ten years later on two of the streams showed continued habitat improvement in the treated area on both streams, and continued increase in population one stream, but lower population and biomass in the treated section compared to the untreated section of the second stream (Hunt 1979, 1985, 1988). Since the late 1970s, the practice of stream bank debrushing in Wisconsin has tended to involve much less intensive cutting (Hunt 1988).

2.1.1.3 Moderating Stream Water Temperature

Stream shoreland vegetation, through the degree of shading, plays an important role in regulating stream water temperature. Net thermal radiation in relation to stream discharge is the primary determinant of stream temperature. The degree of canopy closure, determined by the height, angle, and density of streamside vegetation and stream width, is the key factor in determining stream water temperature; vegetation width is not as important. Studies have consistently shown that summer maximum temperature is significantly higher in streams with unvegetated shoreland than those with well-vegetated shoreland (e.g., Meehan et al. 1977, Swanson et al. 1982, Lynch et al. 1985, Barton et al. 1985, Platts and Nelson 1989). Disturbed streams are characterized by warmer temperatures in summer and colder temperatures in winter and higher daily temperature fluctuation compared to undisturbed streams.

When streamside vegetation is disturbed or reduced, the stream water temperature regimen can be changed. The increase in water temperature that results from shoreland vegetation disturbance has numerous effects on water quality through physical and chemical processes. As water temperature increases, the water's capacity to hold oxygen decreases and microbial activity increases. The consequences of this process are decreased oxygen level and increased nutrient release in the system. For example, slight increases in temperature above 15^{o}C (59^{o}F) produce substantial increases in the amount of phosphorus released because of the exponential increase in conversion rates with increasing temperature (Karr and Schlosser 1978). Stream temperature change can cause shifts in the structure of aquatic communities with resident species being replaced by less desirable, but more tolerant species. In a study of Ontario streams, Barton et al. (1985) found that the only environmental variable which clearly distinguished trout and nontrout streams was weekly maximum water temperature. When all streamside vegetation is removed, summer water temperature can elevate to 85^{o}F or higher. This is intolerable to cold-water fishes, such as trout and salmon, because they usually cannot survive for prolonged periods if temperatures exceed 70^{o}F (Armour et al. 1991).

2.1.1.4 Protecting Stream Banks From Erosion and Maintaining Channel Stability

Shoreland vegetation reduces stream bank erosion and subsequent lateral migration of the stream channel because channel bank roots protect against fluvial (flowing water) erosion and anchor against collapse. In a study of a glacial meltwater river, Smith (1976) reported that erosion rates dropped with increases in root mass in channel bank sediments. Sod-forming grasses may adequately protect the banks of low-gradient streams or ephemeral channels. For many small streams this type of vegetation alone is inadequate to resist the erosional force of flowing water. Along many undisturbed shorelands, woody roots in combination with grass, forbs, and other types of vegetation provide a physical barrier to the effects of high velocities and turbulence and create banks with considerable surface roughness and relative stability (Beschta and Platts 1986). The result is that channel widening and erosion at bends can be either greatly slowed or curtailed, and the natural stream morphology is preserved. During floods, high stream velocities force resilient stream bank vegetation into mats that effectively protect the bank. These mats reduce stream velocities near the bank-water interface, permitting sediments to settle out and build up banks. However, understory vegetation cannot become established along stream banks covered with a very dense forest canopy, which can decrease stream bank stability (Kroner et al. 1992). Because each stream corridor is unique there is no one type of vegetation that can be said to be the best for stabilizing stream banks. In general, a dense and diverse vegetative cover of trees, shrubs, and grass with well-developed root systems provides the best stream bank stability and fish habitat (Ball 1982).

After removal of streamside vegetation, stream bank erosion is inevitably aggravated because of the loss of protection from vegetation. In a study of a Utah stream, Platts et al. (1985) reported that abnormal floods badly damaged channel banks in heavily grazed sections but actually built better channel banks in a protected ungrazed section that had been previously rehabilitated. On the ungrazed site, the amount of undercut bank increased and bank angle decreased. On the grazed site, bank conditions responded in an opposite fashion. Beschta and Platts (1986) demonstrated that woody-rooted vegetation not only helps maintain channel stability by binding and holding soil in place but also adds large organic debris, which is essential for dissipating stream energy and providing slow-velocity areas for fish and other aquatic life. When streamside vegetation is removed, increased stream runoff results in greater peak flows after storms and lower base flows between runoff events. Greater water level fluctuations and increased sediment loading lead to increased bank erosion and excessive in-channel sediment deposition, resulting in wider and shallower channels and loss of the pool and riffle topography beneficial to fish and the aquatic invertebrates on which they feed (Schlosser 1991, Rosgen 1994).

2.1.2 Lake Systems

Lakes are composed of differing habitat zones based on water depth and the type of plant growth. The open water, or limnetic zone, is not influenced by the lake bottom, but the shallower waters of the epilimnion receive enough sunlight to support algal growth, while the deeper, colder waters of the hypolimnion do not. The littoral zone is the near-shore zone where the water is shallow enough to support the growth of rooted aquatic plants. The littoral zone is the focus here, because of its essential role in supporting fish and aquatic life, and because it is the aspect of the lake ecosystem most directly affected by activities in the shoreland.

2.1.2.1 The Littoral Zone

Littoral zone habitats are very important to the structure and function of lake ecosystems (Gelwick and Matthews 1990, Benson and Magnuson 1992). The littoral zone provides fish with spawning sites, foraging sites, and refuge from predation. Transfer of food energy from the littoral zone to the deeper waters of the limnetic zone may influence the overall fish production and biomass on a lake (Boisclair and Leggett 1985). Almost all Wisconsin lake fish spend part of their life cycle or make use of the littoral zone in some way (Becker 1983). Fish that are thought of as deep, cold-water species also rely on littoral areas for spawning and rearing of young. Typically, larger predatory species use littoral areas seasonally for foraging or spawning, while their smaller prey spend all or most of their lives in or near the littoral zone. The littoral fringe, the very shallow water immediately adjacent to the shoreline, is of special importance to small fish.

Fish use of any particular littoral area is governed by the combination of water quality, habitat quality, and existing fish population density. Fish gather in habitats that offer the greatest potential to optimize protection against predation, yet offer access to available food resources (Aboul Hosn and Downing 1994). Complex habitat structure in the littoral zone provides high-quality habitat, because it provides for a variety of needs for a variety of species. Complex cover provides young fish with profitable foraging sites (Werner et al. 1983, Mittelbach 1984) safe from larger predators (Savino and Stein 1982). Fish quickly respond and aggregate near cover, because of its high value and limited nature.

Quantitative assessment methodologies of littoral zone habitat have not yet been fine-tuned for use in lakes, but there is ample documentation in the literature on fish-habitat relationships in lakes, especially for sport fish. Fish are habitat specialists, so each species or guild has its own unique habitat requirements (Gorman and Karr 1978). Hanson and Margenau (1992) demonstrated that stocked fingerling muskellunge use shallow water habitats with a combination of emergent vegetation, submergent vegetation, and woody debris. Craig and Black (1986) found that muskellunge young can also use a combination of emergent, submergent, and floating leaved vegetation as a nursery area. Northern pike require the shallow water and dense mats of short aquatic vegetation found in lake-fringe and stream headwater wetlands for spawning (Clark 1950, Forney 1968). Northern pike fry use these wetlands for protection from predators and for foraging (Franklin and Smith 1963, Frost and Kipling 1967). Adult northern pike and muskellunge use downed logs and rocks as hiding sites from which they ambush their prey. Their hunting success depends on clear water for good visibility. On the other hand, walleye are adapted to hunting in low light and can tolerate lesser water clarity but require clean gravelly substrate for spawning (Becker 1983). Native forage fish, such as white suckers, utilize very shallow littoral areas and stream junctions with gravel substrates for spawning (Krieger 1980). Yellow perch broadcast strands of eggs in 3- to 6-foot-deep water where they can cling to aquatic vegetation, which increases their chance of survival (Clady and Hutchinson 1975). Smallmouth bass reproduction is improved by the presence of woody structure in the littoral zone (Hoff 1991). Bluegill, bass, and crappie spend most of their life cycle in the littoral zone, spawning in areas protected from waves, where they can fan the silt off of coarser substrate and keep their eggs well-oxygenated by fanning. Their body shape and turning ability makes them well-adapted to the cover provided by submerged vegetation to escape predators (Becker 1983).

Complex cover and forage are created by the physical and biological components of the littoral zone: aquatic plants, bottom substrates, woody cover (downed tree trunks and branches), and a diversity of depths. Aquatic vegetation in the shallow waters along shorelines plays a critical role as both protective cover and colonization sites for the invertebrates upon which smaller fish feed (Shramm and Jirka 1989). Different types of aquatic plants play different roles in the littoral zone system, resulting in habitat for a variety of fishes (Jennings et al. 1996a). Floating leaved plants, such as pond lillies provide shading and overhead cover, as well as colonization sites for invertebrates, while emergent vegetation, such as bulrushes, provide more lateral underwater structure and egg attachment sites for both fish and amphibians. Emergent vegetation also acts to dampen wave energy (either natural or from boat wakes), thus protecting spawning areas and reducing shoreline erosion, although in some areas wave energy is too high to allow the establishment of emergent aquatic vegetation (Bonham 1983, Johnson 1994). Overhanging bank vegetation provides overhead cover. Submerged vegetation can provide both underwater lateral cover and overhead cover depending on the species and is heavily colonized by aquatic microorganisms and aquatic invertebrates. These provide a rich food source for juvenile and small fish, amphibians, and larger invertebrates which in turn are eaten by larger fish, other amphibians and reptiles, and predatory birds, such as herons, kingfishers, loons, and bald eagles.

When aquatic plant growth, especially submerged plants, becomes too dense as a result of excessive nutrient loading from the shoreland and larger watershed, the predation success of larger fish is reduced (Glass 1971, Savino and Stein 1982, Gotceitas and Colgan 1987), increasing the survival rate of young fish, and increasing their growth rate. The structure of the fish community shifts to an undesirable overabundance of smaller fish species, such as bluegills and pumpkinseeds (Colle and Shireman 1980, Colle et al. 1987, Theiling 1990), and in smaller sizes of these fish (Schneider 1981).

2.1.2.2 Shoreland Vegetation and the Littoral Zone

Along undisturbed shorelines, the riparian zone contributes to habitat quality in the littoral zone in several ways. Trees in the riparian zone, when they fall into near-shore waters, are the source of this important component of habitat structure. Near-shore waters littered with exposed or submerged woody debris diversify the microhabitats available for a variety of invertebrates, fish, birds, and mammals using the littoral zone. Woody debris plays a role in the aquatic food chain by providing colonization sites for invertebrates. The attached invertebrates and the structure created by the assemblage of branches and logs provides cover and foraging opportunities for juvenile fish and smaller adult species. Male smallmouth bass in Wisconsin excavate nests near logs and boulders for their own cover and that of newly hatched fry (Hoff 1991, Baylis et al. 1993). Dabbling ducks, such as mallards and blue-winged teal, congregate near plant cover and woody debris for foraging (Jahn and Hunt 1964). Some fish, such as bluntnose minnows, and amphibians, such as mudpuppy salamanders, attach their eggs to submerged logs as well as submerged rocks (Hubbs and Cooper 1936, Duellman and Trueb 1988). Floating logs, leaning trees, and overhanging branches also provide basking sites for turtles and snakes, as well as perching sites for shore birds and ambush sites for mink (Allen 1986), raccoons, and other mammals that prey on aquatic life.

Well-vegetated riparian zones stabilize lake shorelines by holding soil in place, in much the same way as described in the previous section on streams. By trapping and transforming sediment and nutrients from runoff, the shoreland maintains littoral water clarity and prevents the siltation of existing bottom substrates, thus preserving good spawning areas. Good water clarity extends the littoral habitat farther into the lake by allowing aquatic plants to grow in deeper water (Chambers and Kalff 1985).

In a manner similar to stream ecosystems, the shoreland provides an essential input into the food chain of lakes by contributing organic material in the form of falling leaves and other dead vegetation. The magnitude of litter input can be directly related to the extent of wooded shoreline at least 10 meters (35 feet) wide (Odum and Prentkis 1978). Leaf litter and other organic material constitutes a large portion of the base of the detrital food chain in lakes by providing food for bacteria and aquatic insects. Leaf litter colonized by bacteria becomes a more valuable food source for aquatic insects (Schallenberger and Kalff 1993). Coarser material in lakes, from branches up to logs, will take increasingly longer periods of time to become colonized by decay organisms and invertebrates and decay more slowly than they do on land (Hodkinson 1975), reducing their role in the food chain but greatly increasing their role in providing long-term habitat structure.

2.1.2.3 Impacts and Shoreland Zoning Effectiveness in Protection of the Littoral Zone

Shoreland development can affect the quality of littoral zone habitat in many different ways. In order to meet their recreational needs and perceptions of a well-managed property, landowners tend to modify the shoreland and the littoral zone in ways that are not beneficial to fish and aquatic life. The direct destruction of aquatic plants occurs when lakeshore owners clear out the "weeds" in an area for a swimming area or pier, or through cutting by boat propellers. Healthy trees are removed in order to provide a view of the lake, while fallen tree limbs and trunks are also removed, and standing dead snag trees are cut down in order to clean up the shoreline. Lots may be cleared of all vegetative layers or cleared of shrubs and ground cover in order to establish a well-manicured, weed-free lawn. Sand blankets are placed over existing bottom substrates to create a swimming area. The effect of these modifications and the effectiveness of shoreland zoning in protecting littoral zone habitat will be discussed in this section.

Impacts of Littoral Habitat Simplification

The combination of the habitat variables discussed above results in habitat complexity. A higher degree of habitat complexity supports a greater diversity and density of fish and aquatic life. When individual components of habitat structure are lost, habitat becomes simplified and the diversity of fish and aquatic life that can be supported is reduced. This relationship has been documented by Beauchamp et al. (1994) in a study of piers and cribs in Lake Tahoe, by Ward et al. (1994) studying the effects of harbor development on migratory salmonids, and by Leslie and Timmins (1994) studying a developed harbor in Lake Huron. Jennings et al. (1996b) recently completed a study comparing the effects of shoreline erosion control structures composed of rip-rap, or seawalls, and undisturbed shorelines on 20 lakes carefully chosen to reflect a cross section of lake types from every region in Wisconsin. Despite the considerable variations in lake types, weather conditions, geography, and water level, consistent differences in fish populations along the three types of shoreline were found. The study concludes that more species of both fish and invertebrates are likely to use habitat provided by rip-rap than seawalls because rip-rap provides more complex habitat. Further, the analysis of cumulative samples suggest that species richness (the number of different species present) is reduced at shorelines modified by retaining walls.

These results suggest that littoral zones that retain features adding habitat complexity, such as woody debris, emergent and floating aquatic plants, and overhanging vegetation, have more abundant and diverse fish populations on a lakewide basis than littoral zones with greatly simplified habitat. Bryan and Scarnecchia (1992) demonstrated the cumulative effect of shoreline development on littoral zone habitat and fish abundance in a glacial lake in Iowa, primarily through destruction of aquatic vegetation. Aquatic vegetation and fish abundance were lower in the littoral zone along developed shoreline segments compared to undeveloped shorelines. The implication of these studies is that the negative impacts of habitat simplification on fish and aquatic life are the result of the cumulative effect of many individual modifications.

Although many of these shoreline activities require permits or must conform to certain standards in chapter 30 regarding navigable waters, or in NR 107 regarding aquatic plant management, there are inherent difficulties in adequately assessing and basing individual permit decisions on cumulative impacts. Addressing cumulative impacts in an individual permit process is very difficult, because of the issue of determining at what point incremental impacts have become significant. Tied into the issue is the concern over the equity of denying to one landowner what has been permitted to the neighbors. However, shoreland zoning standards that control the density of lakeshore development are a good mechanism to reduce the degree of habitat simplification that occurs along the entire shoreline. In response to a survey regarding walleye management in Wisconsin, resident anglers gave a high level of support to fish management activitirect resource protection such as managing shoreline habitat to protect spawning sites, control soil erosion, and conserve wetlands (Wisconsin Department of Natural Resources 1995a).

Impacts of Shoreline Vegetation Removal

While the importance of littoral habitat structure to lake ecology is well accepted, the cumulative impacts of shoreline modifications and vegetation removal on the littoral zone are just beginning to be quantified. Christensen et al. (1996) studied 16 lakes with varying degrees of shoreline residential development in northern Wisconsin and Michigan's upper peninsula. They found a significant reduction in the amount of coarse woody debris as the density of shoreland development increased. This occurs through direct removal of fallen tree trunks and branches from the lake and cutting of trees along the shoreline. The authors conclude that because of the time scales involved in both recruitment of coarse woody debris and decay rate, the reduction of coarse woody debris along the lakeshore may have dramatic long-term consequences for lake ecosystems. This suggests that shoreland zoning standards controlling the intensity of lakeshore development could play a critical role in maintaining this ecosystem function. This study also suggests that the current vegetation standard allowing cutting of dead and diseased trees and only prohibiting clear-cutting is inadequate to maintain a source of coarse woody debris to the littoral zone.

Investigations of the effects on fish behavior of converting natural shoreline vegetation to mowed lawn on oligotrophic (clear, but nutrient-poor) lakes in Canada are in progress (N. Collins, University of Toronto, pers. comm. 1996). Simultaneous videotaping is being used to compare both fish feeding and traffic between the littoral fringe (the very shallow water immediately adjacent to the shoreline) and the mid-littoral zone. The researchers are also comparing fish behavior between shorelines developed with mowed lawn up to the water's edge and undisturbed shoreline. Results to date document the importance of littoral fringe habitat in oligotrophic lakes, with fish feeding rates 10 times higher in the littoral fringe than in the mid-littoral zone, although feeding rates are greatly reduced in littoral fringe areas subjected to higher wave action. Fish traffic levels were 2.5 times higher and feeding rates were 7 times higher along undeveloped shorelines compared to lakeside lawns. These results document the negative impact of the removal of shoreland vegetation and highlight the importance of maintaining natural vegetation along lakeshores as well as streams.

Because it provides an organic nutrient source at the base of the food chain, leaf litter can be a particularly important nutrient source in oligotrophic lakes that have a large lake surface area relative to their drainage basin (France and Peters 1995). In such lakes, the loss of a wooded shoreline buffer can be expected to degrade littoral habitat quality and shift the nutrient dynamics of the lake away from the detrital pathway toward a greater proportion of internal energy sources, such as algal production, that are low in oligotrophic lakes. The loss of this nutrient source could result in lower biomass at all levels in the food chain, ultimately affecting fish production, while such a basic change in the lake's metabolism may prove to be ecologically significant through an as-yet-unrecognized mechanism.

The 35-foot width of the zone to which the vegetation cutting standard applies, appears to agree well with the estimations used by Christensen et al. (1996) and Odum and Prentkis (1978) for the area contributing leaf litter and coarse woody debris to lakes. However, the use of the term clear-cutting in the standard weakens its effectiveness by allowing substantial cutting.

Density Standards and Cumulative Impacts

In addition to the vegetative cutting standards, the lot width and size minimums and shoreland-wetland zoning are the primary means of controlling the cumulative impacts of vegetation removal along the shoreline. A study of shoreland zoning implementation on six lakes in Oconto County found that larger lot sizes were correlated with less overall vegetative cutting and less overall shoreline modification (Ganske 1990). The amount of vegetation modification was found to be independent of lot size, because owners of both larger and smaller lots tended to concentrate tree cutting and brush removal on the center of the lot, and building sizes were comparable. If this relationship holds true in the future, larger minimum lot sizes can be expected to result in less overall vegetation modification. However, trends toward building larger homes with established lawns could negate the potential of larger lot sizes to reduce vegetation modification. Quantitative data on trends in waterfront lot sizes and building sizes would be useful but is not available at this time.

2.2 Policy Implications for Protecting Aquatic Habitat

Buffer effectiveness for the reduction and trapping of sediments, nutrients, and toxicants from runoff water is discussed in the section on water quality (Section 1.3). Water quality and aquatic habitat are interdependent, therefore the implications of the research on sediment and nutrient trapping applies here as well.

Shoreland-wetlands used by northern pike and muskellunge for spawning can often be less than 5 or even 2 acres and are therefore not protected under the shoreland-wetland zoning ordinances of most counties. The important aspect of this very valuable wetland function is not size but vegetation composition and hydrologic connection to lakes and streams (Farrell et al. 1996). The size limitation in county shoreland-wetland ordinances may not adequately protect northern pike spawning areas.

A 35-foot buffer of undisturbed vegetation may be sufficient for maintaining some of the physical functions of shorelines, such as providing vegetative cover for stream bank stabilization, shading to moderate water temperature, and contributing leaf litter and woody debris to aquatic environments. Buffers less than 35 feet wide are not likely to provide more than minimal habitat for aquatic wildlife. Current vegetative cutting standards are inadequate to guarantee a quality buffer, however, because of the extent of vegetation modification potentially allowed under the "don't clear-cut" standard and the allowance for removing dead and dying trees. This can result in degradation of fish habitat by removing important structural elements (tipped-over trees, overhanging branches, and overhanging grassy bank vegetation) from both lake and stream fish habitat. This standard should be revised to focus on maintaining existing natural shoreland vegetation, yet be made flexible enough to allow for restoration projects aimed at improving habitat that require some vegetation removal. A larger buffer setback could provide a greater safety factor for preserving the integrity of the buffer area but would not be effective if the vegetative cutting standard remains unchanged.

Protection of littoral zone habitat for aquatic species may be more effectively accomplished by increasing lot widths and sizes than by increasing the width of the habitat buffer. This is because minimum lot widths can control the density of settlement along the shoreline and reduce the cumulative degrading effect of many piers, sand blankets, seawalls, removal of dead trees, and removal of aquatic plants along a given length of shoreline. The literature provides little guidance on selecting an adequate minimum lot width, but it is clear that greater lot widths would result in greater littoral and stream protection. This issue will be discussed further in Section 4, Cumulative Impacts Considerations.

2.3 Riparian Wildlife Habitat Functions

Vegetated shoreline buffers also preserve habitat for many species of wildlife that could be considered at least partly aquatic species. For example, amphibians and reptiles display a wide variety of life cycles, completing parts of their life cycle in the water and parts on land. Most amphibians require access to water for breeding and early life stages, most turtles breed in the water and lay eggs on land, and some snakes feed both in and out of the water. This report will use the general term *riparian wildlife* to refer to species that are dependent on the conditions present in terrestrial near-shore zones for part of their life cycle and *shoreline dependent* for species that depend on the immediate shoreline and near-shore waters for crucial life functions.

This section consists of discussions of shoreland habitat use by Wisconsin wildlife species and management recommendations by WDNR ecologists. Following these discussions, studies from the literature evaluating buffer effectiveness in various land use contexts is reviewed.

2.3.1 General Observations on Bird and Small Mammal Use of Shorelines and Riparian Corridors in Wisconsin (William Volkert - WDNR-Wildlife Management, Horicon)

Because the wildlife species discussed below are primarily adapted to ecotones, edges, and narrow corridors of shoreline habitat, they can potentially benefit from the type of buffer provided by shoreland zoning standards. Other species have a need for more expansive upland or wetland habitats adjacent to shorelines. For example, bobolinks require extensive grasslands, sandhill cranes require expansive sedge meadows and similar lowland meadow habitats, and red-shouldered hawks require extensive tracts of lowland forests, especially in river bottoms. These species would require a much larger buffer, measured in hundreds of feet and connected to large areas of suitable habitat.

Bird Use of Shoreline Sedges, Wet Meadows, and Prairie Vegetation

These vegetation types provide essential nesting cover for ground-nesting waterfowl. Mallards, blue-winged teal, and Canada geese are commonly found in these shoreline habitats in most regions of our state. These vegetation types may also serve similar functions for other species that nest above ground among dense grasses and sedges. Songbirds that nest in dense grassy cover include sedge wrens, common yellowthroats, and others.

The benefit to and use of this shoreline cover by these species also depend on the type of adjacent aquatic community. In addition to shoreline cover, protection of near-shore aquatic vegetation is also important for waterfowl conservation. For example, waterfowl typically seek shallow water for brooding but avoid deep lakes with high public use and a relative lack of submergent aquatic vegetation. Additionally, sora rails and pied-billed grebes nest among dense stands of emergent vegetation, such as reeds, cattails, and bulrushes, in near-shore waters.

In some cases, narrow strips of unmowed shoreline cover may have significantly higher predation rates, an effect similar to the edge effect found along highway right-of-ways. While nest loss may be high, at least some reproduction can be expected to succeed, compared to mowed strips, which are almost totally lacking in wildlife use. The tall grassy vegetation also provides secure cover for other wildlife outside of the normal nesting season. Sora rails may use sedge shorelines but may be restricted due to the extent of the shoreline area.

Bird Use of Shoreline Shrubs and Brush

Shrub and brush vegetation along shorelines provides important nesting habitat for a variety of riparian songbirds, including yellow warblers, common yellowthroats, swamp sparrows, alder and willow flycatchers, and others. This may also serve as significant cover during migration and for wintering populations of songbirds. Species during migration include the above, plus white-throated sparrows, Lincoln's sparrow, palm warblers, and many others. Wintering species include American tree sparrows and juncos.

Bird Use of Forested Shorelines

Depending on the size and species composition of the trees on lake shorelines, forested shorelines can be important habitat for nesting warbling and yellow-throated vireo, blue-gray gnatcatchers, prothonotary warblers, green herons, wood ducks, hooded mergansers, and others. Forested wetlands, such as lakeshore swamps and bogs or wet pockets along streams, provide habitat for the northern waterthrush which nests in root mounds of uprooted trees or under overhanging stream banks.

Forested shorelines will also be used by upland birds for additional nesting and feeding habitat. Forest-edge species found here may include cedar waxwings, red-winged blackbirds, northern oriole, and downy, hairy, and red-bellied woodpeckers. Migrants dependent on shoreline forest habitat include rusty blackbirds, a variety of warblers, vireos, and flycatchers.

Standing snag trees play a critical role in forested shorelines by providing nesting sites for herons, egrets, eagles, and ospreys. Snags serve as perching sites for fish-eating birds, such as belted kingfishers. Wood ducks, hooded mergansers, and common goldeneyes use the cavities of decaying trees along the shoreline for nesting.

Small Mammal Use of Shoreline Habitat

Shoreline habitats of grasses, sedges, brush, and trees are important sites for rearing young and feeding for a number of common mammals. These include raccoons, muskrats, beaver, mink and other weasels, and perhaps river otters. These sites also provide for a variety of rodents, such as voles, meadow mice, deer mice, and shrews, which serve as an important food base for birds and mammals that prey on them.

Shoreline vegetation as a continuous belt of grasses, shrubs, and trees provides a significant corridor for wildlife movements. Whether this is lining the shores of a river or surrounding the shores of lakes or ponds, these corridors are the highways for wildlife movement for both birds and mammals. Interrupted shoreline vegetation that has been fragmented through clearing, brushing, and mowing creates exposed sites with higher mortality and near zero production of young, and are commonly avoided by wildlife.

2.3.2 Amphibian and Reptile Use of Shorelines and Riparian Zones (Robert Hay - WDNR-Endangered Resources, Herpetologist)

Amphibians are a crucial link between aquatic and land ecosystems. Amphibians and reptiles (known collectively as herptiles) play particularly important roles in aquatic food chains, because they occupy a middle position as both predator and prey, and because they constitute an enormous amount of the biomass in some aquatic and riparian ecosystems. In many aquatic habitats, freshwater turtles represent the majority of the vertebrate biomass (Congdon et al. 1986). As many as 88,000 amphibians were captured in a single year in a 1-hectare temporary pond (Savannah River Ecology Laboratory 1980). The importance of amphibians and reptiles as prey in the diets of raptors, including several that are endangered or threatened, has been well documented by Ross (1989). Twenty-five percent of the successful bald eagle nests along the shoreline of Chesapeake Bay contained turtle remains (Clark 1982), and osprey prey on herptiles during times of low fish availability (Wiley and Lohrer 1973). Because of their large biomass and their movement between terrestrial and aquatic systems, amphibian populations can influence important ecosystem functions such as primary and secondary productivity, nutrient influx, and competition (Seale 1980, Osborne and McLachlan 1985, Cunningham and Brooks 1995).

Most of the amphibian species and many of the reptile species in Wisconsin rely on riparian habitat in some way. Preservation of riparian habitat is essential for this key component of the aquatic food web. Marsh, sedge meadow, and other riparian wetland habitats, being damp to wet and typically dominated by dense vegetation, are productive foraging areas and are particularly important in reducing desiccation of amphibians, while providing good overhead cover for many herptiles.

The following discussion outlines the ways in which riparian habitat is used and the degree to which different herptile species utilize riparian habitat. Since riparian habitat quality is critical for those species that are considered shoreline dependent and for certain threatened and endangered species, more detail is offered on their habitat requirements.

Shoreline-Dependent Herptile Species
There are five frogs and two reptiles that are considered shoreline-dependent species in Wisconsin, because they spend most or all of their life history in a relatively narrow band which typically includes both near-shore aquatic habitat and the near-shore riparian area (Vogt 1981, Oldfield and Moriarty 1994). The frog species include: Blanchard's cricket frog, a state endangered species, the bullfrog and pickerel frog, both special concern species, and the green and mink frogs. The two reptiles include the queen snake, a state endangered species, and the northern water snake.

Although habitat requirements for the frog species vary somewhat, most depend on moist soil and moderate-to-dense vegetative cover in the immediate shoreline to maintain a cool, moist microclimate, hide from terrestrial predators, and escape from fish predators. Bullfrogs and green frogs spend much of their time basking, resting, or foraging in fringe wetlands with tall dense cover, or in tall grassy cover along the shoreline (Flemming 1976). Mink frogs spend most of their time in shallow near-shore water, especially near the inlets and outlets of northern bog lakes and streams, resting on floating mats of vegetation. Similar to green frogs and bullfrogs, pickerel frogs prefer moderate-to-dense vegetation along cold-water streams and springs as well as lakes and medium-sized rivers. They may travel overland to adjacent ponds to breed, taking advantage of warmer waters, which speed up metamorphosing rates (Hay, pers. obs.). However, they are rarely found away from the water's edge (Oldfield and Moriarty 1994). Blanchard's cricket frogs currently occur only in extreme southwestern Wisconsin (Casper 1996). They have a strong preference for very low shoreline vegetation because they rely on their jumping ability to elude predators (Hay 1996). Unlike the other frogs, they could benefit from grazing or mowing along shorelines. All five of these frog species lay their eggs in shallow water among submergent vegetation or submerged tree trunks and branches.

Queen snakes occur along relatively clean streams in southeastern Wisconsin (Casper 1996), in a mix of grass or sedge meadow and shrubby habitats, basking on rocks near or on the shoreline, and in ground cover or brush along the streambank. They are most often found under rocks, in or out of the water, but have not been observed where shorelines are manicured or grazed. The northern water snake prefers similar habitat, but it is widespread throughout Wisconsin, including forested areas, using ponds and wetlands in addition to slow-flowing streams and lakes. It basks in brush or deadfalls overhanging the water or in grassy vegetation. Northern water snakes will utilize rip-rap in appropriate habitats.

Because these species are shoreline dependent, the 35-foot buffer provided by shoreland zoning standards can be a major tool in conserving their habitat. Since they typically use wetland habitat but do not require large wetland areas, much of their habitat is unprotected by shoreland-wetland zoning. With the exception of the Blanchard's cricket frog, their need for dense vegetative cover calls into question the effectiveness of the current vegetative cutting standard to protect their habitat.

Riparian Herptile Species
Riparian herptile species are those which range farther away from water than the shoreline-dependent species, but rely on the riparian zone along streams, lakes, and wetlands. They can be classified into three categories: those that require riparian habitats due to their proximity to permanent water; those that have a preference for riparian habitats over upland habitats; and those that live in habitats that happen to exist in the riparian corridor but can also be found in uplands.

Riparian Dependent
Riparian-dependent species include the wood turtle, a state threatened species, and the western ribbon snake, a state endangered species.

Wood turtles are strictly a riverine turtle and are semiterrestrial, sometimes spending as much or more time on land as in the water. Riparian corridors, especially wetlands dominated by alder and willow brush or lowland hardwood forests are critical habitat for this species. Studies have shown that the juveniles are highly dependent on alder along shorelines (Brewster 1985). Other studies have shown that wood turtles will most often utilize a 300-meter (990-foot) area paralleling the stream or river (R. Buech, USDA-Forest Service, pers. comm. 1993). Buffer zones along riverine corridors should be broad (at least 300 meters wide) where this species occurs, especially in lowland areas. The wood turtle usually nests close to the river edge in areas of open canopy with sandy soils. Sites may occur some distance from water if shoreline areas are not open to the sun or if sandy soils are not present (R. Thiel, WDNR, pers. comm. 1992). Stream bank stabilization activities may convert nesting sites of relatively sandy, somewhat erodible soils into dense vegetation, rendering them useless for nesting (Hay, pers. obs.). These areas are typically southeast, south, or southwest exposures. Stream bank stabilization may be particularly detrimental to wood turtles if other suitable nesting habitat does not exist nearby, especially since this species is a communal nesting species. Many females from a long stretch of river (up to 10 miles in length (C. Brewster, Wisconsin Herptile Working Group, pers. comm. 1991)) are known to return to these discrete sites annually. These turtles also often display nest site fidelity. Alternative sites may not be available or selected. Wood turtles avoid nesting areas where regular human activity is present. Rip-rap, especially if the rocks are large, can act as a barrier preventing access to land. Hatchling mortality can result as hatchlings become entrapped in the cavities within rip-rap while moving from the nest to the water.

Western ribbon snakes live along shorelines of lakes and rivers, or along associated marshes (Vogt 1981). This species is extremely rare in Wisconsin and its distribution is spotty and not well documented. It occurs as far north -as central Wisconsin. Western ribbon snakes prefer open grass or marsh vegetation for hunting amphibians, their primary food source.

Riparian Preferred

Herptile species with a preference for riparian habitats include: the eastern massasauga rattlesnake, a state endangered species; northern leopard frogs (especially newly metamorphosed young); and most aquatic turtles (for nesting), including the eastern spiny softshell, midland smooth softshell, snapping turtle, western and midland painted turtles, common musk, false map, map turtles, and to a lesser degree, Blanding's turtle, a state threatened species (Vogt 1981, Oldfield and Moriarty 1994).

Eastern massasauga rattlesnakes prefer both lowland hardwood forests and open grass/sedge meadows along river corridors, especially near river confluences (Vogt 1981). Gravid females move from these habitats to dryer open upland sites to incubate their young throughout the summer. This makes habitat connectedness very important for this species, and habitat fragmentation is likely a major factor in the decline of this species nationally (King 1995). Riparian areas provide hibernating sites for this species, as they often overwinter underground in mammal burrows, root channels, old tree stumps, and crayfish tunnels (Oldfield and Moriarty 1994).

Northern leopard frogs prefer riparian areas and adjacent wet prairies and fields where summer vegetation ranges from 15 to 30 centimeters in height (Oldfield and Moriarty 1994). This allows for a more humid microclimate while not inhibiting movement as the frogs forage on invertebrates. Younger leopard frogs stay closer to the water but forage in similar habitat.

Most turtles are dependent on well-drained upland open sites that are relatively close to the water for nesting (Hay, pers. obs.). This preference seems compatible with reducing adult turtle predation since these animals are prone to heavy predation in terrestrial habitats. There are situations, especially along extensive forested shorelines in northern Wisconsin, in which some shoreline development may actually increase nesting opportunities by providing needed areas of open canopy. This may potentially increase the recruitment potential by providing additional nesting localities and possibly reduce nest predation rates (fewer available sites mean fewer places for predators to have to search for nests). Although some species of turtles, such as snapping and painted turtles will readily accept nesting in manicured lawns as long as soils are well drained, other species, such as softshell and map turtles shy away from human activity and prefer to nest in isolated areas.

Generalists within Riparian Habitat

Riparian areas that consist of wetlands, especially if wooded, can contain a wide variety of amphibians. The key habitat characteristics for many amphibians are canopy cover and damp soils, providing a preferred cooler microclimate. Typically, broader or more extensive forested habitats provide better microclimates for amphibians than do smaller, narrower forested habitats, because the latter often have lower humidities and warmer surface temperatures. These habitats are not restricted to riparian areas.

The American toad, chorus frogs, and the tree frogs can also be found in open or brushy habitats, as well as in woodlands. All of these amphibians, except for the red-backed salamander and the central newt, breed primarily in ephemeral ponds and wetlands. Ephemeral ponds should be protected from deforestation in riparian areas, as opening the canopy often speeds pond drying and may render them unproductive for amphibians, especially in non-wet years. In many years, it is a race against time to accomplish metamorphosis before pond drying. Forest cutting and thinning has been reported to reduce salamander biomass in several areas around the United States (Blymer and McGinnes 1977, Bennett et al. 1980, Petranka 1994).

Snakes often utilize and prefer a variety of habitat types, ranging from open to closed canopy situations and damp-to-dry conditions (Vogt 1981, Oldfield and Moriarty 1994). Snakes, other than the northern ringneck snake, a special concern species, and others mentioned earlier, have a preference for open habitats but will utilize forest edges and occasionally interiors (e.g., eastern garter snakes). The northern ringneck prefers damp forested areas where it spends much of its time in rotted logs and stumps. These snakes prefer a cooler microclimate than most snakes and are only found in the northern half of Wisconsin. Minton (1972) has demonstrated that this species disappears when deforestation occurs.

2.3.3 Common Loon (*Gavia immer*) Use of Shorelines and Riparian Zones in Wisconsin (Terry Daulton, Coordinator, LoonWatch)

The common loon attracts significant attention from the general public and the scientific community. For many citizens in Wisconsin's northern lakes region, the loon's charismatic appearance and calls have established it as a symbol of the values of northern lakes (Dunn 1992). The loon's position at the upper level of the aquatic food chain and its specific habitat requirements make it vulnerable to human activities such as intensive recreation and shoreline development (McIntyre 1975). The loon is particularly sensitive to environmental contaminants such as mercury and lead (Ensor 1992). Considerable study in Wisconsin has focused on the impacts of toxics on loons and the use of the loon as a biological indicator of aquatic health (M. Meyer, Wisconsin Department of Natural Resources, pers. comm. 1996).

Historically, common loons in the Midwest nested on lakes throughout Wisconsin and as far south as Illinois and Iowa. During the past century, increasing shoreline development on lakes and subsequent loss of habitat and water quality have contributed to the decline of loon populations in southern Wisconsin, Minnesota, and Michigan, and the elimination of nesting in Illinois and Iowa. Declines in common loon populations have also occurred throughout much of the northeast and western United States. The decline of common loons throughout their historical range compounds the importance of maintaining productive habitats in Wisconsin. Today, Wisconsin supports the third largest population of common loons in the lower 48 states, surpassed only by Minnesota and Maine.

In 1995, LoonWatch estimated the Wisconsin common loon population at 3,017 adults, distributed primarily in the 20 northernmost counties. Fifty-seven percent of all adult loons and 70% of loon chicks are found on lakes under 150 acres in size (T. Daulton et al., LoonWatch, unpublished data). Loons can be considered a shoreline-dependent species, using near-shore and shoreline habitats for nesting and chick rearing. During these times, loons are sensitive to disturbance.

Loons are relatively faithful to nesting lakes and even to specific nest locations. Loon nests are built on the shoreline immediately adjacent to water and on a variety of anchored or nonfloating substrate. Eggs are sometimes placed on rock, sedge mat, or other available structures, such as muskrat or beaver lodges. Loons are vulnerable while on land and prefer nesting sites where the lake bottom drops sharply enough to allow easy access to deep water. At these sites, if water levels fluctuate during the season, changes in the distance between nest and water are not drastic (McIntyre 1975).

Loons prefer sheltered locations such as small bays or promontories on the lee side of an island. Along with protection from wind and waves, visual and auditory privacy between adult pairs is important. In Minnesota, less visible loon nests produced significantly more surviving young than more visible nests. In Ontario, hatching success declined as the number of cottages within 150 meters (about 490 feet) of loon nests increased (Heimberger et al. 1983). Vermeer (1973) found that loons preferred to nest on lakes where there is a minimum of human disturbance. In Wisconsin, lakes with nesting loons were found to have significantly lower numbers of dwellings than lakes without loons (Zimmer 1979). In some instances, increasing recreational use of islands by humans have forced loons to abandon traditional nesting territories, moving to bays and shorelines away from human impacts (Titus and Van Druff 1981). McIntyre (1975) found that lakes with higher levels of shoreline development produced higher levels of predation on loon nests. Protection of nesting sites is most critical from ice-out to late June.

After chicks hatch, loon families spend considerable time in shallow-water nursery areas. These are usually back bays or other parts of the lake protected from wind and waves. Nurseries are typically shallow lake-fringe or aquatic bed wetlands, with both submergent and emergent vegetation, that support small fish for forage. Nurseries are not usually located near the nesting site. Most impacts to nursery areas are due to human recreational activity. For example, in Minnesota's Boundary Waters Canoe Area, researchers found that loon pairs on lakes with fewer human contacts produced significantly more surviving young (Titus 1978). While evidence suggests that intensive recreation can impact chick survival, the impacts of shoreline development are not conclusive (McIntyre 1975).

A majority of loons in Wisconsin nest on lakes smaller than 150 acres. A study of shoreline development trends in northern Wisconsin suggests that, with current rates of development, all privately owned lakes larger than 10 acres in size will be fully developed within the next 20 years, possibly sooner (Wisconsin Department of Natural Resources 1996b). This study also found that approximately 97% of northern Wisconsin lakes greater than 200 acres in size have already seen some development. Currently, approximately only 4% of lakes larger than 200 acres (20 lakes) are in public ownership.

Given these trends, the effectiveness of current shoreland zoning standards to protect critical loon habitat becomes of paramount concern. In light of the specific habitat requirements for common loon nesting, it is unclear whether current standards are sufficient to ensure nesting success. Clearing of shrubbery or even modest thinning of trees could reduce protective cover. Minimum lot sizes and widths for both sewered and unsewered lots allow considerably denser development patterns than the density found to impact nesting success in Ontario (Vermeer 1973, Heimberger 1983). At the allowed density, the increased level of human disturbance by land and water, along with the potential from predators introduced or favored by residential areas (dogs, cats, raccoons, foxes, coyotes), may also reduce the potential for loon nesting success. Identification of existing loon nesting sites and nursery areas could allow adoption of special zoning standards to decrease development density and also promote landowner understanding of the value of particular sections of their shoreline for loon reproduction.

2.3.4 The Importance of Shoreland Habitat to Wisconsin Bald Eagles (Michael W. Meyer, WDNR - Integrated Science Services, Rhinelander)

The bald eagle (*Haliaeetus leucocephalus*) population in the north-central United States drastically declined in the 1940s to 1960s because of excessive pesticide exposure (DDT, dieldrin), shooting, and habitat loss. Populations dramatically increased following the ban on DDT and increased federal protection under the Endangered Species Act (1973). The U.S. Fish and Wildlife Service recently downlisted bald eagles from endangered to threatened status in the Great Lakes states. In Wisconsin, active nesting territories have increased from approximately 100 in the early 1970s to more than 600 in 1996 (R. Eckstein, Wisconsin Department of Natural Resources - Wildlife Research, unpublished data). Bald eagles have recolonized much of their historic breeding range in the northern half of the state.

Breeding Habitat Characteristics

Nest and Perch Tree Characteristics

Bald eagles primarily eat fish, especially during the nesting season. Fish comprise more than 95% of prey items delivered to nestlings by adult eagles in northern Wisconsin (Warnke 1996). Because of these feeding habits, nests are typically built in trees within 400 meters of lakes, impoundments, and large rivers in Wisconsin (Wisconsin Department of Natural Resources unpublished data). Supercanopy white pines are most often chosen for nest trees in northern Wisconsin (Wisconsin Department of Natural Resources, unpublished data) and northern Minnesota (Fraser et al. 1985), while large cottonwoods and oaks are often used in the southern half of the state. Many nests are in trees located at or near the shoreline; however, eagles often construct nests further inland when lakes have high recreational use or a large amount of shoreline development (Fraser et al. 1985; R. Eckstein, Wisconsin Department of Natural Resources, pers. comm. 1995). Bald eagles also utilize and defend shoreline perch trees. Perch trees are used by eagles while hunting and as sentry or guard posts to aid in the defense of breeding territories (Stalmaster 1987). Chandler et al. (1995) demonstrated that bald eagle distribution and abundance on the Chesapeake Bay was closely related to the availability of perch trees less than 9 meters (about 30 feet) from the shoreline. Eagles use a wide variety of species for perch trees, most are large with an open spreading form and stout horizontal limbs (Stalmaster 1987). Typically, a perch tree is the tallest tree on a shoreline, with a panoramic view and open exposure on at least one side. Dead trees (snags) are frequently used (Buehler et al. 1991).

Lake Characteristics

To determine whether bald eagles prefer specific lake types when establishing breeding territories in northern Wisconsin, the water chemistry and morphology of lakes where bald eagles nest in Vilas and Oneida counties were compared to those characteristics on lakes where eagles do not nest. Bald eagles are likely approaching carrying capacity in these two counties where the number of active territories exceeds 150 (nearly 25% of the state population). We found bald eagle nest territories are associated with a small percentage of the total number of lakes present. Lakes selected are generally large (greater than 200 acres) clear drainage lakes with neutral pH and moderate-to-high alkalinity (M. Meyer, Wisconsin Department of Natural Resources, unpublished data). It is likely these lake parameters are associated with more abundant prey. Approximately 25% of the Vilas/Oneida county bald eagle population nests on 50- to 200-acre lakes, but again prefer clear drainage lakes within this size class. It is likely that more than 75% of lakes in Vilas and Oneida counties do not provide suitable nesting habitat for bald eagles; many of these are small seepage lakes (less than 50 acres).

Effects of Human Disturbance and Shoreland Development

Many studies have shown that nesting bald eagles avoid areas frequented by people (Fraser et al. 1985, Livingston et al. 1990, Buehler et al. 1991, McGarigal et al. 1991). Bald eagles are most sensitive to human disturbance during the early nesting and incubation period (early March to early May) (Grubb et al. 1992), during which time most nest failures and nest site abandonment occur (Fraser et al. 1985; M. Meyer, pers. obs.). Some bald eagles have habituated to increased human settlement on lakes in northern Wisconsin as approximately 5-10% of nests are located within 100 meters of a house (R. Eckstein, pers. comm. 1995). Nest attempts are often successful at these sites (R. Eckstein, pers. comm. 1995); however, many of these nests are near houses which are seasonally occupied and/or vegetation provides extensive screening between the nest and ground (supercanopy white pine greater than 30 meters in height) (M. Meyer, pers. obs.).

There is a strong selection for nest sites on lakes with shoreline in public ownership in northern Wisconsin, especially lakes with more than 1 mile of public frontage (M. Meyer, unpublished data). While significant, this finding likely understates the importance of undeveloped shoreline for bald eagles as some privately held shoreline remains undeveloped, especially that held by paper companies and the Wisconsin Valley Improvement Corporation.

Implications For Shoreland Management

Lake and river shorelines are critical components of bald eagle breeding habitat in Wisconsin. Shoreline habitat provides bald eagles with nest sites and perch trees from which they forage and defend their territories. Studies have demonstrated that removal of perch trees reduces bald eagle shoreline use. Bald eagle perch trees are frequently dead snags more than 9 meters (about 30 feet) from the shoreline. Current shoreline zoning allows for removal of dead/diseased trees within the 35-foot vegetation buffer zone along shorelines. While removal may be desirable, provisions should be made to protect important bald eagle perch sites. Paradoxically, human shoreline settlement may enhance protection of bald eagle nest trees. The aesthetics of supercanopy white pines are often valued by lakeshore homeowners and healthy trees are seldom removed near home sites. This may account for the increasing number of bald eagle nests in close proximity to houses in northern Wisconsin. The timber value of large white pines frequently results in their harvest away from home sites.

Many bald eagles have adapted to increased shoreline development and lake use by moving their nest sites further inland. The response of eagles to second and third tiers of housing and cluster settlements is currently unknown. Studies in Minnesota found that clusters of homes resulted in greater displacement of eagle nests from shorelines while single seasonal homes had the least impact (Fraser et al. 1985). Development of guidelines for second and third tier housing around lakes and cluster developments should take into consideration the need to protect existing and potential bald eagle breeding territory. Optimally, two substantial stands of supercanopy white pines, 16 hectare (about 40 acres) or larger within 600 meters of shoreline, should be maintained free of development for each occupied eagle territory on lakes, impoundments, and rivers north of Hwy 64. This recommendation accommodates the need to maintain a primary "no disturbance" and secondary "minimal disturbance" buffer zone of 660 feet outward from the nest tree (U.S. Fish and Wildlife Service 1983). Attempts should be made to minimize multiple housing developments within existing breeding territories. Territory size is estimated at 256 hectares (about 630 acres) (U.S. Fish and Wildlife Service 1983).

Bald eagle nest territories are associated with a small percentage of the total number of lakes in northern Wisconsin. These lakes are generally large (more than 80 hectares) clear drainage lakes with neutral pH and moderate-to-high alkalinity. Bald eagle shoreline habitat conservation strategies should be developed for lakes of this type in northern Wisconsin.

Biologists studying bald eagle nest behavior in the Chippewa National Forest in Minnesota concluded that optimal bald eagle management will include maintenance of substantial areas of undeveloped shoreline (Fraser et al. 1985). Bald eagle nests in Vilas and Oneida counties are most frequently found near lakes with more than 1 mile of public frontage, indicating selection for undeveloped shoreline in Wisconsin. This finding argues for an improved understanding of the minimum amount and type of undeveloped shoreline that bald eagles require to maintain breeding territories on lakes. It is doubtful that lakes that are completely settled under current zoning restrictions (one house per 100 feet of shoreline) will remain viable bald eagle nest habitat without improved public education and development of shoreline management strategies. A larger percentage of shoreline will need protection on smaller lakes to provide enough buffer from human disturbance to allow for successful nesting. Nearly 25% of bald eagles in Vilas/Oneida county nest on lakes less than 80 hectares (about 200 acres). Shoreline on these lakes is rapidly being developed and undeveloped shoreline on larger lakes is becoming rare or expensive ($100,000 for 100- by 300-foot vacant lots on Eagle River Chain of Lakes). Shoreline acquisition plans, as contemplated under the Northern Lakes and Shorelands Initiative, should take into consideration the need to protect undeveloped shoreline for breeding bald eagles.

Finally, it is important that laws that impose harsh financial penalties and potential jail terms on individuals who intentionally kill bald eagles or destroy nest trees continue to be enforced. It is likely that bald eagles avoid human settlements because of historic harassment. However, it is now apparent that certain eagles can tolerate human activities at close range. The degree to which bald eagles are able to adjust to the certain continual encroachment on their breeding habitat may well depend upon the level of shooting and harassment those populations experience. Therefore, an emphasis on enforcement and education to minimize harassment to this species is required even if Endangered Species Act protection is removed.

A combination of appropriate habitat protection strategies, shoreland zoning, and enforcement of laws protecting bald eagles from harassment will allow the current coexistence of a healthy bald eagle population with human settlement in northern Wisconsin to continue into the future.

2.4 Shoreland Zoning Effectiveness for Maintaining Riparian Wildlife Habitat

Given the range of ecological functions that take place in riparian areas and associated near-shore waters, how well do the shoreland zoning standards allow for the maintenance of these functions? While the functions provided by shoreland vegetation along streams and lakes are well known, the range of factors involved in these multiple functions make it difficult to quantify the characteristics of an adequate shoreland buffer. Nevertheless, the state of our understanding is such that we can state the likely benefits to different wildlife types from a range of buffer widths, in a given context.

Along forested shorelines, dead, diseased, and dying trees which are left along the immediate shoreline will provide nesting and perching sites for some waterfowl and fish-eating birds. Decaying logs, downed trees, and brushy vegetation provide food and cover, and maintain humid microclimates for shoreline-dependent amphibians and reptiles. Some species, such as painted turtles and snapping turtles, may benefit from openings within well-drained riparian areas, but these are exceptions to the general rule.

Increasing buffer size serves to reduce the amount of disturbances of various kinds to the core area. Disturbances affecting shoreline wildlife range from microclimate changes, such as decreased humidity and increased temperature; to loss of hiding places to escape predators; exposure to an increasing amount of domestic predators, such as cats and dogs, and edge-adapted predators, such as raccoons and foxes; as well as increased competition from edge-adapted species. This holds true for both woodland species and grassland species along shorelines. Although the narrow 35- to 75-foot buffer can provide some key habitat requirements for some shoreline dependent species, more riparian wildlife species would benefit from wider buffers along the shoreline to meet their needs for cover and food.

Research indicates that, at least in forested areas, much larger buffers are required to meet the full range of wildlife habitat needs. It is widely suspected that very narrow forest corridors may only provide habitat for forest-edge species and do not provide sufficient habitat for interior birds (area-sensitive neotropical migrants) (Ambuel and Temple 1983, Robbins et al. 1989, Lynch and Saunders 1991), many of which are currently suffering declining populations. A study of birds in riparian forest buffers of differing widths along streams in predominantly agricultural settings has found that interior species require buffers at least 100 meters (roughly 330 feet) wide, while buffers under 50 meters (165 feet) can provide good habitat for many edge species, including some that are showing population declines (Keller et al. 1993).

Three years of results from an on-going study on no-cut stream buffers of varying widths (50, 150, and 250 feet) maintained adjacent to clear-cut timber harvesting in Michigan's Upper Peninsula illustrate the dynamics of the effect of forest fragmentation on sensitive bird populations (Premo 1994, Premo, White Water Associates, pers. comm. 1996). Results to date show a drastic decline in the number of breeding bird pairs in the 50-foot buffer the first year following harvest and a large decline in the 150-foot buffer the second year, while the 250-foot buffer has showed little change. Breeding pairs were immediately lost from the 50-foot buffer the first year, and in the second year a large proportion of species that attempted to nest and breed in the 150-foot buffer were apparently unsuccessful. A likely explanation for these decreases lies in the expansion into these areas of edge-adapted, nest-robbing predators, such as American crows, blue jays, common grackles, and gray jays, and the brown-headed cowbird, a brood parasite, attracted by the favorable habitat created for them by the clear-cut. Some of these species (crows, cowbirds, and grackles) were completely absent from the study area prior to harvest. Competition, nest-parasitism, and nest-predation from these species contributed to the lowered reproductive success of other species nesting in the buffer strips. Continued monitoring will increase the reliability of the results, and allow an analysis of the effect of the growth of the red pine plantation established in the clear-cut area.

A two-year study conducted in eastern Maine of the effectiveness of buffer strips left during timber harvest compared the composition of the bird community between an undisturbed lakeshore and a lakeshore buffer strip 70-100 meters (230-330 feet) wide adjacent to a clear-cut. Researchers found that breeding bird density and species richness were lower in the buffer strip than in the undisturbed lakeshore, although 59% of the species observed were found in both the buffer and undisturbed lakeshore (Johnson and Brown 1990). The authors conclude that the minimum width of buffer strip needed to support a bird community that is similar to an undisturbed lakeshore community is still unknown, but they believe that most species examined in the study would be provided with adequate habitat by a buffer strip 75 meters (250 feet) wide, with an absolute cutting restriction placed on the first 25 meters (85 feet), as recommended by Small and Johnson (1985).

The increase in species richness with wider riparian buffers appears to hold true for other types of wildlife as well as birds. Dickson (1989) reported that wider riparian forests maintain a higher abundance of amphibians, reptiles, and some mammals than narrow corridors. Little formal research is available on the size of upland buffers required for these types of riparian wildlife, but it appears that wide buffers are needed for some species. Gomez and Anthony (1996) recommend riparian management zones of 75-100 meters (250-330 feet) in forested areas. The size of upland buffers to protect nest and hibernation sites for freshwater turtles in a Carolina Bay (a semipermanent freshwater wetland) was found to range from 73 meters (240 feet) to protect 90% of the sites, to 275 meters (900 feet) to protect 100% (Burke and Gibbons 1995).

Along forested lakeshores and wetlands, some wildlife species may require much larger segments of undisturbed shoreline and larger forested buffers back from the shoreline to successfully nest and reproduce. Research in Ontario has produced a model used by the province of Ontario as part of the Ontario Lakeshore Capacity study to predict the impact of lakeshore development on water quality, fisheries, and various wildlife species (Teleki and Herskowitz 1986). Some findings were made regarding species of particular concern in our northern lakes region. Common loon reproductive success was shown to decline when two or more cottages occur within 250 meters (825 feet) of the nesting site (Heimberger et al. 1983). A study of the impact of shoreline development on breeding bald eagles on the Chesapeake Bay showed that housing construction within 80-250 meters (265-825 feet) resulted in bald eagle territorial abandonment (Chandler et al. 1995).

A Wisconsin Department of Natural Resources research project has begun to quantify shoreline impacts on wildlife in the northern Wisconsin region by testing the predictions of the Ontario model for common loons and bald eagles, combining existing data with expanded field studies. The project will also examine the relationship between shoreline development and mink, breeding songbird, and amphibian abundance, across a range of lake and vegetation types (M. Meyer, Wisconsin Department of Natural Resources, pers. comm. 1997). These studies can provide a starting point for a research effort that could ultimately allow identification of indicator species most sensitive to degraded water quality, alteration of riparian vegetation, and disturbance from human activities, including human-associated predators, such as dogs, cats, raccoons, and cowbirds. The habitat needs of these indicator species can be used to identify critical shoreline habitat and help develop regional guidelines for a buffer adequate to protect these species.

The lot width and size minimums and shoreland-wetland zoning are the primary means of controlling the overall amount of shoreline habitat disturbance along shores of entire lakes, both in the water and in the riparian zone. A study of shoreland zoning implementation on six lakes in Oconto County found that larger lot sizes were correlated with less overall vegetative cutting and less overall shoreline modification (Ganske 1990). The amount of vegetation modification was found to be independent of lot size, because owners of both larger and smaller lots tended to concentrate tree cutting and brush removal on the center of the lot and building sizes were comparable. If this relationship holds true in the future, larger minimum lot sizes can be expected to result in less overall vegetation modification. However, trends toward building larger homes with established lawns could limit the potential of larger lot sizes to reduce vegetation modification. Quantitative data on trends in lot sizes and building sizes would be useful but are not available at this time.

2.5 Summary of Policy Implications for Maintaining Riparian Habitat

2.5.1 Buffer Quality and Management Considerations

There is a clear need to provide a buffer of appropriate vegetation for specific wildlife needs. However, different wildlife species or guilds require different types of vegetation. There is no universally applicable recommendation for managing vegetated buffers for wildlife. Defining what constitutes appropriate vegetation varies on a case-by-case basis and depends on both existing soil and vegetation conditions and management goals. For instance, Wisconsin wildlife managers (Wisconsin Department of Natural Resources-Wildlife Management undated publication) generally recommend allowing tree and shrub invasion to take place in order to obtain greater wildlife benefits from the increased food supply of berries seeds and nuts, a variety of cover, and a future supply of snag trees for nest and den cavities. Cutting of undesirable trees and shrubs such as box elder, buckthorn, and Tartarian honeysuckle is recommended. However, along some trout streams, especially in southwestern Wisconsin, fish managers remove shrub vegetation or allow carefully controlled grazing to maintain grassy stream banks. Prairie and savanna restoration projects will also involve limiting woody vegetation.

Management plans identify target species, while recognizing impacts to other species. It will be appropriate to encourage different vegetation types in different settings. Conflicts between management goals can arise (for instance, should a specific trout stream reach flowing through an alder thicket be managed for trout production or protection of threatened wood turtle habitat?). Given the wide range of possible specific management methods for streamside, wetland, and lakeshore buffers, it is not advisable to set absolute standards for vegetation management in the shoreland buffer area. Since shoreland vegetation standards need to be kept as simple as possible to be effectively administered, it makes sense to place the emphasis on minimizing disturbance of the vegetation in the buffer, yet allow flexibility to approve a well-thought-out restoration plan which meets the statutory objectives of shoreland zoning. It is important to provide a mechanism for adequate review of proposed plans that require vegetative cutting to ensure that an undesirable loophole is not created.

2.5.2 Buffer Size

As buffer width increases, wildlife benefits increase. Larger buffers offer a greater chance of undisturbed nesting, habitat variability, better foraging opportunities, and the chance to establish adequate territories for animals that live in the shoreland. Wider buffers will provide better habitat for most species except for edge-adapted species, many of which are already common in our modern fragmented landscape. Wider riparian buffers can be expected to provide an adequate variety of microhabitats and thus offer a greater chance of avoiding predators, finding suitable habitat, and establishing adequate territories. Protecting wetlands can add significant fish and wildlife habitat to the shoreland area and preserve water quality.

The literature on buffers for habitat protection makes it clear that there is no magic number that will automatically guarantee a certain level of protection. The most scientifically justifiable approach in determining the appropriate buffer for a certain level of protection around a given water body would be to send out a team of biologists to mark out the buffer in the field. The resulting buffer width would vary with topography, shoreline vegetation type, and adjacent habitat. Such an approach is impractical in the context of planning and zoning, which must be done comprehensively on a broad scale. However, the literature does point to some rules of thumb about what can be expected from different ranges of buffer width:

- Buffers less than 35 feet wide are not likely to provide more than very minimal habitat for riparian wildlife. The current dimensional standards can provide habitat for more edge-adapted species and provide a travel corridor for wildlife movement to larger areas of suitable habitat, but fragmentation of this corridor by frequent clear-cut areas greatly reduces this value.

- The current standards provide moderate protection of littoral habitat in lakes and stream bank stabilization, depending on the degree of vegetation removal. The allowance for removing dead and diseased trees allows degradation of habitat for cavity-nesting birds and mammals, and removes an important structural element (tipped-over trees and overhanging branches) from both lake and stream fish and aquatic life habitat.

- A buffer strip 100-200 feet wide along streams and rivers can provide for overall benefits to shoreline dependent wildlife, riparian wildlife, and many generalist species. Buffers of this size can be protective of stream habitat and water quality as well.

- Wildlife-focused restorations of prairie wetlands use the rule of thumb of restoring 3 acres of upland grassland to every 1 acre of wetland (Wisconsin Department of Natural Resources-Wildlife Management undated publication) in order to provide nesting cover for waterfowl and shorebirds, and the associated upland habitat that other wetland wildlife such as mink, muskrats, amphibians, and reptiles require.

- Since much of the habitat for riparian wildlife, especially amphibians, occurs in small wetlands, maintaining protection for wetlands under 2 acres is important for providing adequate wildlife habitat in the shoreland zone.

- One-hundred-foot buffers around ephemeral ponds in forested areas could provide protection for amphibians to complete metamorphosis before the ponds dry up.

- Species that cannot tolerate a great deal of human-related disturbance and destruction of riparian habitat, such as loons, eagles, and wood turtles benefit from wider buffers and overall density controls. A combination of greater buffer widths and larger lot sizes is justified in areas that offer currently suitable habitat for these species.

- Buffers of at least 250 feet with a connection to other suitable habitat are needed to provide adequate habitat for area-sensitive wildlife species, particularly neotropical songbirds and some herptiles.

2.5.3 Buffer Implementation

Larger buffers on individual lots could be accomplished through requiring greater setback distances, wider lots, and larger lot sizes. On currently lightly developed shorelines or undeveloped lakes, this approach could provide the greatest protection for the widest variety of species. On currently developed shorelines, the particular pattern of land use and resulting habitat will determine the fruitfulness of requiring larger lots and greater setbacks. If habitat is already effectively fragmented, shoreline vegetation altered, and littoral zone habitat degraded, a sufficient buffer may not be achievable.

Along some lakeshores and streams, however, significant segments of shoreline with high aquatic and riparian wildlife value can be identified, and protected by special zoning standards, easements, or purchase. A lakewide, or watershed-wide planning process could be the vehicle by which the resources' suitability for different uses and vulnerability to specific impacts are analyzed. Zoning standards can then be more effectively tailored to actual resource protection needs and the community's sense of the best use of its water resources.

Buffers of sufficient size to support area-sensitive species are very unlikely to be acceptable as a matter of mandatory land-use controls but may be achievable as voluntary management measures practiced by large landholders, such as federal and state forests and paper companies. Large wildlife buffers make sense for forest-harvesting practices in areas where there are large enough intact forest types to support area-sensitive species. Unfortunately WDNR-Forestry staffing limitations do not allow development and implementation of different Forestry Best Management Practices for different wildlife needs at this time (S. Holaday and D. Zastrow, WDNR-Forestry, internal memorandum to S. Jones and T. Bernthal, August 7, 1996).

Some buffer designers propose a multiple zone approach that allows successively more intense land uses farther away from a core undisturbed zone, and attempts to meet objectives for both aquatic/riparian wildlife protection and adequate sediment and nutrient retention. For instance, the Forest Service has developed a model multiple-zone streamside buffer for agricultural lands, with a 15-foot undisturbed forest zone immediately adjacent to the stream, followed by a 60-foot managed forest zone, and a 20-foot grassland runoff control zone (Welsch 1991). The undisturbed zone next to the stream is primarily to allow for stream shading and contribution of woody debris to the stream, as well as habitat for amphibians and reptiles. The managed forest zone allows for economic use (periodic harvest) and for the establishment of herbaceous understory cover, while still providing diverse habitat structure as a corridor for movement along the stream. The bulk of the sediment retention and slowing of runoff flow is intended to be accomplished in the outermost 20-foot grassland zone.

3. SHORELAND ZONING AND PRESERVATION OF NATURAL BEAUTY

A University of Wisconsin - Extension survey of Wisconsin lakefront owners found that peace and quiet and the enjoyment of natural beauty are by far the most important reasons Wisconsin lakefront owners give for owning lakefront property, with fishing and hunting also important (Korth et al. 1994). A survey of angler motivations in Minnesota found that all categories of respondents gave enjoyment of nature and the outdoors, relaxation, and being in a quiet and peaceful place as the three most important reasons for fishing (Cunningham and Anderson 1992). Walleye anglers surveyed in Wisconsin listed user conflicts, along with numbers and sizes of fish caught, and loss of fish habitat as the most important problems affecting the quality of their fishing experience (Wisconsin Department of Natural Resources 1995a).

These surveys indicate that shoreland standards to preserve natural beauty and reserve natural shore cover are very important to both the riparian property owners and the public seeking enjoyment of our lakes and streams. Shoreland standards restrict tree and shrub cutting and restrict the placement of structures within a 75-foot distance from the water's edge as a means of preserving the natural appearance of the shoreline as viewed from the water and minimizing the obtrusiveness of structures along the shoreline.

The quality of the experiences available to the those using public waters has been affected by user conflicts among anglers, swimmers, users of non-motorized boats, motor boat operators, and jet-ski enthusiasts as our waters become more intensively used and shorelands more densely developed. The issue of reducing user conflicts can be indirectly approached through zoning controls to limit the overall intensity of shoreland development and standards for riparian access lots (referred to as keyhole lots).

3.1 Shoreland Zoning Effectiveness in Preserving Natural Beauty

Wisconsin's shoreland standards for building setbacks, boathouse restrictions, vegetative cutting standards, and lot size and width standards are designed to preserve the natural beauty of the shoreland, not only from the perspective of shoreland homeowners but also by those viewing the shoreline from navigable waters. Thus, the standards are based primarily on preserving the natural beauty of the shoreline as viewed from the water.

Studies in coastal zone areas have indicated that greater visual diversity results in greater aesthetic and visual appeal, therefore a vegetated buffer with a diversity of vegetation will have greater aesthetic value than a single species buffer or no buffer at all (Mann 1975, Simeoni 1979, Forman and Godron 1986). Generally, the landscape aesthetic assessment literature has found that more natural scenes, those in which human presence or activities are relatively less visually apparent, are consistently preferred over scenes where human development is more obvious (Kaplan et al. 1972, Carls 1974, Anderson 1976, Brush and Palmer 1979).

Two studies were reviewed that evaluated the effectiveness of Wisconsin's shoreland zoning standards in protecting natural beauty as viewed from the water. Both used public evaluation methods, asking people to judge slides depicting different structures in different lakeshore settings. Thus, the results are not the judgments of artists or professional aestheticians, but reflect the perceptions of the general public.

Gobster (1982) found that the structures that people perceived as being appropriate in natural settings were on sites with greater vegetation screening and were less obtrusive in color contrast than the structures perceived as appropriate in more developed settings. Gobster's results agree with those of Wohlwil (1979), who found that the most appropriate structures are not size obtrusive and have a low color contrast with the natural surroundings. These results indicate that maintaining a screen of intact natural shoreline vegetation and noncontrasting building colors serve to blend shoreline structures into an otherwise more natural scene.

Macbeth (1989) specifically tested the hypothesis that the overall aesthetics of lakeshores, as measured by ratings of "developed lakeshore aesthetics," are proportional to the building setback, lot width, and clearing of the buffer area as defined by Wisconsin's shoreland zoning standards and also to the attractiveness of the buildings and visual water/air quality. He found that the degree of vegetative screening and the attractiveness of the buildings were the most important predictors of overall aesthetic quality. This study also found there was agreement between different groups of subjects on what is aesthetically pleasing on developed lakeshores.

In another public evaluation study in Wisconsin, Chenowith and Kapper (1996) noted that of 1,300 responses to slides showing varying degrees of shoreline development, only 37 (2.8%) of the responses indicated that adding a seawall to the scene would improve the appearance of the lake. This lends strong support to the notion that limiting the number of visible structures along a shoreline minimizes the impact of shoreland development on natural scenic beauty. Macbeth (1989) also notes the visual impact of structures allowed along the shoreline, such as boathouses, shoreline storage sheds, and large piers, and suggests that size restrictions, color requirements, and requirements for vegetative screening, where possible, be incorporated into shoreland zoning standards.

Chenowith and Kapper (1996) also found that the lower the existing level of development along the shoreline, the greater the negative visual impact of adding a seawall; but even on almost completely developed shorelines, adding a seawall was still viewed as a negative impact. This indicates that shoreland zoning structure limitations can be expected to garner the most support and therefore be most effective in preserving natural beauty along undeveloped and lesser developed shorelines. However, limitations on the placement of structures are supported by public perception of natural beauty, even along highly developed shorelines (though to a lesser degree).

3.2 Policy Implications for Preserving Natural Beauty

These studies verify that vegetative buffer standards that provide some screening are necessary for the preservation of natural beauty as shorelines are developed, and that obtrusive buildings along the immediate shoreline should be discouraged. A further policy implication is that painting shoreland structures in low-contrast earth tones would increase the overall attractiveness of developed shoreland as viewed from the water.

Given the public's preference for natural-appearing scenes, limiting the density of development to preserve natural vegetation along the shoreline can play an important role in minimizing the cumulative aesthetic impacts of shoreland development on a lakewide basis. Studies of lakeshore development have shown vegetative disturbance to be independent of lot size, resulting in less overall vegetative disturbance on developed lakes with larger lot size than lakes developed with smaller lot sizes (Clark et al. 1984, Ganske 1990). However, the current "30 feet in any 100 feet" clear-cutting standard could allow greater vegetation clearing to take place on larger lots. As larger homes are built, the desire for an unobstructed view of lake could result in more tree and shrub cutting and limit the effectiveness of large lot zoning to provide vegetative screening. One way of addressing this issue is to change the vegetative cutting standard to an absolute minimum width viewing and access corridor per lot.

Current NR 115 standards for new structures and expansions of nonconforming structures do not address the issue of structure height. Structures taller than the surrounding tree canopy can be expected to be visually obtrusive. This could be addressed by a standard that sets either an absolute height limitation or sets a height limitation based on the height of existing screening vegetation. Another way to accomplish greater vegetative screening along developed shorelines would be to require plantings to provide greater screening for visually obtrusive structures in cases where a nonconforming structure is being expanded or remodelled.

4. CUMULATIVE IMPACTS CONSIDERATIONS

Previous sections in this report have discussed various impacts which shoreland development can have on aquatic and riparian systems. Water quality is degraded by the delivery of nutrients from construction sites, impervious surfaces, and excessive fertilizer and pesticide application. These factors contribute to algal blooms and excessive submergent vegetation in lakes, degraded fish habitat in streams, and the crowding out of native vegetation in wetlands by monocultures of exotic or aggressive species. Fish habitat is threatened by sediment delivery, through burial of spawning substrates and decreased water clarity. Complex fish habitat structure is altered by modifications of the littoral zone such as constructing piers, constructing seawalls, removing woody debris from the water, clearing out aquatic plants, placing sand blankets over the existing substrate, and removing overhanging vegetation from the shoreline. The resulting simplified habitat results in lower fish abundance and diversity.

Individual actions may only occasionally cause serious impacts, such as the loss of a critical spawning and nursery grounds on a lake with scarce appropriate habitat for a particular species. However, it is interaction of factors and the cumulative effect of many small impacts that degrades water quality and habitat for fish and aquatic life. Likewise, it is the cumulative impact of many structures close together, close to the water, and with minimal screening that degrades the natural beauty of the shoreline.

The modeling results and empirical studies cited earlier (Dennis 1986, E&S Chemistry Inc. 1992, J. Panuska, Wisconsin Department of Natural Resources, memorandum to P. Sorge, 1995) demonstrate that phosphorus levels can increase with even small levels of residential development around lakes. A recently completed study, comparing the impacts of different artificial erosion control structures, concluded that extensive shoreland development and conversion of natural shoreline to shoreline protection structures will likely have serious cumulative and lakewide impacts on fish and aquatic wildlife populations (Jennings et al. 1996b).

Studies of streams from around the country in a variety of urbanizing areas have identified a threshold of 10% impervious area in a watershed, beyond which stream water quality and habitat begin to degrade (Schueler 1994a). The mechanisms of the degradation process are well known. As impervious surface increases, surface runoff increasingly dominates over infiltration and groundwater recharge. This allows more rapid runoff and higher peak flows in streams, increases stream bank erosion and sediment loading to the streambed. The result is wider, straighter sediment-choked streams, greater temperature fluctuation, loss of streamside habitat, and loss of in-stream habitat. The naturally variable stream substrate is covered over by sand and silt, and nutrient, pathogen, and pollutant loading is increased. Engineering responses to flooding have exacerbated the ecological damage by severely simplifying stream habitat. Research in southeastern Wisconsin has documented the impact of impervious area and wetland loss on alteration in stream hydrology (Hey and Wickencamp 1996). Research is needed to better quantify the effect on fish and aquatic invertebrates from differing levels of urbanization and also to evaluate the effectiveness of best management practices to ameliorate these impacts.

The degradation of wetland water and habitat quality as surrounding development intensifies has also been documented. Hicks (1995) found a well-defined inverse relationship between fresh-water wetland habitat quality and impervious surface coverage, once impervious cover exceeded 10% of the wetland's watershed.

The literature clearly indicates many ways in which the cumulative impacts of shoreline development can lead to the degradation of aquatic ecosystems and the loss of natural beauty along the shoreline.

However, it is very difficult to determine the thresholds at which these impacts become cumulatively significant. The difficulty of sorting out the complex interplay between habitat variables, the physical, chemical, and biological setting, and the effect of other land uses in the watershed make it difficult to set a threshold level at which shoreline development significantly degrades the integrity of streams and lakes. A study of cumulative impact methodology notes that "a systematic process that couples spatial and temporal dynamics within the context of a landscape altered by human activities is essential, but not yet available" (Cooper and Cwikiel 1995). While it has not been possible to make conclusions regarding specific lot sizes and widths, it is clear that limiting overall development intensity is essential to protect water quality and habitat, preserve natural beauty, and maintain the peaceful qualities of the shoreline that are the primary features attracting people to the waterfront.

4.1 Cumulative Impacts and Sewered Subdivisions Density Standards

The current standards allowing greater densities for sewered areas are not justified, based on the findings regarding habitat alteration in the littoral zone and phosphorus loading from nonpoint sources. Consider, for example, the development of a lake shoreline in accordance with NR 115 minimum standards for sewered subdivisions. Assuming the subdivision is platted to the maximum allowable density, the shoreline vegetation will be severely fragmented into 30-foot openings (assuming clear-cut areas are centered on each lot) alternating with 70-foot sections of buffer. Such a level of fragmentation severely limits the ability of riparian wildlife to find sufficient cover from predators and meet other habitat requirements along the shoreline.

If every lot has a pier, there will be a pier every 65 feet and significant aquatic plant removal. Removal of coarse woody debris could be expected along a large proportion of the developed shoreline, and some shoreline erosion control structures may be present. Some owners will also want to establish swimming beaches in front of their lots.

The cumulative impacts to the littoral zone arising from increased density are loss of cover and foraging habitat for fish and amphibians supplied by aquatic plants and woody debris, loss of substrate diversity, and possible loss of spawning grounds. This increased level of density can be expected to result in a more modified and simplified littoral zone, resulting in a greater potential for substantial loss of fish and aquatic life habitat, reduced fish production, and changes in the size structure of fish communities. Some reduction in nitrogen and phosphorus loading will likely occur with the substitution of sanitary sewer for septic systems. However, in light of the greater cumulative impacts to habitat and natural beauty resulting from increasing the overall density of development, a trade-off does not appear justified.

Some of these shoreline activities require permits or must conform to certain standards in chapter 30 regarding navigable waters or NR 107 regarding aquatic plant management, but these programs have very limited ability to address cumulative impacts. Addressing cumulative impacts in an individual permit process is very difficult, because of the issue of determining at what point incremental impacts have become significant. Tied into the issue is the concern over the equity of denying to one landowner what has been permitted to the neighbors.

4.2 Cumulative Impacts and the Need for Shoreland Zoning Based on Local Planning

The difficulties experienced in taking cumulative impacts into account in permit decisions demonstrate the importance and desirability of considering them up front in a planning process. Shoreland zoning standards could be linked to a strong planning process that considers the sensitivity of different aquatic resource to degradation from shoreline development, the suitability of different aquatic resources for particular uses, and the need to provide for orderly development and desirable economic growth. Cumulative impacts can be effectively addressed by setting standards based on assessing the carrying capacity of a water body under the assumption that it will eventually be developed to the maximum allowable density.

Ecological processes in lakes, streams, shoreland wetlands, and other shoreland types are understood well enough to identify waters that are more vulnerable to water quality, habitat, and scenic degradation from shoreland development impacts. Coupling this knowledge with the goals and priorities of the community, a local government can develop a management plan that identifies classes of water bodies that require more protective standards.

Through such a planning process, local government identifies the priority resources and major sources of degradation in its area and sets up a rating system using a set of criteria for sorting water bodies into different classes. Different regions may utilize different criteria or rate criteria differently, depending on their policy goals and the nature of their resources. It is essential that any resource classification system identify the key processes and relationships in a region that more protective shoreland zoning could affect.

Too often, zoning standards are adopted without a clear understanding of what they are attempting to accomplish. The requirement for mandatory adoption of shoreland zoning standards is necessary to set a floor for resource protection but not sufficient to ensure good land-use planning. Good zoning standards are a result of, not a substitute for, good land-use planning. Unfortunately, the imposition of mandatory shoreland zoning standards can have the effect of allowing localities to avoid thinking through the issues involved and simply adopt the required standards because they have no choice.

The standards required by NR 115 are clearly minimum standards and, in some cases, may not be able to provide for suitable development of unique resources, such as shallow lakes, unique plant and animal communities, or unique development patterns. It may not be possible to fine-tune a set of statewide regulations to adequately address all the resource protection and development issues that arise from the wide spectrum of physical, biological, social and economic conditions found throughout Wisconsin. Local planning, with technical assistance provided by agencies, such as the DNR, Department of Agriculture, Trade, and Consumer Protection (DATCP), Regional Planning Commissions, and UW-Extension, can provide local solutions to unique situations. Local innovations that can improve protection of natural scenic beauty, control water pollution, protect fish and aquatic life, and meet the other statutory goals should be encouraged.

While the DNR and other state agencies cannot abandon the statutory mandate to insist that at least minimal standards are upheld, greater resources need to be offered to communities to develop real land-use planning that adequately addresses local water resource issues. Lake Management Planning grants are already being made available for county-wide planning efforts and this effort should be continued and strengthened. Specifically, the department's biological and planning expertise can be directed to developing assessment methodologies and supporting the resource inventories that local governments need to identify vulnerable water bodies and areas not suitable for intensive uses. With the development of water basin teams, the DNR should be better able to offer this expertise.

For this reason, it makes sense to allow for some flexibility for innovative zoning standards to replace current required minimums in order to address unique local conditions. However, the burden of proof must be put on the proponent to show that a proposal will be more protective of the resource than current minimum dimensional standards. Minnesota's shoreland program provides a model for such an approach. Local governments may adopt standards not in strict conformance with Minnesota's shoreland standards, provided the statutory purposes are satisfied, if alternative standards are developed as part of a comprehensive study and planning effort and the alternative standards are approved by the Minnesota Department of Natural Resources. A process and a set of standards for evaluating alternative proposals are provided by administrative code.

4.3 Cumulative Impacts - Some Alternative Approaches

The clear implication of existing information is that water quality and habitat of streams, lakes, and wetlands begin to degrade as watersheds become more densely developed. Because many urbanizing areas are currently unincorporated, current shoreland zoning standards play an important role in maintaining at least a minimal stream buffer to protect stream banks and control the intensity of development. Serious attention needs to be paid to assuring that equivalent shoreland protection is provided when unincorporated areas are annexed, as required by statute. Much work is being done to develop better ways of site development that limit impervious areas through narrower streets and smaller parking lots, incorporate stream buffers, and utilize nonstructural stormwater management methods, such as eliminating curbs and gutters and directing flow to vegetated strips instead of storm sewers (Schueler 1995). Ultimately, a more comprehensive watershed planning approach is needed to address stormwater and erosion control issues, if we are to achieve the goal of development that adequately preserves our aquatic resources.

While current shoreland zoning standards emphasize limiting development impacts through minimum lot dimensions, the planning literature suggests an effective alternative in the form of cluster development, which can minimize impervious area and provide larger common open space by clustering lots together farther back from the shore and providing a common access corridor to the shore (Schueler 1994b). Well-planned cluster development in a shoreland context could involve trading smaller lots for greater open space in common ownership along the shoreline.

From a larger watershed perspective, converting rural land to large lots in upland areas is believed to be counterproductive to water resource protection by creating larger road systems and more overall impervious area (Arnold and Gibbons 1996). An alternative cluster design features a return to a "traditional town" layout. With smaller lot sizes, smaller street widths, and different parking configurations, the developer can offer the same amount of residential, commercial, office, and industrial space as conventional design, while preserving natural features with generous buffers and greatly reducing overall impervious area (South Carolina Coastal Conservation League 1995).
A recent modeling study compared the water quality impacts of conventional versus "neo-traditional town" subdivision design on a 583-acre site (South Carolina Coastal Conservation League 1995). The neo-traditional town design traded higher building densities for about 400 acres of open space and a wide buffer along a river, while the conventional design offered 30 acres of open space. Total water quality impacts were significantly greater under the conventional design build-out scenario. The conventional design generated 43% more runoff and 3 times the amount of sediment loading. It resulted in greater nitrogen and phosphorus inputs and greater chemical oxygen demand than the neo-traditional town design.

However, in terms of development in undeveloped or minimally developed shoreland areas, the benefits to habitat protection of the greater buffer provided by larger lot sizes and greater widths, in combination with vegetative cutting restrictions, could be expected to outweigh the potential for greater impervious area. Limitations on the amount of impervious area per lot would be the most direct means of reducing impervious surface in shoreland areas. This approach has been incorporated into recent revisions of county shoreland ordinances in Waupaca and Calumet counties. Schueler (1995) recommends a system of watershed-based zoning with differential regulations related to the percentage of impervious area in a watershed. Such a system has recently been implemented on the Suquamish Reservation in Washington state (D. Flynn, Suquamish Tribe, pers. comm. 1996).

Shoreland zoning regulations need to be flexible enough to allow innovative development designs that protect water quality, habitat, and natural beauty through means other than those set in current standards. A case-by-case review process could be set up which would require the proponent to demonstrate to the department that the innovative development plan will be more effective in meeting the statutory goals set for the shoreland zoning program. Appropriate standards on cluster development are needed to insure that open space goals are achieved, and questions of riparian access may need to be resolved.

One of the most advanced and innovative approaches that allows local governments to address the cumulative water quality impacts is being pioneered by the state of Maine. Maine has developed a method for subdivision review in lake watersheds that allows local governments to explicitly consider the cumulative impacts of phosphorus loading over a 50-year time period in a quantifiable way (Lea et al. 1990, Dennis et al. 1992). This method is based on a comprehensive planning process at the watershed level and requires a fairly intensive data-gathering effort. Based on extensive water quality data collected by the Maine Department of Environmental Protection, a town can determine the water quality goal for a lake to be maintained over the next 50 years. Based on the water quality goal, the lake's current water quality, and its sensitivity to phosphorus loading, the town sets an acceptable level of phosphorus export increase to the lake from development in its watershed. The town must then estimate the future area to be developed based on the developable acreage (eliminating wetlands and steep slopes shown on USGS maps) and projected growth in the watershed.

The planning process results in a *per acre phosphorus allocation* that becomes the basis for the subdivision review process. New subdivision proposals are required to be designed not to exceed the phosphorus export allocation. The developer is free to choose from a number of phosphorus control methods to meet the allocation: reducing road widths and lengths, reducing the number of lots, limiting vegetation removal, providing permanent buffer strips (through deed restrictions) in proper locations, constructing wet detention ponds, and constructing infiltration systems. The phosphorus export for a subdivision is calculated based on available information on soils, topography, and vegetation; phosphorus export coefficients developed for these conditions; and treatment factors assigned to the various design options.

5. SUMMARY OF POLICY IMPLICATIONS

Review of the current scientific literature affirms that the present standards provide at least minimal protection of habitat and water quality. However, additional water quality and habitat initiatives are needed to prevent degradation of aquatic resources. The literature indicates that, up to a point, larger lot sizes and widths and wider buffer zones would be more effective in meeting statutory objectives, but that a broader watershed approach to addressing the cumulative impacts of nonpoint pollution, hydrologic alteration, and habitat degradation will ultimately be required. Two issues of particular concern are the need to take a proactive approach to addressing stormwater problems in urbanizing areas and the need to incorporate better planning into the development of local shoreland zoning ordinances.

5.1 Buffer Size

In reviewing stream and wetland buffer size requirements, Castelle et al. (1994) concluded that buffers should be a minimum of 15-30 meters (50-100 feet) under most circumstances. Buffers less than 5-10 meters (roughly 15-35 feet) wide provide little protection of aquatic resources under most conditions. Several conclusions can be reached regarding shoreland standards and buffer size:

- Individual site conditions vary so greatly that it is not possible to set in advance a universally applicable buffer width that is adequate yet not unduly restrictive.

- Shoreland standards instituting buffers of less than 35 feet would not be likely to be adequate to meet the statutory objectives of shoreland zoning, especially for water quality, fish, and habitat protection.

- Current standards for structure setbacks and vegetation cutting are appropriate as **minimums** for control of sediment and nutrient delivery, but larger buffers would be more effective up to a point.

- Water quality benefits can generally be expected to increase with increasing buffer widths up to about 100 feet, beyond which a point of diminishing returns is reached. Increasing buffer width beyond 100 feet will, in most situations, be primarily beneficial for shoreland wildlife.

- **If properly maintained**, the 35- to 75-foot buffer provided by Wisconsin's shoreland zoning standards can be expected to provide moderate levels of some important ecological and aesthetic functions. A properly maintained buffer of this size can: provide vegetative screening for structures; maintain physical conditions such as bank or shore stabilization; shade streams and lakes; minimize disturbances to the littoral fringes of lakes; improve stream and lake habitat structure by allowing for contribution of woody cover and organic matter to lakes and streams; provide habitat for some shoreline-dependent wildlife, such as certain amphibians that utilize narrow corridors; and provide perching spots for fish-eating birds and ambush sites for other shoreline predators.

- All other things being equal, wider buffers will provide for a greater diversity of shoreland-dependent wildlife, by protecting more habitat from outright destruction or deterioration, by reducing human-related disturbance, and by reducing the level of competition and predation from edge-adapted species. For instance, WDNR wildlife managers recommend a riparian buffer of 100-200 feet along stream corridors.

- Shoreland species that cannot tolerate a great deal of human-related disturbance and destruction of riparian habitat, such as loons, eagles, and wood turtles, benefit from wider buffers. Greater density controls, through minimum lot widths and sizes, are also an important tool for protecting these species from disturbance.

- Large wildlife buffers (250 feet and larger) could be an important tool for biodiversity preservation in situations where forest harvesting takes place within areas of large enough intact forest habitat to support area-sensitive species. It may be difficult to adopt and implement buffers of this size.

5.2 Buffer Quality

As important as the issue of size is the need for adequate standards to maintain the quality of the habitat in the shoreland buffer. This consideration can be obscured if debate focuses on buffer size alone. The vegetative cutting standard does not put enough emphasis on preserving shoreline habitat. It can be interpreted to allow almost total removal of the natural vegetation, because the standard only prohibits clear-cutting. Drastic vegetative alteration, such as complete conversion to a manicured lawn underneath a few trees, can reduce the buffer's effectiveness to near zero for wildlife habitat and reduce the natural appearance of the shoreline. Overuse of fertilizers and pesticides for lawn maintenance on residential waterfront property may eliminate the intended nutrient retention function of the shoreland buffer area, even though the property is in nominal compliance with vegetative cutting standards. The allowance for the removal of dead or dying trees or shrubbery, while understandable from the standpoint of public acceptability, can result in long-term impacts on fish and aquatic habitat in lakes and streams and reduce habitat for many shoreland wildlife species. The "30 feet in any 100 feet" clear-cutting allowance also results in the fragmentation of shoreline habitat with negative consequences for most species.

5.3 Wetlands

Wetlands function both as protectors and enhancers of downstream aquatic resources and are themselves intrinsically valuable aquatic resources. Protector functions, such as downstream water quality protection and flood storage, should not be overemphasized at the expense of intrinsic functions that have value in themselves and add to landscape level ecological processes, such as plant diversity, wildlife habitat, and natural beauty. In particular, the impacts to intrinsic functions should not be overlooked when evaluating proposals for stormwater management.

Since wetlands are degraded by the same processes that affect streams and lakes, they too should be afforded the protection offered by maintaining a vegetated buffer through structure setbacks and vegetative cutting restrictions. Wetlands cannot maintain their protector or intrinsic functional values indefinitely in the face of negative impacts from polluted runoff, hydrologic alteration, and habitat loss. Vegetated buffers around wetlands are necessary to reduce disturbance to wildlife, maintain ecological connectivity to uplands, and reduce sediment and nutrient loading to the wetland.

Under current standards, rezoning requests for shoreland-wetlands cannot be approved if the proposal would result in a significant impact on protected functional values listed in NR 115. Chapter NR 103, Wisconsin's Water Quality Standards for Wetlands lists the same general functional values but describes them more completely, especially for fish and aquatic life. Adopting into NR 115 the description of functional values contained in NR 103 would allow a better understanding of the criteria for evaluating rezoning requests.

Wetland water quality, wildlife, and aesthetic functions are as dependent on factors of landscape position, land-use context, and surrounding habitat as size. Wetlands smaller than 2 acres can play critical roles, both individually and cumulatively, in protecting water quality and providing wildlife habitat and natural beauty. These should be protected by shoreland-wetland zoning, especially floodplain wetlands and lake-fringe wetlands. Small wetlands could be zoned as shoreland-wetlands as they are delineated in the field. Any size limitation should be based on the feasibility of mapping on the Wisconsin Wetland Inventory, rather than a notion that functions are insignificant below a certain size.

5.4 Density Controls

Given the need to provide for the right of riparian access, fragmentation and simplification of shoreline habitat are inevitable as shoreline property is developed. Lot width and size standards provide a way of limiting the cumulative impacts of shoreline development by reducing the density of settlement along the shoreline, thereby reducing the intensity of use. In combination with a limit on clearing per lot and clear standards for vegetation removal, larger lot widths can preserve longer stretches of buffered shoreline and reduce the amount of direct modification of fish habitat. For shoreline species sensitive to human disturbance, greater lot width minimums are necessary to provide an adequate buffer.

5.5 Sewered Subdivision Standards

The allowance for smaller lot sizes and widths is not justified given the cumulative impacts to aquatic and riparian life associated with the increased intensity of development allowed in sewered subdivisions. These impacts are greater littoral and riparian habitat fragmentation and simplification, greater fragmentation of the water quality buffer, greater aesthetic impacts on the natural appearance of the shoreline, and greater potential for user conflicts.

5.6 Erosion and Sediment Control

The shoreland buffer area by itself is not a substitute for adequate erosion and sediment control during construction. The 35- to 75-foot shoreland buffer is not likely to provide adequate sediment trapping if appropriate erosion and sediment control methods are not used during construction. Specific erosion and sediment control standards need to be applied to construction in the shoreland area. Technical assistance from the DNR and/or the county Land Conservation Department is needed to implement effective erosion and sediment control.

5.7 Shoreland Zoning and Local Land-Use Planning

Shoreland zoning can be most effectively utilized when there is an understanding of what it can accomplish in a given context. More protective zoning standards can then be rationally linked to the location where the resource protection goals of the community can be met. The department as well as other agencies can support local water resource planning efforts to improve their shoreland zoning standards. Since planning must be comprehensive for the region of interest (most likely a county), the plan must be based on readily available information and generally accepted relationships. There is a trade-off between a thorough understanding of each water body and a practical land-use plan that relies upon generalizations that hold true for a particular region and set of objectives.

Based on the information found in this review, the following set of observations can be offered to shed light on where more protective shoreland zoning standards could be called for:

- As a water quality measure, shoreland zoning can generally address a larger percentage of the sediment and nutrient inputs to seepage lakes in small watersheds than drainage lakes in large watersheds, because drainage lakes are more affected by inflowing streams carrying sediment and nutrients from their larger watersheds. However, any reduction of excessive sediment and nutrient loading is helpful in any type of lake.

- Forested watersheds generally have fewer existing nonpoint pollution problems than agricultural or urbanizing watersheds, and have better existing wildlife habitat; therefore, shoreland zoning standards can be expected to be relatively more effective.

- Streams and wetlands in developing areas can offer important aesthetic amenities such as green space and wildlife corridors.

- Shallow lakes are usually more affected by nutrient inputs than deeper lakes and are vulnerable to carp problems. Shallow lakes provide high-quality fish and wildlife habitat, but because of their naturally high level of aquatic plant growth they are not suitable for many of the uses lakeshore owners may desire, such as motor boating and swimming, and their fish and wildlife values are degraded by attempts to modify them for such uses.

- Other factors being equal, presently undeveloped and lightly developed shorelines and near-shore waters offer better fish and wildlife habitat, greater natural beauty, and better water quality than developed shorelines.

- Other factors being equal, irregular-shaped lakes, with a greater length of shoreline per acre of water, will be subject to a greater amount of development and recreational user pressure per acre of water, and receive a larger total nutrient input from the shoreland area than circular-shaped lakes of the same size. Irregular-shaped lakes will also have a relatively larger proportion of ecologically important near-shore and shoreland habitat than circular-shaped lakes of the same size.

- Visual impacts to waterfront owners and recreational users from obtrusive shoreland structures may be especially severe on smaller and more irregular-shaped lakes with small bays.

5.8 Forestry and Agriculture

While the major application of shoreland zoning is to residential development along lakes and streams, the vegetation standards also apply to forestry and agricultural practices. In these situations, where long stretches of shoreline are in the same ownership, the "30 feet in any 100 feet" clear-cutting allowance does not make sense and should be replaced by standards that relate better to those activities. The shoreland program should continue to work closely with the priority watershed program and other agricultural programs to promote and monitor the use of buffers along streams running through farmland. The voluntary best management practices for water quality, recently developed to guide logging operations, are being evaluated by the Bureau of Forestry over the next several years. The results of this evaluation should provide insight into the best means of accomplishing water quality protection during logging activities. Protecting riparian wildlife habitat for area-sensitive species will likely require larger buffer zones than are recommended for protecting water quality. Best management practices to protect riparian wildlife habitat should also be considered.

5.9 Alternative Approaches

Some areas that hold promise for improving aquatic resource protection are conducting resource classification planning, promoting cluster development, explicitly incorporating buffer zones into land-use plans, identifying shorelines with high wildlife value, and developing better buffer maintenance standards. Innovative approaches to protecting high-priority shorelines through tax incentives and easements should be pursued. Progress in these areas can be made through a partnership between local governments, shoreland property owners, developers, and natural resource professionals examining local conditions and finding solutions to local concerns.

6. CONCLUSIONS FROM THE LITERATURE REGARDING NR 115 STANDARDS

There have been great advances in the understanding of aquatic and riparian ecology, soils and hydrology, and the sediment-trapping ability of vegetated buffers, as well as in the public perception of natural beauty, since the shoreland program was conceived and initiated in the late 1960s. Nevertheless, the professional judgement on which the shoreland standards were based has held up surprisingly well.

This section addresses specific resource protection gaps in NR 115 standards identified through the literature review. Some suggestions are made for both NR 115 changes and other programmatic approaches to address these gaps. It should be understood, however, that any actual rule or program changes must be made from a broader perspective than the scientific literature. Other sections of the main report, Shoreland Management Program Assessment, consider the impact of current development trends, practical program implementation issues, existing institutional structures, and the delicate balance that must be struck between private rights and public obligations. The NR 115 Issues and Options Table in Section 4.2 of the main report incorporates all these perspectives in identifying possible options for changes to NR 115. Likewise the Program Support Initiatives Table in section 4.1 of the main report lists educational, technical assistance, and other initiatives that could be undertaken without initiating a change in the NR 115 administrative code.

6.1 NR 115 Standards

6.1.1 Structure Setbacks

In regards to standards affecting structure setbacks, the literature suggests:

- The current minimum structure setback and vegetative cutting distances are minimally effective. Any reduction in these distances is not likely to meet statutory objectives. Water quality objectives could be more effectively met by increasing the structure setback to 100 feet.

- The current exemption from the structure setback for boathouses has strong negative consequences for natural scenic beauty, fragments shoreland buffer vegetation and increases impacts to near-shore aquatic habitat. Eliminating the exemption for boathouses would greatly increase the ability of the standards to preserve shore cover and protect fish and aquatic life.

- Riparian wildlife benefits and benefits to shoreline-dependent wildlife would increase with larger structure setbacks and would be particularly beneficial on currently undeveloped or lightly developed shorelands where continuous undisturbed habitat currently exists.

- Mitigative measures, such as requiring the planting of native vegetation for screening or changing exteriors to earth-colored tones, as a condition for allowable expansions of nonconforming structures would increase effectiveness in preserving shore cover and natural beauty.

- The language in NR 115 allowing relaxation of the 75-foot structure setback where there is "an existing pattern of development" creates a major loophole weakening the ability of the standards to control the placement of structures. The result is increased fragmentation and destruction of shore cover and increased delivery of sediments and nutrients to water bodies as an undesirable pattern of development is perpetuated. Limiting the practice of setback averaging by setting an absolute minimum structure setback statewide would greatly reduce impacts to natural beauty, shore cover, and water quality. Based on the literature review a 50-foot absolute minimum setback would be justified.

6.1.2 Vegetative Cutting Standard

The vegetative cutting standard is the key to establishing an effective shoreland buffer for water quality, natural beauty, and habitat protection but has some severe flaws in the way it is worded. Revising the vegetative cutting standard to eliminate loopholes and clarify its intent could strengthen its ability to maintain natural vegetative cover and reduce fragmentation of shoreland habitat. The literature emphasizes the benefits of reducing human disturbance and maintaining the structural diversity of vegetation in the buffer area. This includes grasses, sedges, and forbs in the ground layer in addition to trees and shrubs. More specifically:

- Describing this section as "preservation of shoreland buffer" or "preservation of natural shoreland transition zone" and including "protection of fish and aquatic habitat" would clarify the intent of this section to apply to ground-layer herbaceous cover as well as trees and shrubs.

- Replacing the prohibition on clear-cutting with a prohibition on vegetative cover removal would clarify and simplify the interpretation of this standard.

- Changing the exception allowing removal of "dead, diseased and dying trees or shrubbery" to a more strictly limited exception would make this standard more enforceable and more capable of meeting objectives for protecting fish and aquatic life. Some flexibility could be built into a revised standard allowing vegetation removal only for safety hazards or where necessary for restoring and maintaining native prairie vegetation or other shoreline habitat restoration projects.

- Replacing the "30 feet in any 100 feet" allowance to clear-cut with an allowance to remove a limited amount of vegetation in a "viewing and access corridor" of a certain total width per lot would greatly reduce the cumulative fragmentation of shoreland habitat. A standard that set a total allowable corridor width per lot would ensure that larger lot sizes could not increase the total allowable vegetation removal and would be more effective in reducing cumulative impacts.

6.1.3 Density Controls - Minimum Lot Widths and Sizes

Although the literature does not yet quantify the specific intensity of development at which cumulative impacts become significant, the relationship between increasing intensity of development and impacts to fish and aquatic habitat, water quality, and natural beauty is clearly established. This indicates that, at a minimum, current lot sizes should be maintained. Further conclusions regarding density controls are:

- Increasing the current minimum standard for lot widths and sizes would reduce the potential for cumulative impacts.

- Allowing increased density for sewered subdivisions in the shoreland is not a wise trade-off because it results in increased overall physical disruption of shoreland buffer vegetation, increased destruction or degradation of nears-shore habitat, and increased impact to shoreline natural beauty. Raising the minimum lot size and width for sewered lots to the level of unsewered lots would eliminate these extra impacts.

- A better way to accommodate the demand for near-water living would be to develop standards for cluster development in shoreland areas that allow greater overall density in return for maximizing the length of contiguous undisturbed shoreline.

- Standards are needed to prevent overly intense use of near-shore waters by preventing an overabundance of owners with riparian rights. Setting width standards for riparian access (keyhole) lots could provide a means of control overall density and intensity of near-shore use.

6.1.4 Runoff Management

- Setting a limit on the allowable percentage of impervious area per lot is justifiable due to the negative effects of watershed imperviousness. In setting a limit one must take into account the amount of connected impervious surface in the streets and other public areas of the watershed.

- Develop specific erosion and sediment control standards and stormwater management standards to replace special exception permits for grading and filling permits. These are issues that should be pursued on a broader scale (throughout a local jurisdiction) rather than specifically in the shoreland jurisdictional zone. Efforts should be targetted toward the unit of government which offers the greatest likelihood of efficient and effective administration.

6.1.5 Wetlands

- Establish buffers around wetlands by establishing a structure setback from the edge of wetlands and applying vegetation removal standards within a certain distance of wetlands.

- Clarify that wetlands of any size within the shoreland that can be mapped on the Wisconsin Wetland Inventory may be zoned as shoreland-wetlands.

- Clarify that routing stormwater to a shoreland-wetland is not a permitted use and would require a rezoning amendment.

6.2 Other Program Support Recommendations

- Provide technical assistance to counties in identifying priority areas for greater protection, based on existing riparian habitat quality, littoral zone habitat quality, lake and stream characteristics, watershed characteristics, and the existing level of development. Provide assistance in identifying areas in which more protective shoreland zoning standards can be most effective.

- Promote and provide technical assistance to counties in drafting erosion and sediment control ordinances, road construction best management practices, and stormwater management ordinances.

- Explore and promote the use of shoreline easements and greenways along lakes, rivers, and associated wetlands as a way of maintaining a habitat buffer.

- Continue to promote an understanding of shoreline habitat along lakes, streams, and wetlands and its importance to fish populations and other aquatic life in these ecosystems. Promote low-impact shoreline living and shoreland habitat restoration, focusing on actions waterfront owners can take to recognize and preserve good shoreline and near-shore habitat where it exists. Encourage waterfront owners to maintain the natural vegetative community, rather than attempting to establish suburban-style lawn, and disrupting near-shore habitat.

- Continue to seek avenues for making prospective shoreland owners aware of the applicable zoning regulations, and provide explanations to landowners of the rationale for shoreland zoning regulations.

6.3 Research Needs

The Shoreland Management Program should continue to cooperate with fish ecology, wildlife ecology, limnology, and water quality researchers within the department to address the gaps in our ability to better assess impacts to aquatic and riparian resources.

- Quantify the relationship between littoral zone habitat quality and shoreland development for lakes in Wisconsin. The association of fish populations on littoral habitat structure is well established. However, the effect of different shoreline activities, such as removal of woody debris, aquatic plant removal, placement of sand blankets, and construction of piers, on littoral habitat structure, and the mechanisms by which habitat modification affects fish communities should continue to be investigated. The eventual goal of this line of research should be a better understanding of the degree of modification that results in negative impacts on fish communities.

- Quantify the relationship between shoreland development and bald eagle, loon, mink, breeding songbird, and amphibian abundance across a range of lake and vegetation types. These studies can provide a starting point for a research effort that might ultimately allow identification of indicator species most sensitive to degraded water quality, alteration of riparian vegetation, and disturbance from human activities and human-associated predators. The habitat needs of these indicator species could be used to identify critical shoreland habitat and help develop regional guidelines for maintaing an adequate buffer along high quality sections of shoreline.

- Continue to quantify the effect on fish and aquatic invertebrates from differing levels of urbanization and also to evaluate the effectiveness of stormwater best management practices to ameliorate these impacts.

- Develop a methodology for assessing shoreland and near-shore habitat quality along lake shorelines similar to that which exists for streams.

- Continue to develop modeling capabilities to better evaluate the effectiveness of vegetative buffers to trap sediment and remove nutrients from runoff.

REFERENCES

Aboul Hosn, W., and J. A. Downing. 1994. Influence of cover on the spatial distribution of littoral-zone fishes. *Canadian Journal of Fisheries and Aquatic Sciences* 51:1832-38.

Allen, A. W. 1986. Habitat suitability index models: mink, revised. U.S. Fish & Wildlife Service. Biological Report 82(10.127). 23 pp.

Ambuel, B. A., and S. A. Temple. 1983. Area-dependent changes in the bird communities and vegetation of southern Wisconsin forests. *Ecology* 64:1057-68.

Anderson, L. 1976. Visual absorption capability for forest landscapes. USDA-Forest Service, Klamath National Forest, Eureka, California.

Angermeier, P. L., and J. R. Karr. 1984. Relationships between woody debris and fish habitat in a small warmwater stream. *Transactions of the American Fisheries Society* 113:716-26.

Armour, C. L., D. A. Duff, and W. Elmore. 1991. The effects of livestock grazing on riparian and stream ecosystems. *Fisheries* 16:7-11.

Arnold, C. L., and C. J. Gibbons. 1996. Impervious surface coverage: the emergence of a key environmental indicator. *Journal of the American Planning Association* 62(2):243-258

Ball, J. 1982. Stream classification guidelines for Wisconsin. Wisconsin Department of Natural Resources.

Bannerman, R. T., D. W. Owens, R. B. Dodds, and N. J. Hornewer. 1993. Sources of pollutants in Wisconsin stormwater. *Water Science and Technology* 28(3-5):241-59.

Barton, D. R., W. D. Taylor, and R. M. Biette. 1985. Dimensions of riparian buffer strips required to maintain trout habitat in Southern Ontario streams. *North American Journal of Fisheries Management* 5:364-78.

Baylis, J. R., D. D. Wiegmann, and M. H. Hoff. 1993. Alternating life histories of smallmouth bass. *Transactions of the American Fishery Society* 122:500-10.

Beauchamp, D. A., E. R. Byron, and W. A. Wurtsbaugh. 1994. Summer habitat use by littoral-zone fishes in Lake Tahoe and the effect of shoreline structures. *North American Journal of Fisheries Management* 14:385-94.

Becker, G. C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison, WI. 1052 pp.

Beilfuss, R. D., and D. R. Siebert. 1996. Reading landscapes: a field assessment methadology for understanding wetlands in their catchments. pp. 505-25 *in* R. D. Beilfuss, W. R. Tarboton, and N. N. Gichuki, eds. *Proceedings of the 1993 African Crane and Wetland Training Workshop*. International Crane Foundation, Baraboo, WI.

Benke, A. C., T. C. Van Ardsall, D. M. Gillespie, and F. K. Parrish. 1984. Invertebrate productivity in a subtropical blackwater river: the importance of habitat and life history. *Ecological Monographs* 54:25-63.

Bennet, S. H., J. W. Gibbons, and J. Glanville. 1980. Terrestrial activity, abundance and diversity of amphibians in differently managed forest types. *American Midland Naturalist* 103(2):412-16.

Benson, B. J. and J. J. Magnuson. 1992. Spatial heterogeneity of littoral fish assemblages in lakes: relation to species diversity and habitat structure. *Canadian Journal of Fisheries and Aquatic Sciences* 49:1493-1500.

Bernthal, T. W., and S. A. Jones. 1997. Shoreland management assessment report. Wisconsin Department of Natural Resources.

Beschta, R. L. 1979. Debris removal and its effect on sedimentation in an Oregon Coast Range system. *Northwest Science* 53:71-77.

Beschta, R. L., and W. S. Platts. 1986. Morphological features of small streams: significance and function. *Water Resources Bulletin* 22:369-79.

Bilby, R. E., and G. E. Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. *Ecology* 61:1107-13.

Blymer, M. J., and B. S. McGinnes. 1977. Observations on possible detrimental effects of clearcutting on terrestrial amphibians. *Bulletin of the Maryland Herpetology Society* 13(2):79-83.

Boisclair, D., and W. C. Leggett. 1985. Rates of food exploitation by littoral fishes in a mesotrophic north-temperate lake. *Canadian Journal of Fisheries and Aquatic Sciences* 42:556-66.

Bonham, A. J. 1983. The management of wave-spending vegetation as bank protection against boat wash. *Landscape Planning* 10:15-30.

Brewster, C. M. 1985. Wood Turtle, *Clemmys insculpta*, research in northern Wisconsin. *Bulletin of the Chicago Herpetology Society* 20:13-20.

Brinson, M. M. 1993. A hydrogeomorphic classification for wetlands. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS. Technical Report WRP-DE-4.

Brush, R., and J. Palmer. 1979. Measuring the impact of urbanization on scenic quality: land use change in the northeast. Pp. 358-364 *in* Daniel, Zube, and Driver, eds. *Assessing Amenity Resource Values*. USDA/USFS General Technical Report RM-68. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Bryan, M. D., and D. L. Scarnecchia. 1992. Species richness, composition and abundance of fish larvae and juveniles inhabiting natural and developed shorelines of a glacial Iowa lake. *Environmental Biology of Fishes* 35:329-41.

Buehler, D. A., T. J. Mersmann, J. D. Fraser, and J. K. D. Seegar. 1991. Effects of human activity on bald eagle distribution on the northern Chesapeake Bay. *Journal of Wildlife Management* 55:282-90.

Burke, V. J., and W. Gibbons. 1995. Terrestrial buffer zones and wetland conservation: a case study of freshwater turtles in a Carolina bay. *Conservation Biology* 9:1365-69.

Carls, G. 1974. The effects of people and man-induced conditions on preferences for outdoor recreation landscapes. *Journal of Leisure Research* 6: 113-24.

Casper, G. S. 1996. Geographic distributions of the Amphibians and Reptiles of Wisconsin. Milwaukee Public Museum. 87 pp.

Castelle, A. J., A. W. Johnson, and C. Conolly. 1994. Wetland and stream buffer size requirements - a review. *Journal of Environmental Quality* 23: 878-82.

Chambers, P. A., and J. Kalff. 1985. Depth distribution and biomass of submerged aquatic macrophyte communities in relation to secchi depth. *Canadian Journal of Fisheries and Aquatic Sciences* 42:701-09.

Chandler, S. K., J. D. Fraser, D. A. Beuhler, J. K. D. Seegar. 1995. Perch trees and shoreline development as predictors of bald eagle distribution on Chesapeake Bay. *Journal of Wildlife Management* 59:325-32.

Chenowith, R. and T. Kapper. 1996. Natural scenic beauty. Pp. 97-135 *in* M. Jennings, K. Johnson, and M. Staggs, eds. *Shoreline Protection Study: A Report to the Wisconsin State Legislature.* Wisconsin Department of Natural Resources. PUBL-RS-921-96.

Christensen, D. L., B. J. Herwig, D. E. Schindler, and S. R. Carpenter. 1996. Impacts of residential lakeshore development on coarse woody debris in north temperate lakes. *Ecological Applications* 6(4):1143-1149.

Clady, M. and B. Hutchinson. 1975. Effects of high winds on eggs of yellow perch in Oneida Lake, New York. *Transactions of the American Fisheries Society* 104:524-25.

Clark, K. L., D. L. Euler, and E. Armstrong. 1984. Predicting avian community response to lakeshore cottage development. *Journal of Wildlife Management* 48(4):1239-47.

Clark, C. F. 1950. Observation of the spawning habits of northern pike, *Esox lucius*, in northwestern Ohio. *Copeia* 1950:258-88.

Clark, W. S. 1982. Turtles as a food source of nesting bald eagles in the Chesapeake Bay region. *Journal of Field Ornithology* 53:49-51.

Cole, G.A. 1983. Textbook of limnology, 3rd edition. Waveland Press. Prospect Heights, Illinois.

Colle, D.E. and J.V. Shireman. 1980. Coefficients of condition for largemouth bass, bluegill, and red-ear sunfish in hydrilla-infested lakes. *Transactions of the American Fisheries Society* 109:521-531.

Colle, D.E., J.V. Shireman, W.T. Haller, J.C. Joyce and D.E. Canfield Jr. 1987. Influence of hydrilla on harvestable sport-fish populations, angler use, and angler expenditures at Orange Lake, Florida. *North American Journal of Fisheries Management* 7:410-417.

Comerford, N. B., D. G. Neary, and R. S. Mansell. 1992. The effectiveness of buffer strips for ameliorating offsite transport of sediments, nutrients and pesticides from silvicultural operations. National Council of the Paper Industry for Air and Stream Improvement, Inc. Technical Bulletin No.

631.

Congdon, J. D., J. L. Greene, and J. W. Gibbons. 1986. Biomass of freshwater turtles: a geographic comparison. *American Midland Naturalist* 115:165-73.

Cooper, C. B., and J. W. Cwikiel. 1995. Cumulative impact assessment in Michigan's wetland permit program. Michigan Department of Natural Resources. 201 pp.

Craig, R. E., and R. M. Black. 1986. Nursery habitat of muskellunge in southern Georgian Bay, Lake Huron, Canada. *American Fisheries Society Special Publication* 15:79-86.

Cummins, K. W. 1975. The ecology of running waters: theory and practice. Pp. 277-293 *in* D. B. Baker, W. B. Jackson, and B. L. Prater, eds. *Proceedings of the Sandusky River Basin Symposium International Joint Committee on the Great Lakes*. Heidelberg College, Tiffin, OH.

Cunningham, P. and C. Anderson. 1992. Opinions of angler groups and fisheries professionals in Minnesota. Minnesota Department of Natural Resources Investigational Report 422. 22pp.

Cunningham, D. C. and R. J. Brooks. 1995. The role of amphibians in community structure and energy transfer at the terrestrial-aquatic interface. Abstract. *Proceedings of the North American Lake Management Association*. Toronto, Ontario. Nov. 5-10, 1995.

Dennis, J. 1986. Nutrient loading impacts: phosphorus export from a low-density residential watershed and an adjacent forested watershed. *Lake and Reservoir Management: Vol II.*

Dennis, J., J. Noel, D. Miller, C. Eliot, M. Dennis, and C. Kuhns. 1992. Phosphorus control in lake watersheds: a technical guide to evaluating new development, revised September 1992. Maine Department of Environmental Protection. 111 pp.

Desbonnet, A., V. Lee, P. Pogue, D. Reis, J. Boyd, J. Y. Willis and M. Imperial. 1995. Development of coastal vegetated buffer programs. *Coastal Management* 23:91-109.

Detenbeck, N. E., C. A. Johnston and G. J. Niemi. 1993. Wetland effects on water quality in the Minneapolis/St. Paul metropolitan area. *Landscape Ecology* 8:39-61.

Dickson, J. G. 1989. Streamside zones and wildlife in southern U.S. forests. *In* R. E. Gresswell, B. A. Barton, and J. L. Kershner, eds. *Practical approaches to riparian resource management: an educational workshop*, May 8-11, 1989, Billings MT. U.S. Bureau of Land Management.

Dillaha, T. A., R. B. Reneau, S. Mostaghimi, and D. Lee. 1989. Vegetative filter strips for agricultural nonpoint source pollution control. *Transaction of ASAE* 32:513-19.

Dillon, P. J., W. A. Schneider, R. A. Reid, and D. S. Jeffries. 1995. Lakeshore capacity study: Part 1 - Test of effects of shoreline development on the trophic status of lakes. *Lakes and Reservoir Management* 8(2):121-29.

Duellman, W. E. and L. Trueb. 1988. Biology of Amphibians.

Dunn, T.D. 1992. Status of the Common Loon in Wisconsin. *Passenger Pigeon* 54:19-29.

E&S Environmental Chemistry, Inc. 1992. Pickerel/Crane lake diagnostic and feasibility study.

Elder, J. F. 1987. Factors affecting wetland retention of nutrients, metals, and organic materials. Pp. 178-184 *in* J. Kusler and G. Brooks, eds. *Proceedings of the National Wetland Symposium: Wetland Hydrology*. Association of State Wetland Managers, Berne, New York.

Ensor, K.L., D.D. Hewig, and L.C. Wemmer. 1992. Mercury and lead in Minnesota Common Loons *(Gavia immer)*. Minnesota Pollution Control Agency, St. Paul, Minnesota. 32pp.

Farrell, J.M., R.G. Werner, S.R. LaPan, and K.A. Claypoole. 1996. Egg distribution and spawning habitat of northern pike and muskellunge in a St. Lawrence River marsh, New York. *Transactions of the North American Fisheries Society* 116:40-49.

Flemming, P. L. 1976. A study of the distribution and ecology of *Rana clamitans* Latreille. Ph.D. thesis, University of Minnesota, Minneapolis. 170 pp.

Forman, R. T. T., and M. Godron. 1986. Landscape ecology. J. Wiley & Sons.

Forney, J. L. 1968. Production of young northern pike in a regulated marsh. *New York Fish and Game Journal* 15:143-54.

France, R. L., and R. H. Peters. 1995. Predictive model of the effects on lake metabolism of decreased airborne litterfall through riparian deforestation. *Conservation Biology* 9(6):1578-86.

Franklin, D. R., and L. L. Smith. 1963. Early life history of the northern pike, *Esox lucius L*., with special reference to the factors influencing the numerical strength of year classes. *Transaction of the American Fisheries Society* 92:91-110.

Fraser, J. D., L. D. Frenzel, J. E. Mathiesen. 1985. The impact of human activities on breeding bald eagles in north-central Minnesota. *Journal of Wildlife Management* 49:585-92.

Frost, W. E., and C. Kipling. 1967. A study of reproduction, early life, weight-length relationship and growth of pike, *Esox lucius L*. in Windemere. *Journal of Animal Ecology* 36:651-93.

Ganske, L. 1990. Lakeshore development: a study of six Oconto Co., Wisconsin lakes. MS thesis, University of Wisconsin - Green Bay.

Garrison, P. 1993. Lake Ripley paleoecological study. Wisconsin Department of Natural Resources. 5 pp.

Garrison, P., and J. Winkelman. 1995. Paleoecological study of Little Bearskin Lake, Oneida County. Wisconsin Department of Natural Resources.

Garrison, P., and J. Hurley. 1993. Interim report on Lake Minocqua paleolimnological study. Wisconsin Department of Natural Resources. 22 pp.

Garrison, P. in press. Round and Long Lakes paleoecological study. Wisconsin Department of Natural Resources.

Gelwick, F. P., and W. J. Matthews. 1990. Temporal and spatial patterns in littoral-zone fish assemblages of a reservoir (Lake Texoma, Oklahoma-Texas, U.S.A.). *Environmental Biology of Fishes* 27:107-120.

Glass, N. R. 1971 Computer analysis of predation energetics in the largemouth bass. Pp 325-363 in B. C. Patten, ed. *Systems Analysis and Simulation Ecology, Volume 1*. Academic Press, New York.

Gobster, P. H. 1982. Factors influencing the visual compatibility of development in shoreland areas. M.S. thesis, University of Wisconsin - Madison.

Godrey, S., and J. McFalls. 1992. Texas Department of Transportation and Texas Transportation Institute field testing program for slope erosion control products, flexible channel lining products, temporary and permanent erosion control products. Pp. 335-339 *in Environment is Our Future: Proceedings of Conference XXIII, International Erosion Control Association*, February 18-21, 1992, Reno, Nevada.

Gomez, D. M., and R. G. Anthony. 1996. Amphibian and reptile abundance in riparian and upslope areas of five forest types in western Oregon. *Northwest Science* 70:109-19.

Gorman, O. T., and J. R. Karr. 1978. Habitat structure and stream fish communities. *Ecology* 59:507-15.

Gotceitas, Y. and P. Colgan. 1987. Selection between densities of artificial vegetation by young bluegills avoiding predation. *Transactions of the American Fisheries Society* 116:40-49.

Gregory, S. V., G. A. Lamberti, D. C. Erman, K. V. Koski, M. L. Murphy, and J. R. Sedell. 1987. Influence of forest practices on aquatic production. Pp. 233-255 *in* E. O. Salo, and T. W. Cundy, eds. *Streamside Management: Forestry and Fishery Interactions*. University of Washington, Institute of Forest Resources, contribution No. 57.

Grubb, T. G., W. W. Bowerman, J. G. Giesy, G. A. Dawson. 1992. Responses of breeding bald eagles to human activities in northcentral Minnesota. *Canadian Field-Naturalist* 106: 443-53.

Gurtz, M. E., G. R. Marzolf, K. T. Killingbeck, D. L. Smith, and J. V. McArthur. 1988. Hydrologic and riparian influence on the import and storage of coarse particulate organic matter in a prairie stream. *Canadian Journal of Fisheries and Aquatic Science* 45:655-65.

Hansmann, E. W., and H. K. Phinney. 1973. Effects of logging on periphyton in coastal streams of Oregon. *Ecology* 54:194-199.

Hanson, D. A. and T. L. Margenau. 1992. Movement, habitat selection, behavior, and survival of stocked muskellunge. *North American Journal of Fisheries Management* 12:473-83.

Hay, R. W. 1996. Blanchard's cricket frog, *Acris crepitans blanchardi*, in Wisconsin: A status report. Wisconsin Department of Natural Resources.

Heimberger, M., D. Euler and J. Barr. 1983. The impact of cottage development on common loon reproductive success in central Ontario. *Wilson Bulletin* 95:431-39.

Hey, D. L., and J. Wickencamp. 1996. Some hydrologic effects of wetlands. In How to Integrate Wetlands with Watershed Planning: A Workshop. The Wetlands Initiative, Chicago, Illinois.

Hicks, A. L. 1995. Impervious surface area and benthic macroinvertebrate response as an index of impact from urbanization on freshwater wetlands. MS thesis, University of Massachusetts, Amherst, Massachusetts.

Hodkinson, I. D. 1975. Dry weight loss and chemical changes in vascular plant litter of terrestrial origin, occurring in a beaver pond ecosystem. *Journal of Ecology* 63:131-42.

Hoff, M. H. 1991. Effects of increased nesting cover on nesting and reproduction of smallmouth bass in northern Wisconsin lakes. Pp 39-43 *in* D. C. Jackson, ed. The first international smallmouth bass symposium. Warmwater Streams Committee, South Division, American Fishery Society, Nashville, Tennessee.

Hollis, G. E. 1975. The effects of urbanization on floods of different recurrence intervals. *Water Resources Research* 11:431-35.

Hubbs, C. L., and G. P. Cooper. 1936. Minnows of Michigan. Cranbrook Institute of Science, Bulletin 8. 95pp.

Hunt, R. L. 1979. Removal of woody streambank vegetation to improve trout habitat. Wisconsin Department of Natural Resources. Technical Bulletin 115. 36 pp.

Hunt, R. L. 1985. A follow-up assessment of removing woody streambank vegetation to improve trout habitat. Wisconsin Department of Natural Resources. Research Report No. 137. 23 pp.

Hunt, R. L. 1988. A compendium of 45 trout stream habitat development evaluations in Wisconsin during 1953-1985. Wisconsin Department of Natural Resources. 80 pp.

Jackson, G. W., L. C. Johnson, and J. L. Arts. 1981. Controlling runoff and erosion from land development projects: some institutional tools. University of Wisconsin - Extension. Madison, Wisconsin.

Jahn, L. R., and R. A. Hunt. 1964. Duck and coot ecology and management in Wisconsin. Wisconsin Department of Natural Resources. Technical Bulletin No. 33. 212 pp.

Jennings, M., M. Bozek, G. Hatzenbeler, and D. Fago. 1996a. Fish and habitat. Pp. 1-48 in M. Jennings, K. Johnson, and M. Staggs, eds. Shoreline Protection Study: A Report to the Wisconsin State Legislature.Wisconsin Department of Natural Resources. PUBL-RS-921-96.

Jennings, M., K. Johnson, and M. Staggs. 1996b. Shoreline protection study: a report to the Wisconsin State Legislature. Wisconsin Department of Natural Resources. PUBL-RS-921-96.

Johnson, S. 1994. Recreational boating impact investigations, Upper Mississippi River system, Pool 4, Red Wing, Minnesota. Long Term Resource Monitoring Program Special Report 94-S004.

Johnson, W. N., Jr., and P. W. Brown. 1990. Avian use of a lakeshore buffer strip and an undisturbed lakeshore in Maine. *Northern Journal of Applied Forestry* 7:114-17.

Johnson, T. R. 1987. The amphibians and reptiles of Missouri. Missouri Department of Conservation, Jefferson, MO. 368 pp.

Johnston, C. A., N. E. Detenbeck, and G. J. Niemi. 1990. The cumulative effect of wetlands on stream water quality and quantity: a landscape approach. *Biogeochemistry* 10:105-41.

Jones, R. C., and C. C. Clark. 1987. Impact of watershed urbanization on stream insect communities. *Water Resources Bulletin* 23:1047-55.

Kaplan, R., S. Kaplan, and J. Wendt. 1972. Rated preference and complexity for natural and urban visual material. *Perception and Psychophysics* 12:352-56.

Karr, J. R., and I. J. Schlosser. 1978. Water resources and the land-water interface. *Science* 201:229-34.

Keller, C. M. E., C. S. Robbins, and J. S. Hatfield. 1993. Avian communities in riparian forests of different widths in Maryland and Delaware. *Wetlands* 13:137-44.

King R. S. 1995. Habitat use, movement patterns, and thermo-ecology of the eastern Massasauga rattlesnake. Paper presented at the Midwest Fish and Wildlife Conference. Dec 6, 1995, Detroit, Michigan.

Korth, R., M. Dresen, and D. Snyder. 1994. *Lakes Tides* survey. Wisconsin Lakes Program, UW-Extension - Stevens Point.

Krieger, D. A. 1980. Life history of catostimids in Twin Lakes, Colorado, in relation to a pumped-storage powerplant. M.S. Thesis. Colorado State University, Fort Collins, Colorado. 116 p.

Kroner, R., J. Ball, and M. Miller. 1992. Big Green Lake priority watershed project: a final evaluation monitoring report. Wisconsin Department of Natural Resources.

Langford, R. L., and M. J. Coleman. 1996. Biodegradable erosion control blankets prove effective on Iowa wildlife refuge. In *Proceedings of Conference XXVII-Erosion Control Technology, Feb. 27- Mar. 1, 1996, Seattle, Washington.* The International Erosion Control Association, Steamboat Springs, Colorado.

Lea, F., T. Landry, and B. Fortier. 1990. Comprehensive planning for lake watersheds. Androscoggin Valley Council of Governments, Maine Department of Environmental Protection. 53 pp.

Lenat, D. R, and J. K. Crawford. 1994. Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. *Hydrobiologia* 194:185-99.

Leslie, J. K., and C. A. Timmins. 1994. Ecology of young-of-the-year fishes in Severn Sound, Lake Huron. *Canadian Journal of Zoology* 72:1887-97.

Lind, O. T., and L. Davalos-Lind. 1993. Detecting the increased eutrophication rate of Douglas Lake, Michigan: the relative areal hypolimnetic oxygen deficit method. *Lake and Reservoir Management* 8(1):73-76.

Livingston, S. A., C. S. Todd, and W. B. Krohn. 1990. Habitat models for nesting bald eagles in Maine. *Journal of Wildlife Management* 54:644-53.

Lontz, W. and S. Andrews. 1981. The local resource-regulation connection: Town of Wascott Lakes'

Plan. Prepared by the Town Board of Wascott Township, Wisconsin, in cooperation with Douglas County, the Northwest District Zoning Administrators Association, and the University of Wisconsin Extension. 25p.

Lynch, J. F., and D. A. Saunders. 1991. Response of bird species to habitat fragmentation in the wheatbelt of Western Australia: interiors, edges and corridors. Pp. 143-158 *in* D. A. Saunders and R. J. Hobbs, eds. *Nature Conservation 2: The Role of Corridors*.

Lynch, J. A., E. S. Corbett, and K. Mussallem. 1985. Best management practices for controlling nonpoint-source pollution on forested watersheds. *Journal of Soil and Water Conservation* 40:164-67.

Macbeth, E. J. 1989. The relationship of shoreland zoning elements to the aesthetics of developed lakeshores in Wisconsin. M.S. thesis, University of Wisconsin-Stevens Point.

Madison, C. E., R. L. Blevins, W. W. Frye, and B. J. Barfield. 1992. Tillage and grass filter strip effects upon sediment and chemical losses. p. 331 in *Agronomy Abstracts*. ASA, Madison, Wisconsin.

Mann, R. 1975. Aesthetic resources of the coastal zone. Roy Mann Associates, Inc.

Mason, J.W., D.J. Graczyk and A. Kerr. 1991. Effects of runoff on smallmouth bass populations in four southwestern Wisconsin streams. pp. 28-38 in D.C. Jackson, ed. *The First International Smallmouth Bass Symposium*. Mississippi Agricultural and Forestry Experiment Station, Mississippi State University. 175 pp.

Masterson, J.P., and R.T. Bannerman. 1994. Impacts of stormwater runoff on urban streams in Milwaukee County, Wisconsin. In *National Symposium on Water Quality - American Water Resources Association - November 1994*.

McGarigal, K., R. G. Anthony, and F. B. Isaacs. 1991. Interactions of humans and bald eagles on the Columbia River estuary. *Wildlife Monographs* 115:1-47.

McIntyre, J.W. 1975. Biology and behavior of the Common Loon *(Gavia immer)* with reference to its adaptability in man-altered environments. PhD Dissertation. University of Minnesota, Minneapolis, Minnesota. 243pp.

Meehan, W. R., F. J. Swanson, and J. R. Sedell. 1977. Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply. U.S. Forest Service. General Technical Report RM-43:137-143.

Michael, H. J., K. J. Boyle and R. Bouchard. 1996. Water quality affects property prices: a case study of selected Maine lakes. Maine Agricultural and Forest Experiment Station. Miscellaneous Report 398.

Minnesota Department of Natural Resources - Division of Waters. 1976. Shoreland management classification system for public waters. Shoreland Management Supplementary Report No. 1 (Second Edition).

Minton, S. A., Jr. 1972. Amphibians and reptiles of Indiana. Indiana Academy of Science Monograph 3. 346 pp.

Mittelbach, G. G. 1984. Predation and resource partitioning in two sunfishes (Centrarchidae). *Ecology*

65:499-513.

Murphy, R. J., C. P. Hawkins, and N. H. Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. *Transaction of American Fisheries Society* 110:469-78.

Naiman, R. J., and J. R. Sedell. 1979. Benthic organic matter as a function of stream order in Oregon. *Archiv Fu Hydrobiologie* 87:401-22.

Nilsen, H. C., and R. W. Larimore. 1973. Establishment of invertebrate communities on log substrates in the Kaskaskia River. Illinois. *Ecology* 54:366-74.

Oberts, G. L. 1981. Impact of wetlands on watershed water quality. Pp. 213-226 *in* B. Richardson, ed. *Selected Proceedings of the Midwest Conference on Wetland Values and Management*. Freshwater Society, Navarre, Minnesota.

Odum, W.E. and R.T. Prentkis. 1978. Analysis of five North American lake ecosystems. IV. Allocthonous carbon inputs. *Verh. International Verein Limnology* 20:574-580.

Oldfield, B., and J. J. Moriarty. 1994. Amphibians and reptiles native to Minnesota. University of Minnesota Press, Minneapolis. 237 pp.

Osborne, P. L. and A. J. McLachlan. 1985. The effect of tadpoles on algal growth in temporary, rain-filled rock pools. *Freshwater Biology* 15:77-87.

Palfrey, R, and E. Bradley. 1982. Buffer area study. Maryland Department of Natural Resources. Coastal Resources Division. Tidewater Administration. Baltimore, Maryland, 30 pp.

Petranka, J.W. 1994. Response to impact of timber harvesting on salamanders. *Conservation Biology* 8(1):302-304.

Platts, W. S., and R. L. Nelson. 1989. Stream canopy and its relationship to salmonid biomass in the intermountain west. *North American Journal of Fisheries Management* 9:446-457

Platts, W. S, K. A. Gebhardt, and W. L. Jackson. 1985. Effects of large storm events on basin-range stream habitats. Pp. 30-35 *in* Riparian Ecosystems and Their management: Reconciling Conflicting Uses. USDA Forest Services, General Technical Report RM-120:.

Premo, D. 1994. Bird survey of buffer zones along Fence River: an experimental study update. *Strategies*, Vol. 3, Issue 1. Published by White Water Associates, Amasa, Michigan.

Rabeni, C. F., and M. A. Smale. 1995. Effects of siltation on stream fishes and the potential mitigation role of the buffering riparian zone. *Hydrobiologia* 303:211-19.

Richards, C., G. E. Host, and J. W. Arthur. 1993. Identification of predominant environmental factors structuring stream macroinvertebrate communities within a large agricultural catchment. *Freshwater Biology* 29:285-94.

Robbins, C. S., D. K. Dawson, and B. A. Dowell. 1989. Habitat area requirements of breeding forest birds of the Middle Atlantic States. Wildlife Monograph 103.

Robinson, C.A., Cruse, and Gaffarzadeh. 1996. Vegetative filter strip effects on sediment concentration in cropland runoff. *Journal of Soil and Water Conservation* (May-June):227-30.

Rosgen, D. 1994. A classification of natural rivers. *Catena* 22:169-99.

Ross, D. 1989. Amphibians and reptiles in the diets of North American raptors. Wisconsin Endangered Resources Report 59. Wisconsin Department of Natural Resources, 33p.

Savannah River Ecology Laboratory. 1980. A biological inventory of the proposed site of the Defense Waste Processing Facility on the Savannah River Plant in Aiken, South Carolina. Savannah River Ecology Laboratory Annual Report, FY-1980. SREL-7UC-66e. Aiken, South Carolina.

Savino, J. F., and R. A. Stein. 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submerged vegetation. *Transaction of the American Fisheries Society* 111:255-66.

Schallenberger, M. and J. Kalff. 1993. The ecology of sediment bacteria in lakes and comparisons with other aquatic ecosystems. *Ecology* 74(3):919-934.

Schlosser, I. J. 1982. Trophic structure, reproduction success, and growth rate of fishes in a natural and modified headwater stream. *Canadian Journal of Aquatic Science* 39:968-78.

Schlosser, I. J. 1991. Stream fish ecology: a landscape perspective. *Bioscience* 41:704-12.

Schmid, W. D. 1965. Some aspects of the water ecology of nine species of amphibians. *Ecology* 46:261-69.

Schmude, K., M. Jennings, K. Otis, and R. Piette. 1996. Invertebrates. Pp. 49-61 in M. Jennings, K. Johnson and M. Staggs, eds. Shoreline Protection Study: A Report to the Wisconsin State Legislature. Wisconsin Department of Natural Resources. PUBL-RS-921-96.

Schneider, J.C. 1981. Fish communities in warmwater lakes. Michigan Department of Natural Resources Fisheries Research Report No. 1890. Ann Arbor, Michigan.

Schueler, T.R. 1992. Design of stormwater wetland systems. Metropolitan Washington Council of Governments. Washington, DC. 148 p.

Schueler, T. R. 1994a. The importance of imperviousness. *Watershed Protection Techniques* 1:100-11.

Schueler, T. R. 1994b. Use of cluster development to protect watersheds. *Watershed Protection Techniques* 1:137-40.

Schueler, T.R. 1995. Site planning for urban stream protection. Co-published by Metropolitan Washington Council of Governments, Washington DC, and Center for Watershed Protection, Silver Spring, Maryland. 232 p.

Seale, D. B. 1980. Influence of amphibian larvae on primary production, nutrient influx, and competition in a pond ecosystem. *Ecology* 61:1531-50.

Shaw, B., C. Mechenich, and L. Klessig. 1994. Interpreting lake water quality data: a citizen's guide.

University of Wisconsin - Extension, Steven's Point, Wisconsin. 21 p.

Shramm, H.L. and K.J. Jirka. 1989. Epiphytic macroinvertebrates as a food resource for bluegills in Florida lakes. *Transactions of the American Fisheries Society* 118:416-426.

Simeoni, A. E. 1979. A study of regional development along the south shore region of Rhode Island, using a visual approach based on existing environmental factors. M.S. thesis, Cornell University, Ithaca, New York.

Simon, B. D., L. J. Stoerzer, and R. W. Watson. 1987. Evaluating wetlands for flood storage. Pp. 104-09 in J. Kusler and G. Brooks, eds. *Proceedings of the National Symposium: Wetland Hydrology*. Association of State Wetland Managers, Berne, New York.

Simonson, T. D., J. Lyons, P. D. Kanehl. 1994. Guidelines for evaluating fish habitat in Wisconsin streams. North Central Forest Experiment Station

Small, M. F., and W.N. Johnson, Jr. 1985. Wildlife management in riparian habitats. Pp. 69-90. *In Proceedings of a symposium: Is good forestry good wildlife managment?* Maine Agriculutural Experimental Station, Miscellaneous Publication No. 689. Orono, ME.

Smith, D. 1976. Effect of vegetation on lateral migration of anastomosed channels of a glacial meltwater river. *Geological Society American Bulletin* 87:857-860.

Soranno, P. A., S. L. Hubler, and S. R. Carpenter. 1996. Phosphorus loads to surface waters: a simple model to account for spatial patterns of land use. *Ecological Applications* 6(3):865-78.

South Carolina Coastal Conservation League. 1995. Getting a rein on runoff: how sprawl and the traditional town compare. South Carolina Coastal Conservation League Land Development Bulletin, No. 7. 8 pp.

Stalmaster, M. 1987. The Bald Eagle. Universe Books, New York.

Swanson, F. J., S. V. Gregory, J. R. Sedell, and A. G. Campbell. 1982. Land-water interactions: the riparian zone. p. 67-291. In: R.L. Edmonds (editor), Analysis of Coniferous Forest Ecosystems in the Western United States. US/IBP Synthesis Series 14. Stroudsburg, PA, Hutchinson Ross Publishing Company.

Teleki, G. C., and J. Herskowitz. 1986 Lakeshore capacity study integration - a simulation model for predicting the impact of lakeshore cottage development on the environment. Ontario Ministry of Municipal Affairs, Research and Special Projects Branch. 82pp.

Theiling, C.H. 1990. The relationships between several limnological factors and bluegill growth in Michigan lakes. Michigan Department of Natural Resources Fisheries Research Report No. 1970. Ann Arbor, Michigan.

Titus, J.R. 1978. Response of the Common Loon (*Gavia immer*) to recreational pressure in the Boundary Waters Canoe Area, northeastern Minnesota. PhD. Dissertation. Syracuse University of New York, CESF Syracuse, New York.

Titus, J. and L. Van Druff. 1981. Response of the Common Loon to recreational pressure in the

Boundary Waters Canoe Area, northeastern Minnesota. Wildlife Monograph No. 79, Wildlife Society. 59pp.

United States Fish & Wildlife Service. 1983. Northern States Bald Eagle Recovery Plan. 76 pp.

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. Pp. 457-467 *in* P. E. Greeson, J. R. Clark, and J. E. Clark, eds. *Wetland Functions and Values, the State of Our Understanding*. American Water Resources Association, Minneapolis, Minnesota.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Science* 37:130-37.

Vermeer, K. 1973. Some aspects of the breeding and mortality of Common Loons in east-central Alberta. *Canadian Field-Naturalist* 87:403-408.

Vogt, R. C. 1981. Natural history of amphibians and reptiles of Wisconsin. Milwaukee Public Museum, Milwaukee, WI. 205 pp.

Ward, D. L., A. A. Nigro, R. A. Farr, and C. J. Knutsen. 1994. Influence of waterway development on migrational characteristics of juvenile salmonids in the lower Willamette River, Oregon. *North American Journal of Fisheries Management* 14:362-71.

Warnke, D. K. 1996. A comparison of nesting behavior of bald eagles breeding along Western Lake Superior and adjacent inland Wisconsin. University of Minnesota-St. Paul. M.S. Thesis. 76 pp.

Waters, T.F. 1995. Sediment in streams: sources, biological effects and control. American Fisheries Society Monograph 7. Bethesda, Maryland. 251 p.

Weber, S. P. 1994. The influence of groundwater and sediment characteristics on the aquatic macrophyte community of Legend Lake, Wisconsin. University of Wisconsin - Stevens Point. M.S. Thesis.

Welsch, D. 1991. Riparian forest buffers: function and design for protection and enhancement of water resources. Forest Resources Management, Northeastern Area State and Private Forestry, United States Forest Service. Report NA-PR-07-91.

Werner, E. E., G. G. Mittelbach, D. J. Hall, and J. F. Gilliam. 1983. Experimental tests of optimal habitat use in fish: the role of relative habitat profitability. *Ecology* 64:1525-39.

Wiley, J. W. and F. E. Lohrer. 1973. Additional records of nonfish prey taken by ospreys. *Wilson Bulletin* 85:187-97.

Wisconsin Department of Natural Resources - Bureau of Fisheries Management. 1995. Wisconsin angler survey: walleye management in the 90's.

Wisconsin Department of Natural Resources. 1995. Wisconsin's forestry best management practices for water quality. Publication FR093.

Wisconsin Department of Natural Resources. 1996a. Shoreline protection study: findings and recommendations.

Wisconsin Department of Natural Resources. 1996. Northern Wisconsin's lakes and shorelands: a report examining a resource under pressure. 18pp.

Wisconsin Department of Natural Resources - Bureau of Wildlife Management. Undated. Wildlife and your land: a series about managing your land for wildlife.

The Wisconsin Land Conservation Board. 1984. Erosion in Wisconsin. Madison, Wisconsin.

Wohlwill, J. F. 1979. What belongs where: research of fittingness of man-made structures in natural environments. Pp 48-58 in Daniel, Zube, and Driver, eds. *Assessing amenity resource values*. USDA Forest Service General Technical Report RM-68, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Wright, A. H. and A. A. Wright. 1949. Handbook of frogs and toads. Comstock Press, Ithaca, NY. 640 pp.

Xiang, W. N. 1993. Application of a GIS-based stream buffer generation model to environmental policy evaluation. *Environmental Management* 17:817-27.

Zimmer, G.E. 1979. The status and distribution of the Common Loon in Wisconsin. MS Thesis. University of Wisconsin - Stevens Point. 63pp.

Zimmerman, R. C., J. C. Goodlett, and G. H. Comer. 1967. The influence of vegetation on channel form of small streams. p. 255-275, In: Symposium on River Morphology. International Association of Scientific Hydrology, Publication 75, Bern, Switzerland.Aboul Hosn, W., and J. A. Downing. 1994. Influence of cover on the spatial distribution of littoral-zone fishes. *Canadian Journal of Fisheries and Aquatic Sciences* 51:1832-38.